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INSTRUCTIONS FOR AUTHORS

Any article relevant to orthopaedic surgery, orthopaedic science and the teaching of either will be considered for publication. Articles will be enthusiastically received from alumni, visitors to the department, members of the Iowa Orthopaedic Society, residents and friends of the University of Iowa Department of Orthopaedics. We request that all illustrations be 5 × 7 inch black and white glossy prints for reproduction purposes. The journal will be published annually in May or June. The deadline for receipt of articles for the 1986 journal is January 1, 1986.

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The Iowa Orthopaedic Journal

The University of Iowa
Department of Orthopaedics

Editors of a new journal such as the *Iowa Orthopaedic Journal* while free of strict guidelines, must maintain educational quality and establish an identity. With the fifth edition, we hope to meet the standards of the preceding editions. The name, *Iowa Orthopaedic Journal*, implies its purpose: to publish examples of Iowa's contributions to orthopaedics. The contents of this edition provide testament to its educational excellence. For this, we thank the authors. A publication befitting these authors' endeavors can only result from personnel attentive to crucial details. We appreciate the secretary efforts of Jeanette Marsh, Rebecca Dull, and Kay Redlinger and the administrative assistance of Sandy Bredman and Dale Clark.

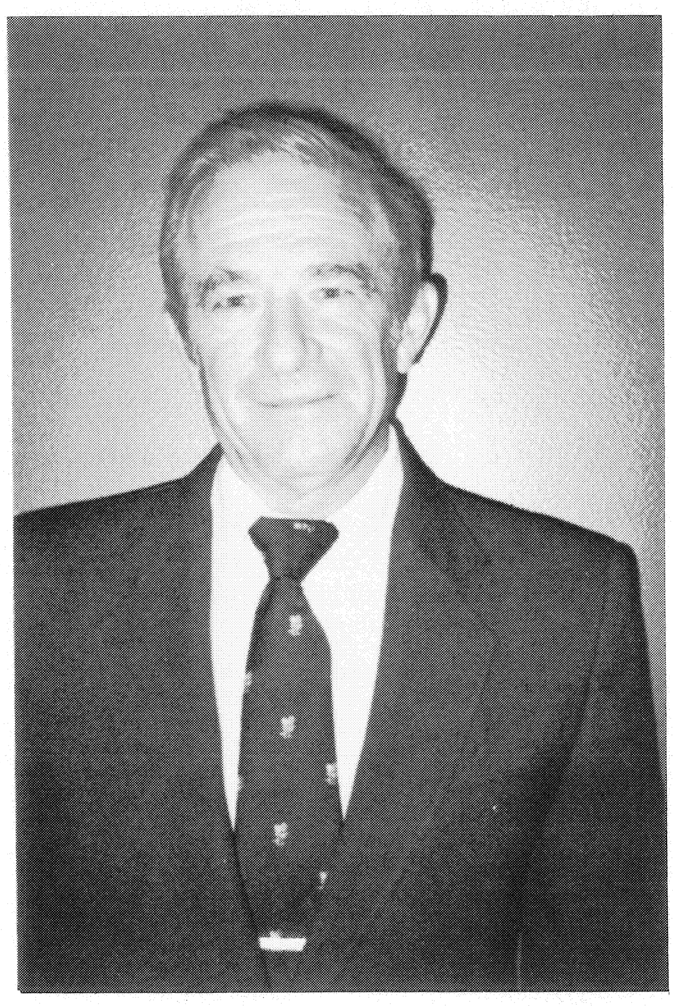
Talented alumni and the long-standing Iowa orthopaedic traditions provide numerous means of adding a unique twist to our journal. Past editions have acknowledged contributions of departmental educators. To extend this policy of enumerating departmental accomplishments, we thought that the alumni who have attained chairmanship represented a noteworthy group. Combining the goals of education and merit recognition, we invited Dr. Kettelkamp to provide us one of his "classic" articles and a personal update on that subject. Much to our good fortune, Dr. Kettelkamp accepted, and his reprint and update on proximal tibial osteotomies appear in this journal. By review, we gain new insight into the past and view present trends with a different perspective. Hopefully, the plethora of Iowa orthopaedic talent will continue to fuel our journal's efforts.

While designed as an educational adventure for residents, the journal's quality depends on guidance from the faculty, especially Drs. Clark, Cooper, and Weinstein. The culmination of editorial and managerial activities in a final product is reward for the residents. We hope the product allows various modes of expression and provides a source of pride for Iowa alumni.

PMS
MDV

Reginald R. Cooper, M.D.

Previous issues of the Iowa Orthopaedic Journal have been dedicated to distinguished past and retiring professors in the University of Iowa, Orthopaedics Department. As President-Elect of the Academy of Orthopaedic Surgeons, we thought it appropriate that Dr. Cooper be one of this year's honorees. Dr. Cooper, Head of the Iowa Department of Orthopaedic Surgery since 1973, was elected second Vice-president at the 1985 meeting of the Academy. He will assume the presidency at the 1987 meeting. Born in West Virginia, he started medical school at West Virginia University and finished at the Medical College of Virginia. He completed training in Orthopaedic Surgery at the University of Iowa. From there he has pursued a prominent career as a clinical and basic researcher, educator, and administrator. Included among his accomplishments are the Kappa Delta Award, past President of the Orthopaedic Research Society, past Secretary of the American Academy of Orthopaedic Surgeons, Deputy-Editor of Clinical Orthopaedics and Related Research, and numerous visiting professorships. He is the first Carroll B. Larson Professor of Orthopaedics. As future Academy President, he will direct the world's largest and most prestigious orthopaedic organization. The alumni, staff, and residents wish to congratulate Dr. Cooper on his academy election, and thank him for his years of strong leadership at Iowa.



Donald B. Kettelkamp, M.D.

Dr. Kettelkamp, as our guest author, adds special significance to the fifth edition of the *Iowa Orthopaedic Journal*. A native Iowan, he graduated from Cornell College in Mount Vernon, Iowa. The University of Iowa conferred onto him both his M.D. and an M.S. in orthopaedic surgery. An assistant orthopaedic professorship at Albany Medical College and later a professorship at the University of Iowa Orthopaedic Department laid the foundation for transition to chairmanship at the University of Arkansas (1971-1974) and then at Indiana University (1974-1984). Currently, he serves as the Associate Medical Dean at Texas Tech University in El Paso. His many professional honors and accomplishments place him among the orthopaedic elite. He has assumed many diversified roles — teacher, surgeon, investigator, author, and administrator. Memories of him are an integral part of Iowa orthopaedics.

From well over one hundred literary contributions, he has chosen to update us on proximal tibial osteotomies. For his following effort, our journal is indebted, and for this and his many other investigations, orthopaedics is enriched.

**RESULTS OF PROXIMAL TIBIAL OSTEOTOMY THE EFFECTS OF TIBIOFEMORAL ANGLE, STANCE-PHASE FLEXION-EXTENSION, AND MEDIAL-PLATEAU FORCE*

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Abstract: Forty-eight knees were evaluated after proximal tibial osteotomy, performed for varus deformity, to determine the desired amount of correction of the deformity, the effect of osteotomy on knee motion during gait and on medial-plateau force during standing, and the relationships between these factors and the result. Correction of the tibiofemoral angle to 5 degrees of genu valgum or more produced the best and most lasting results. Stance-phase flexion-extension increased and rotation decreased in knees with good results while the other gait parameters were not significantly changed. Medial-plateau force was decreased by successful tibial osteotomy. The knees with the best and most lasting results had 7 degrees of stance-phase flexion-extension or more during walking and either a valgus tibiofemoral angle of 5 degrees or more or a medial-plateau force of 50 per cent of body weight or less.

The results of proximal tibial osteotomy for primarily unicompartmental arthritis, reported by a number of authors[1-11,18,20-23], have established the efficacy of this procedure but have left unanswered the following questions, some of which are equally applicable to any type of knee reconstruction: (1) What is the desired tibiofemoral (valgus) angle? (2) Does proximal tibial osteotomy for unicompartmental arthritis make tibiofemoral motion during walking more normal? (3) What is the distribution of force on the medial tibial plateau? (4) Are the tibiofemoral angle, tibiofemoral motion during walking, force on the medial tibial plateau, and the clinical result interrelated? We report some answers to these questions as determined in a study of forty-eight knees after proximal tibial osteotomy for varus deformity.

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Material

Forty-eight osteotomies, forty-two unilateral and three bilateral, were performed in twenty-two men and twenty-three women. The average age was fifty-eight years (range, thirty-nine to seventy-three years) and the average weight, 76.6 kilograms (range, 43.2 to 100.9 kilograms). The osteotomies were performed for primary degenerative arthritis in forty-one knees, for rheumatoid arthritis in four, and for degenerative arthritis secondary to fracture of a tibial plateau in one and fracture of the proximal part of the tibia in another. The remaining osteotomy was done to correct an angular deformity following malunion of a fracture of the medial femoral condyle. Pain with activity and arthritis of the medial compartment with loss of the cartilage space were the indications for proximal tibial osteotomy in these patients. Rheumatoid arthritis was a relative contraindication, but four patients (ages: thirty-five, thirty-five, thirty-six, and fifty-nine years) with only medial compartment disease were included because of their relatively young ages. Loss of bone in the medial tibial plateau sufficient to preclude some weight being born on both plateaus postoperatively became a contraindication after two knees with bone loss of this type were operated on unsuccessfully. The preoperative flexion deformity was 20 degrees or less in all but one knee which had a deformity of 30 degrees. All knees had an arc of motion of 65 degrees or more preoperatively. The results after bilateral osteotomy in the same patient were as good as those after a unilateral procedure in patients with disease in only one knee. The average follow-up, as of December 1972, was thirty-eight months (range, eighteen to 162 months). There were thirty-seven closing-wedge and eleven dome osteotomies. One was done immediately below the tibial tubercle; all others were above the tubercle.

Method

The clinical assessment of the result in each of the forty-eight knees was based on the history and clinical examination, using criteria that were tested by detailed clinical correlation and statistical analyses, to be described. The tibiofemoral (varus-valgus) angles were measured from the preoperative and postoperative weight-bearing roentgenograms of all forty-eight knees.

The tibiofemoral motion (knee motion) during walking, measured with a three-plane electrogoniometer, was determined for twenty-seven knees both preoperatively and postoperatively. Because none of these twenty-seven knees had poor results after thirty-two months, five additional knees were measured postoperatively. Two of these had poor results. The electrogoniometer was applied to the lateral side of the limb, as described previously[15]. Flexion-extension during stance and swing phases of walking, abduction-adduction, and rotation were measured for each of twenty strides and the average values were recorded for each knee. Cadence (the number of strides per minute) was determined from the paper recording of knee motion. Stride length was calculated from the number of strides taken, as measured on the walkway.

The force distribution on the medial tibial plateau was calculated from measurements made on 183-centimeter standing roentgenograms, as described by Kettelkamp and Chao. This calculation uses the mechanical angle of the knee, which is the difference between the angle formed by the mechanical axis of the femur (a line drawn from the center of the femoral head to the center of the knee) and the horizontal, and the angle formed by the longitudinal axis of the tibia and the floor. Also needed for this calculation are the point of the tibiofemoral contact on each tibial plateau and several other measurements[13].

The postoperative force on the medial tibial plateau was computed for thirty-four knees, but the preoperative force was calculated for only nine of them. Force calculations for twenty-six normal knees were used to establish the normal range of force on the medial plateau.

Using the aforementioned data, the following correlations were made: (1) stance-phase flexion-extension with the tibiofemoral angle, in thirty-two knees; (2) stance-phase flexion-extension with the medial-plateau force, in twenty-nine knees; and (3) tibiofemoral angle with the medial-plateau force, in thirty-four knees.

All measurements and assessments of the clinical results were made in December 1972. The clinical results were then reassessed in 1974. The later clinical results served as additional evidence of the effects of the tibiofemoral angle, tibiofemoral motion, and plateau force on the result, since the results at this time identified the patients whose results were good initially but later became poor. Appropriate statistical techniques, including the chi square test, Kruskal-Walls' t test, and the paired t test, were used to evaluate the significance of the findings.

Results

Clinical Assessment

Clinical results were rated on the basis of the need for external support and the amount of pain during activity. With a good result, the patient used no external support (crutches) and had either no pain or only mild discomfort after unusually heavy activity. With an acceptable result, the patient used no external support but had mild knee pain after a day's work. With a poor result, the patient either used external support or had knee pain after working for a few hours or walking a few blocks.

Pain with activity, one of the two determinants of the clinical result, was rated on an eight-point scale:

1. No pain.
2. Discomfort only after unusually heavy activity.
3. Mild knee pain present after a day's work but not limiting activity.
4. Mild pain after a day's work, limiting activity.
5. Pain after working for a few hours or walking a few blocks.
6. Pain after only one hour's activity or walking less than on block.
7. Pain with every step.
8. Constant pain.

Thus, a good result would mean a pain rating of one or two; an acceptable result, a rating of three or four; and a poor result, a rating of five, six, seven, or eight. The average postoperative score was 1.3 for the knees with good results, 3.7 for those with acceptable results, and 5.1 for those with poor results (Table 1). The degree of preoperative pain with activity did not have any bearing on the final result, since all three groups had an average score of six for pain with activity.

In 1972, after an average follow-up of thirty-eight months, there were twenty-seven good, twelve acceptable, and nine poor results, or 81 per cent good and acceptable results, a figure comparable to the percentages reported by others but higher than that reported by Insall and associates after five years. In 1974, two years later in our study, the average follow-up was sixty-two months; 67 per cent had good and acceptable results, seven of the knees previously in these categories having dropped to poor.

Reliability of the Clinical Result Classification

Because the reliability of the clinical result classification was extremely important in our analyses of the roles played by the tibiofemoral angle, knee motion, and plateau force as determinants of the result, we correlated the clinical assessment of the results with the following clinical variables: rest pain, ability to put on and remove shoes and stockings, ability to go up and down stairs, ease of walking on rough ground, and capacity to sit down in a chair and get up. For the correlation, these clinical variables were scored preoperatively and postoperatively in the knees with good, acceptable, and poor results. The preoperative and postoperative scores for each of the variables were then correlated with the result.

Rest pain was scored using a seven-point scale:

1. No pain.
2. Pain after unusually heavy activity.
3. Pain occasionally after a day's work.
4. Pain after a day's work but sleep not disturbed.
5. Pain after a day's work and sleep disturbed.
6. Sleep always disturbed regardless of activity.
7. Constant pain.

There were no statistically significant difference among the average preoperative scores for rest pain in the three result groups (Table 1). The postoperative average ratings, on the other hand, were significantly related to the results at the $p \leq 0.005$ level. Of the knees with good results, twenty-five caused no rest pain, one caused rest pain after unusually heavy activity, and one caused occasional pain at the end of a day's work. Of the knees with acceptable results, six caused no rest pain, three caused occasional pain after heavy work, one occasionally caused pain after a day's work, and two always caused pain after a day's work. Of the nine knees with poor results, four caused no rest pain, one led to pain after unusually heavy work, one caused pain occasionally after work, and three caused pain that disturbed sleep.

Ability to put on shoes and stockings was scored using the following four-point scale:

1. No difficulty.
2. Able to do both but with difficulty.
3. Able to put on stockings but not tie shoes.
4. Unable to put on shoes and stockings.

There was no significant difference among the average preoperative grades for this variable in the three result groups (Table 1). The postoperative ratings, however, were related to the results at the $p \leq 0.01$ level of confidence. Twenty-five knees with good, ten with acceptable, and three with poor results caused the patients no difficulty with shoes and stockings, while two with good, two with acceptable, and six with poor results made for difficulty.

Ability to ascend and descend stairs was scored according to a four-point scale:

1. No difficulty.
2. Able to do so slowly, stepping up or down with either foot.
3. Able to step up or down with one foot only.
4. Unable to negotiate stairs.

Here, too, there was no significant difference among the average preoperative grades for this activity in the three result groups (Table 1). The postoperative average scores, on the contrary, did correlate with the results at the $p \leq 0.005$ level of confidence. Of the knees with good results, eleven caused no difficulty, nine forced the patients to ascend and descend slowly, alternating right and left feet, and seven made the patients proceed stiff-legged, always advancing the same foot. Of the knees with acceptable results three caused no difficulty, one forced the patient to ascend and descend slowly, and eight made the patients always advance the same foot. Of the knees with poor results, one caused no difficulty, five made the patients always advance the same foot, and three forced the patients to avoid stairs.

Ability to walk on rough ground was scored on a four-point scale:

1. No trouble.
2. Must be careful and may have pain or giving way.
3. Always has pain.
4. Avoids rough ground.

Here also there was no significant difference among the average preoperative scores for this activity in the three result groups (Table 1). The postoperative average scores, however, did correlate with the results at the $p \leq 0.05$ level. Of the knees with good results, sixteen caused no trouble on rough ground, seven made the patients be careful because of knee pain, and four caused the patients to avoid rough ground. Of the knees with acceptable results, three caused no trouble, four made the patients be careful, one led to pain on rough ground, and four forced the patients to avoid rough ground. Of the knees with poor results, three forced the patients to be careful, three caused pain, and three made the patients avoid rough ground.

Ability to sit down in a chair and get up was scored using a four-point scale:

1. No trouble.
2. Can do so but with discomfort.
3. Can do so only with support (using upper extremities for support).
4. Unable to get up and down.

The average preoperative scores for this ability in the three result groups were again not significantly different (Table 1). Postoperatively, however, the ability to sit down in a chair and get up was related to the result ratings at the $p \leq 0.005$ level of confidence. Of the knees with good results, twenty-three caused no difficulty rising and sitting down, three made for some discomfort, and one required the patient to use the chair arms for support. Of the knees with acceptable results, four made for no difficulty, seven caused some discomfort, and one required the patient to use support. Of the knees with poor results, two caused no difficulty, five caused discomfort, and two required the patient to use support for sitting down in a chair and rising from it.

Table 1

Preoperative and Postoperative Average Scores for Five Clinical Variables versus Clinical Assessments of Results

Clinical Variables		Clinical Assessment of Results Good (N27)	Acceptable (N12)	Poor (N9)
Rest pain	Preop.	3.6	4.3	3.6
(7-point scale)*	Postop.	1.1	1.9	3.4
Shoes and stockings	Preop.	1.3	1.4	1.5
(4-point scale)*	Postop.	1.1	1.2	1.6
Stairs	Preop.	2.5	2.7	3.1
(4-point scale)*	Postop.	1.9	2.4	3.0
Rough ground	Preop.	2.4	3.0	2.4
(4-point scale)*	Postop.	1.7	2.5	3.0
Sitting and rising	Preop.	2.0	1.9	1.8
(4-point scale)*	Postop.	1.2	1.8	2.0
Pain with activity†	Preop.	6.0	6.0	6.0
(8-point scale)	Postop.	1.3	3.7	5.1

*Average preoperative and postoperative scores for five clinical variables versus good, acceptable, and poor result ratings as judged from the severity of pain with activity and need for external support (crutches). The average scores for pain with activity using the scoring system described in the text are also given for reference.

The maximum possible score for each variable (lowest rating) is indicated in parentheses under each variable. In each case a score of one represents normal.

†One of the criteria used in the clinical assessment (see text) is listed here for reference.

Distance walked was scored on a three-point scale:

1. Any distance.
2. Not more than one to three blocks.
3. Less than one block.

No preoperative scores were obtained. Postoperatively, the distance the patient could walk was related to the result rating at the $p \leq 0.01$ level. All patients with a good result could walk more than three blocks. Of those with acceptable results, eight could walk more than three blocks and four could walk one to three blocks. Of the patients with poor results, six walked more than three blocks; two, one to three blocks; and one could not walk a block.

The postoperative increase in the distance the patient was able to walk, as judged by the patient, was also related to the results at the $p \leq 0.005$ level. All patients with good results could walk further than preoperatively. Of those with acceptable results, eleven could walk further than preoperatively and one was unchanged, while among those with poor results, three could walk further; five, the same distance; and one, less than preoperatively.

The per cent of pain relief following osteotomy was determined by asking the patients whether the pain was completely relieved (100 per cent less pain); 75, 50, or 25 per cent less than before osteotomy; unchanged; or worse than before osteotomy. The patients considered pain associated with both rest and activity in their assessment. As might be expected, the relief of pain after osteotomy also correlated with the result ratings at the $p \leq 0.005$ level. Of the knees with good results, twenty caused no pain, six caused mild pain (75 per cent less than before surgery), and one caused 50 per cent less pain than preoperatively. Of those with acceptable results, two caused no pain; two, 75 per cent less; and seven, 50 per cent less pain than before surgery, while one had no improvement. However, the pain in this last knee decreased by 75 per cent between the 1972 and 1974 follow-ups. Of the knees with poor results, one caused no pain; two had a 50 per cent improvement; one, a 25 per cent improvement; and five, no improvement in the pain.

The absence before operation of any significant differences among the three result groups with respect to pain with activity and ability to carry out daily activities indicated that these variables were of no value as predictors of the result. The highly significant relationships between our result classification and the postoperative pain and function ratings, on the other hand, showed that the result classification was satisfactory and could be used for evaluating the role of tibiofemoral angle, knee motion, and plateau force in determining the result.

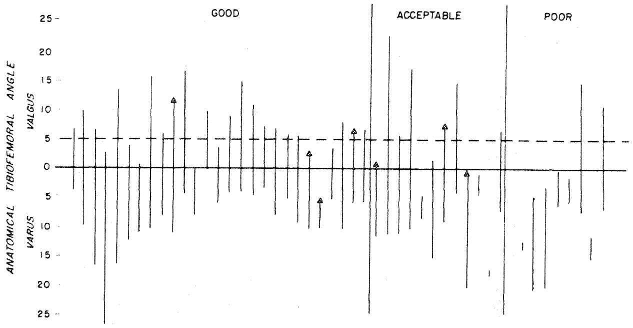

Fig. 1: Tibiofemoral angle: Preoperative (lower end of vertical lines) and postoperative (top of vertical lines) tibiofemoral angles versus clinical results after follow-up of thirty-eight months. The lines with a solid triangle at the top identify the knees in which good and acceptable results changed to poor after two additional years of follow-up.

Clinical Results versus Tibiofemoral Angle

The effects of the amount of correction of this angle at thirty-eight months and at sixty-two months are shown in Figure 1. At thirty-eight months, correction to less than 5 degrees of genu valgum was associated with 66 per cent good and acceptable results compared with 92 per cent good and acceptable results in the knees corrected to a tibiofemoral angle of 5 degrees of genu valgum or more. The difference was even greater two years later, when only 47 per cent of the results were good and acceptable in the knees with less than 5 degrees of genu valgum compared with 81 per cent in the knees with 5 degrees of genu valgum or more. Therefore, the answer to the question as to the proper amount of correction in terms of the tibiofemoral angle is that correction should be to 5 degrees of genu valgum or more, since this amount of correction will result in a greater percentage of good and acceptable results and the results will last longer.

Gait Measurements versus Clinical Result

Tibiofemoral motion while walking (stance and swing-phase flexion-extension, abduction-adduction, and rotation), cadence, stride length, and velocity were measured after tibial osteotomy in thirty-two knees, of which twenty-seven had had preoperative measurements, in an effort to determine whether knee motion during walking was made more normal by proximal tibial osteotomy and whether the amount of knee motion was related to the result (Table II).

Knee flexion: Preoperative flexion deformity average 7.6 degrees for the knees with good results, 7.6 degrees for those with acceptable results, and 5.4 degrees for those with poor results. These differences were not significant. The postoperative flexion deformity averaged 4.3 degrees for the knees with good results, 4.3 for the ones with acceptable results, and 5.9 for those with poor results. Here, too, the differences were not significant. The maximum preoperative flexion averaged 111 degrees for the knees with good results, 122 degrees for those with acceptable results, and 104.4 degrees for those with poor results — also differences that were not significant. The maximum postoperative flexion averaged 108.8 degrees, 106.1 degrees, and 112.9 degrees, respectively, for the knees with good, acceptable, and poor results. Again, the differences were not significant. Therefore, the amount of flexion deformity and the maximum possible flexion of the knee were not related to the result.

As shown in Table 2, the average knee motion during walking, cadence, and stride length for normal knees and for knees treated by osteotomy were correlated with the early (thirty-two-month) and late (sixty-two-month) clinical assessments of the result and also with the corresponding preoperative gait measurement. The preoperative values for the knees with good and acceptable results did not differ significantly, while no preoperative data were available for the knees with poor results.

Stance-phase flexion-extension: Knee flexion during stance phase "flattens the arc through which the center of gravity of the body is translated" and is, therefore, one of the major determinants of gait[19]. The amount of stance-phase flexion-extension correlates well with the clinical status (pain, instability, angular deformity, and range of motion) of knees with rheumatoid[14] and degenerative arthritis (unpublished data). Stance-phase flexion-extension would be expected, therefore, to reflect the results of osteotomy, and such was the case (Fig. 2). Thirteen of nineteen knees with good results had increased stance-phase flex-

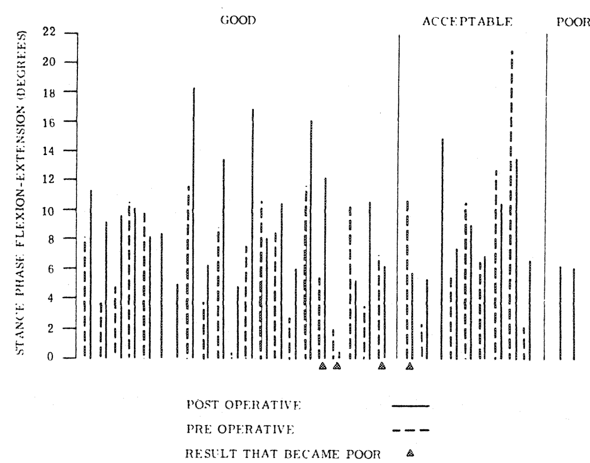

Fig. 2: Stance-phase flexion-extension: Preoperative (broken line) and postoperative (solid line) stance-phase flexion-extension values in the twenty-seven knees for which these values were available. Five additional knees (two good, one acceptable, and two poor results) were measured because none of the twenty-seven knees examined preoperatively had poor results at the first follow-up. Their postoperative values are shown by the solid lines without the accompanying preoperative values. The four knees in which the result changed to poor between the first and second follow-ups are identified by solid triangles.

Table 2

Gait Measurement*

		Good			Acceptable			Poor		
	Normal (N44)	Preop. (N19)	38 Mos. Postop. (N21)	62 mos. Postop. (N8)	Preop. (N8)	38 Mos. Postop. (N9)	62 Mos. Postop. (N8)	Preop. —	38 Mos. Postop. (N2)	62 Mos. Postop. (N6)
Stance-phase flexion-extension *(Deg.)*	20.6	6.8	9.3	9.8	8.9	8.2	8.5	—	6.1	6.1
Swing-phase flexion-extension *(Deg.)*	67.4	43.4	45.4	45.3	40.1	44.0	42.3	—	37.0	42.8
Abduction-adduction *(Deg.)*	11.2	9.4	9.6	9.8	8.6	8.7	7.1	—	11.1	11.5
Rotation *(Deg.)*	13.3	11.8	8.2	7.6	12.9	7.8	7.3	—	8.9	10.8
Cadence *(Strides/min.)*	115.0	60.2	65.2	66.1	46.0	62.9	63.2	—	64.4	62.0
Stride length *(cm)*	156.5	97.0	94.7	102.4	88.0	94.7	94.7	—	81.8	51.7
Velocity *(cm/sec.)*	300.0	97.3	102.9	112.8	67.5	99.3	99.8	—	87.8	53.4

*Normal measurements were taken from the data of Kettelkamp and co-workers[15] and of Murray and associates. Thirty-eight and sixty-two months of follow-up are average durations. In order to demonstrate any possible prognostic significance of the gait data, the averages at sixty-two months were computed after regrouping the knees so that those that had good or acceptable results at thirty-eight months but subsequently dropped to the poor level at sixty-two months were included in the poor category.

The postoperative measurements for stance-phase flexion-extension in the patients with good results were significantly different from those in patients with poor results. Rotation was significantly decreased in the knees with good and acceptable results but not in the ones with poor results. The results after an average follow-up of sixty-two months indicated that early good and acceptable results in knees with small values for stance-phase flexion-extension and larger values for rotation tended to become poor after longer follow-up.

ion-extension after osteotomy and three showed a difference of only a degree or less between the preoperative and postoperative measurements. Of the eight knees with acceptable results, four had increased and four had decreased stance-phase flexion-extension after surgery. The postoperative increase was significant ($p \leq 0.05$) in the knees with good results. The amount of postoperative stance-phase flexion-extension was also significantly greater in the knees with good results than in those with acceptable and poor results ($p = 0.05$). Finally, the greater average flexion-extension of the knees with results that remained good after longer follow-up (average, sixty-two months) suggested that knees with good postoperative stance-phase flexion-extension are more likely to retain a good result.

Swing-phase flexion-extension: The amount of swing-phase flexion-extension was not significantly altered by proximal tibial osteotomy nor was it related to the result (Table 2).

Abduction-adduction: Abduction-adduction (motion in the coronal plane) was also not significantly altered by osteotomy, though the average amount of postoperative motion was slightly greater in the knees with poor results than in those with good and acceptable results (Table 2).

Tibial rotation: Tibial rotation decreased after tibial osteotomy in the knees with both good and acceptable results ($p = 0.05$) (Table 2). When the knees with results which dropped to poor after longer follow-up were transferred to the poor group and the average rotations were calculated, the rotations decreased still more in the knees with good and acceptable results but increased in the ones with poor results. Since transverse rotation tends to increase with gait velocity, this increase in the knees with poor results after longer follow-up might be explained on the basis of velocity of walking. However, the average velocity of the patients whose knees had poor results was only half that of the ones with good results. Possibly, the difference reflects the postoperative decrease in the translatory shift of the tibia on the femur in knees with good results. This shift is frequently seen in knees with degenerative genu varum.

Cadence, stride length, and velocity: Cadence (the number of strides per minute) increased following osteotomy. Stride length, which is related to limb length and swing-phase flexion-extension, remained about the same. Velocity of progression (cadence multiplied by stride length) increased in the patients with good and acceptable results but was still much less than normal.

In answer to the question, "Does osteotomy improve tibiofemoral motion during walking?", therefore, our findings show that in the knees with lasting good results (at sixty-two months) stance-phase flexion-extension, cadence, and velocity improved postoperatively and remained so. Rotation decreased in knees with good results, presumably because of improved stability and decreased abnormal motion.

Medial-Plateau Force

The force on the medial tibial plateau while standing on both lower limbs was calculated for thirty-four knees after osteotomy, for nine of these same knees before osteotomy, and for twenty-six normal knees. In a normal person standing on both limbs, the total force on both plateaus of each knee is 0.46 times body weight, the balance (0.04 times body weight for each knee) being accounted for by the weight of the leg (distal to the knee). In the twenty-six normal knees, the force passing through the medial plateau averaged 0.25 times body weight, with a range of from 0.02 to 0.53 (Fig. 3). The person with a force of only 0.02 times body weight on the medial plateau had genu valgum. In the nine knees evaluated preoperatively, the force on the medial plateau averaged 0.86 times body weight, with a range of from 0.57 to 0.996. Postoperatively, this force in all the thirty-four knees averaged 0.44 times body weight in the ones with good results, 0.40 in those with acceptable results, and 0.32 in the two knees

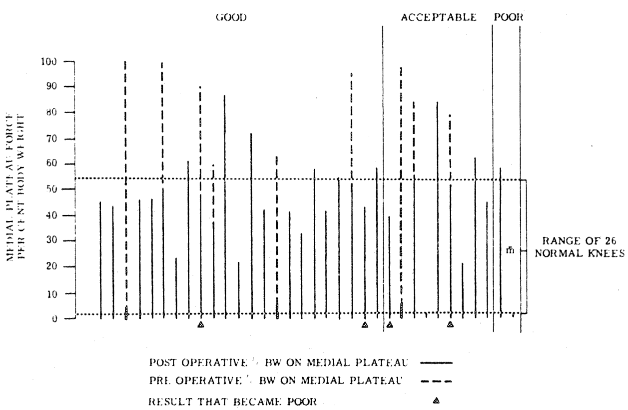

Fig. 3: Medial-plateau force: Calculated forces expressed as per cent of body weight in thirty-four knees after operation (solid lines) and in nine knees before operation (broken lines above solid lines). Two of the knees, one with an acceptable and the other with a poor result, had no load on the medial plateau after surgery because of excessive valgus correction and transmission of all the force to the lateral plateau. The range of forces on the medial tibial plateau of twenty-six normal knees is indicated by the two horizontal dotted lines m being the mean value. There were twenty-three good, nine acceptable, and two poor results after an average follow-up of thirty-eight months. The four good or acceptable results which subsequently became poor are identified by solid triangles.

with poor results for which we had these data. Of the two knees with poor results, one had no force on the medial plateau because of overcorrection into too much genu valgum, and the other had a force of 0.63 times body weight due to undercorrection and persistent genu varum. The values for individual knees are given in Figure 3.

Proximal tibial osteotomy, therefore, reduced the force on the medial tibial plateau in most knees with symptomatic relief, but the force in many of these knees was still above normal.

Interrelationships of Findings

In an attempt to define other factors that might influence the outcome of osteotomy, we correlated the clinical results with the following combinations: (1) tibiofemoral angle and stance-phase flexion-extension; (2) stance-phase flexion-extension and force on the medial plateau; and (3) force on the medial plateau and tibiofemoral angle.

Results — tibiofemoral angle and stance-phase flexion-extension: The 1972 follow-up data for tibiofemoral angle versus stance-phase flexion-extension were plotted for the thirty-two knees for which information was available (Fig. 4), using 7 degrees of stance-phase flexion-extension (approximately three standard deviations below normal)[15] as the minimum motion consistent with a good result.

Correlation of the amount of correction of the genu varum with the results after the two follow-up periods revealed the following: Of the twenty-one knees with correction to less than 5 degrees of genu valgum, fourteen had good or acceptable results and seven had poor results at thirty-eight months, while ten had good or acceptable results and eleven, poor results at sixty-two months. Of the twenty-seven knees with correction to 5 degrees of genu valgum or more, on the other hand, twenty-five had good or acceptable results and two, poor results at thirty-eight months, while twenty-two had good or acceptable and five had poor results at sixty-two months. Therefore, in the knees corrected the lesser amount the results were good or acceptable in 66 per cent at thirty-eight months and in 47 per cent at sixty-two months; in the knees with greater correction the results were good or acceptable in 92 per cent at thirty-eight months and in 81 per cent at sixty-two months. The minimum acceptable correction was established, therefore, as 5 degrees of genu valgum.

At both the 1972 and 1974 follow-ups, the results were good and acceptable in the knees that had a valgus tibiofemoral angle of at least 5 degrees as well as stance-phase flexion-extension of 7 degrees or more. At the 1972 follow-up (average, thirty-eight months), eleven of the twenty-one knees with good results, two of the nine with acceptable results, and neither of the two with poor results met these criteria (Fig. 4). Two years later (average follow-up, sixty-two months), three of the eleven good results and one of the two acceptable results in the knees that did not meet these criteria had dropped to poor. At the last follow-up, therefore, the results in the knees with a valgus tibiofemoral angle of 5 degrees or more and stance-phase flexion-extension of 7 degrees or more were significantly

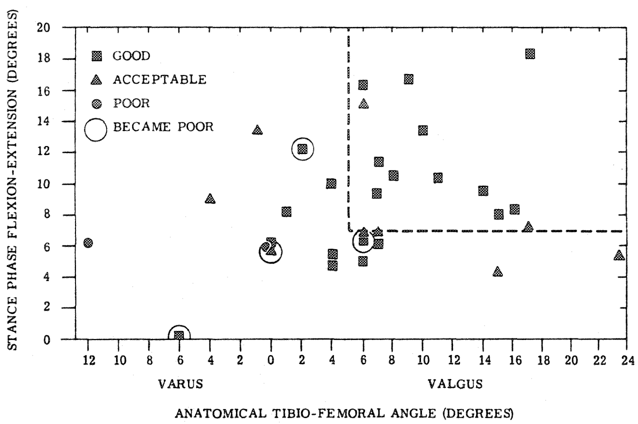

Fig. 4: Stance-phase flexion-extension versus tibiofemoral angle: The thirty-two knees with available data at the thirty-two-month follow-up are plotted according to their stance-phase flexion-extension and tibiofemoral angle. The thirteen with stance-phase flexion-extension of 7 degrees or more and correction of the tibiofemoral angle to 5 degrees of genu valgum or more are enclosed within the broken lines in the upper right corner. The three knees which became poor results after additional follow-up are identified by the open circles. The knees with a tibiofemoral angle of 5 degrees or more and stance-phase flexion-extension of 7 degrees or more were the ones more likely to continue to have good results (p = 0.025).

better (p = 0.025) than those in the knees which did not meet these criteria.

Our findings imply that a knee with correction to a valgus angle of 5 degrees or more and stance-phase flexion-extension of 7 degrees or more probably has a good result and probably will continue to have a good result after longer follow-up.

Results—stance-phase flexion-extension and medial-plateau force: The 1972 follow-up data for stance-phase flexion-extension versus medial-plateau force expressed as per cent of body weight were plotted (Fig. 5) choosing a force of 50 per cent (0.5) of body weight as the maximum amount consistent with a good result, since this was about the upper limit found in the normal knees. Suitable data were available on twenty-nine knees. Six knees with good results had either less than 7 degrees of stance-phase motion or a force in excess of 0.5 times body weight. However, stance-phase flexion-extension of 7 degrees or more and a plateau force of 50 per cent of body weight or less did correlate with good results at the p = 0.025 level for the 1972 results and at the p = 0.005 level for the 1974 results.

Therefore, a knee with these characteristics (7 degrees of stance-phase flexion-extension or more as well as a medial tibial-plateau force of 0.5 times body weight or less) was likely to have a good result and one that would remain good.

Results — tibiofemoral angle and medial-plateau force: The 1972 data for the tibiofemoral angle versus the medial-plateau force were plotted (Fig. 6) selecting correction to

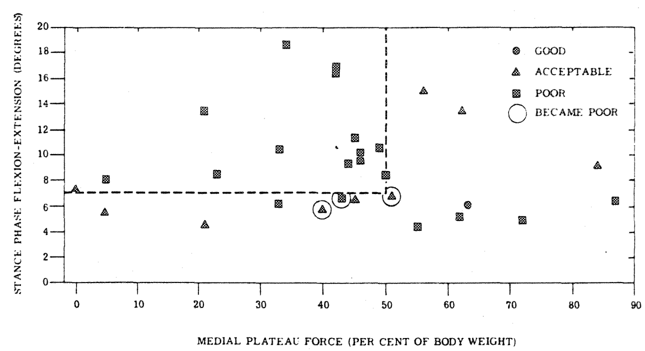

Fig. 5: Stance-phase flexion-extension versus medial-plateau force: Of the twenty-nine knees for which these data were available at the thirty-two-month follow-up, thirteen are within the area in the upper left corner enclosed by the broken lines, one marking 7 degrees of stance-phase flexion-extension and the other, 50 per cent of body weight (see text). Three knees in which the results changed from good or acceptable to poor after additional follow-up are enclosed in open circles. The knees that had stance-phase flexion-extension of 7 degrees or more and a medial tibial-plateau force of 50 per cent of body weight or less were the ones more likely to have a good result (p = 0.025) and to continue to have a good result (p = 0.005).

a valgus tibiofemoral angle of 5 degrees as the minimum (as in the previous correlations) and medial-plateau forces of from 1 through 50 per cent of body weight for this correlation. This force range approximated the normal values, which ranged from 2 to 53 per cent of body weight (Fig. 3). There was a roughly linear relationship between the tibiofemoral angle and the medial-plateau force (Fig. 6). The knees with good results showed a tendency to have 5 degrees of valgus angulation or more and forces of 0.01 to 0.5 times body weight on the medial plateau, but the relationship was not significant (p = 0.1) in either the 1972 or 1974 results.

Thus, there was a tendency for the tibiofemoral angle and the medial-plateau force to be related to the result, but this combination of factors was not a prognostic value.

Discussion

Desired Tibiofemoral Angle

The rationale of proximal tibial osteotomy is simple — to change the varus deformity to valgus angulation and to decrease loading of the medial plateau[16]. The question is how much valgus angulation is the correct amount. Coventry recommended 5 degrees overcorrection beyond the assumed normal angle of 5 to 8 degrees of genu valgum, or a final tibiofemoral valgus angle of 10 to 13 degrees[5]. Bauer and associates recommended correction to a valgus tibiofemoral angle of 3 to 16 degrees. We found that the correction should be to at least 5 degrees of genu valgum but could not specify an upper limit with certainty. One knee in our series had an acceptable result with a valgus tibiofemoral angle of 23 degrees, a finding which suggests that there is probably considerable individual variation.

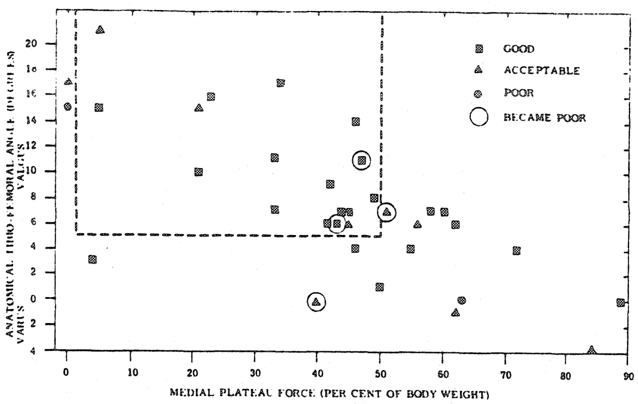

Fig. 6: Tibiofemoral angle versus medial-plateau force: Of the thirty-four knees with data on the tibiofemoral angle and medial-plateau force at the thirty-two-month follow-up, seventeen had a valgus tibiofemoral angle of 5 degrees or more and a plateau force of from 1 to 50 per cent of body weight. The data on these knees are enclosed by the broken lines in the upper left corner. The knees in which good or acceptable results became poor with additional follow-up are enclosed in open circles. A roughly linear relationship is evident between tibiofemoral angle and medial-plateau force. While there was a tendency for the knees with good results to fall within the desired limits (a valgus tibiofemoral angle of 5 degrees or more and a medial-plateau force of 1 to 50 per cent of body weight), the relationship was not significant (p = 0.1).

Our current opinion, based on our experience and that of others, is that the tibiofemoral angle should be corrected to a valgus angle of 5 degrees or more, and we try to achieve a valgus angle of 8 to 11 degrees.

Knee Motion following Tibial Osteotomy

Most authors reported that proximal tibial osteotomy for degenerative genu varum usually improves the patient's functional ability[1-11,18,20-23]—that is, the ability to walk and do other activities — and usually decreases pain. In this study we tried to determine whether motion between the tibia and femur during walking decreased or returned toward normal. We found improvement in only stance-phase flexion-extension in knees that were virtually asymptomatic after osteotomy. The average improvement in these asymptomatic knees was small but significant when compared with their preoperative measurements and with the measurements of other knees with less satisfactory results.

The other measurements of knee motion during walking after osteotomy were either unchanged (swing-phase flexion-extension and abduction-adduction) or decreased (rotation). Normally, the range of swing-phase flexion-extension tends to increase with increasing cadence and stride length—the extreme example of this type of increase being running, when all three (swing-phase flexion-extension, cadence, and stride length) increase markedly. Since neither cadence nor stride length were markedly improved following osteotomy, the failure of swing-phase flexion-extension to increase appreciably would be anticipated.

The range of abduction-adduction during gait also did not change appreciably after osteotomy. Since the preoperative measurements of this motion were close to the normal range (9.2 to 11.2 degrees), little change after osteotomy might be expected. The preoperative measurements were also similar to those obtained in a previously studied group of rheumatoid knees (average, 9 degrees)[13]. Because the amount of abduction-adduction was similar in these knees before and after osteotomy as well as in previously studied normal knees[15], knees after meniscectomy[12], and knees with rheumatoid arthritis[13], we believe that the amount of abduction-adduction is a non-specific characteristic of walking, and that when the amount of abduction-adduction becomes excessive, external support is required to keep this motion within normal limits.

Rotation was decreased after tibial osteotomy in the patients who had good results, but we do not know the reason why this happened.

Therefore, proximal tibial osteotomy increased stance-phase flexion-extension and decreased rotation during walking in patients with good results, but the other gait characteristics were not significantly changed.

Medial-Plateau Force

The objective of proximal tibial osteotomy is to decrease but not eliminate the load on the medial tibial plateau. Our calculations of the force on the medial tibial plateau in thirty-four knees after osteotomy showed that this force was within the normal range in most of them. The mean values, however, were greater than we had anticipated. The relatively high forces on the medial plateau found in some knees with a good clinical result may be explained by inaccuracies in the measurements for the calculation, a relative decrease in the actual force on the medial side during walking as opposed to standing, or, as the result of the degenerative changes, by an increase in the contact area on the medial side compared with normal and hence less force per unit area (stress). At this time, we are unable to discern whether these three possibilities, singly or in combination, were responsible.

Interrelationships of Findings

We believe that correlations of the clinical result with stance-phase flexion-extension, tibiofemoral angle, and medial-plateau force provided information of prognostic significance. In any knee which had stance-phase flexion-extension of 7 degrees or more and either a tibiofemoral angle of 5 degrees or more or a medial-plateau force ranging from 1 to 50 per cent of body weight, the result was usually good and remained good.

These biomechanical assessments (knee motion during walking, tibiofemoral angle, and medial-plateau force) provide a more critical method of determining the results of proximal tibial osteotomy and have greater prognostic significance than clinical evaluation alone. We believe that similar biomechanical assessments after other knee-reconstruction procedures, particularly implants, might be of even greater importance.

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UPDATE ON PROXIMAL TIBIAL OSTEOTOMY

Proximal tibial osteotomy for unicompartmental degenerative arthritis of the knee became a popular operative procedure during the 1960's and 1970's. Clinical results of proximal tibial osteotomy and experience with newer total knee replacements have better defined the indications for this procedure.

The primary indication for proximal tibial osteotomy is unicompartmental degenerative arthritis with an associated varus deformity. Knee flexion-extension should exceed 70 degrees with less than a 15 to 20 degree flexion contracture. The knee should be stable. Peripheral circulation should be normal. Given the above prerequisites proximal tibial osteotomy is the procedure of choice in a young (under 55 to 60 years of age), active and/or heavy individual.

Rheumatoid and other types of inflammatory arthritis contraindicate this procedure. Osteonecrosis with significant collapse or loose bodies is also best treated by arthroplasty rather than osteotomy.

Studies by Coventry and Insall, et al indicate approximately 60 percent satisfactory results at 10 year follow-up. This percentage is less than for recent 10 year follow-up studies on total condylar types of arthroplasty, however the patient populations are not comparable.

Proximal tibial osteotomy is a technically demanding procedure as evidenced by under and over correction being the primary causes of failure. Technical improvements include standing hip to ankle roentgenograms to determine desired correction and the use of image intensifier in the operating room to measure correction obtained during surgery.

In 1969 or 1970 Dr. Paul Maquet visited the Orthopaedic Department at the University of Iowa. Dr. Maquet subsequently published a book on the biomechanics of degenerative arthritis of the knee. In this text he presented the technique and results of curved (barrel-vault) proximal tibial osteotomy. The curved cuts are similar to the dome osteotomy that Dr. Carroll B. Larson taught me in 1960 though the method of fixation differed. Correction was based on a mechanical angle with 2 to 4 degrees mechanical valgus, the accepted correction of a varus deformity. This correction equates to 10 to 11 degrees anatomical valgus in most patients. Maquet uses compression clamps for fixation. This technique permits fine tuning of the correction during the first post-operative week based on full length roentgenograms of the extremity. Maquet's barrel vault proximal tibial osteotomy can provide very accurate correction. The barrel vault procedure is technically demanding and carries greater risk of anterior compartment syndrome than does the closing wedge technique. Details of both procedures are presented in Evart's volumes on operative orthopaedics and are beyond the scope of this commentary.

In summary proximal tibial osteotomy for unicompartmental degenerative genu varum continues to have a place in our armamentarium. The indications, technical details and results are considerably better understood now than at the time of the cases in my preceding paper.

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EVALUATION OF THE MULTIPLY OPERATED LUMBAR SPINE

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INTRODUCTION

Approximately 300,000 *de novo* laminectomies are performed each year in the United States. Unfortunately, approximately 15 percent of these patients will continue to have some discomfort and disability[9]. If injection of a chemonucleolytic agent is considered the equivalent of surgery, the percentage of patients with recurrent pain is even higher. The ideal solution for these people would, of course, be avoidance of any surgery. Proper surgical indications for the initial procedure should be strictly followed[4,7,16]. If objective criteria for surgical intervention are not present, surgery should not be undertaken. There is no place for "exploring" the lumbar spine.

Once the physician is faced with a patient who has recurrent pain from a laminectomy, his job is to differentiate those who have symptoms secondary to mechanical lesions from those who have pain secondary to some other underlying problem. The principle mechanical lesions are recurrent herniated disc, spinal instability, and spinal stenosis; these entities are amenable to surgical intervention. Patients who have scar tissue (whether from arachnoiditis or perineural fibrosis), psychosocial instability, or a systemic medical disease cannot be helped by any type of additional lumbar spine surgery.

The primary aim for the physician is to obtain an accurate diagnosis. Although it seems obvious, this essential step often is omitted and inappropriate care rendered. The purpose of this paper is to review the major points in the evaluation of the multiply operated lumbar spine patient and to discuss each of the above mentioned diagnostic entities and their distinguishing features.

EVALUATION

Evaluation of the multiply operated lumbar spine patient includes the history, the physical examination, and appropriate roentgenographic studies. Specific information must be obtained from each field. The assessment of these cases can be quite confusing and therefore must be approached in a standardized manner. With accurate information from each of the above areas, a diagnosis usually can be gleaned.

History

The histories of patients with multiple low back operations can be quite complicated. However, there are three major, specific historical facts that will help with the decision making process. The first point is the number of previous lumbar spine operations. Studies in both the United States and Canada, show that with each additional procedure, the percentage of good results markedly decreases[2,14]. Regardless of the diagnosis, a second operation statistically has only a 50 per cent chance of success, and with a third operation the patient is more likely to be made worse than better. Thus, the prognosis for a patient undergoing a second or third spine operation is only fair at best.

The second historical point is the length of the pain-free interval after his previous operation. If the patient's leg pain persisted after surgery, the possibilities are that the nerve root was not decompressed properly, that the wrong level was explored, or that the disc was not completely excised. If the leg pain returned six or more months after surgery, the possibility of a new, herniated disc at the same or a different level exists. Finally, a gradual recurrence of pain following a pain-free interval of between one and six months suggests a diagnosis of scar tissue. This can take the form of true arachnoiditis or some type of epidural fibrosis[2].

The final historical point of importance is the patient's pain pattern. If back pain is the major complaint, instability, tumor, infection, or scar tissue should be the main considerations. If leg pain is the major complaint, one should consider a herniated disc or spinal stenosis. Should both back and leg pain be present, then spinal stenosis and/or scar tissue are the leading possibilities.

Physical Examination

The physical examination must be meticulously performed. It is very helpful to have the results of a previous examination by a dependable examiner so that a comparison between pre- and postoperative states can be made. The neurologic examination and evaluation of a tension sign such as the sitting straight-leg raising test are the major focal points.

A neurologic finding is significant only if there is a change that has occurred since the last surgical procedure. If there was an absent ankle jerk before the first operation, the finding of the continued loss of the ankle jerk is not significant. Only the documentation of a new neurologic loss is meaningful.

A positive straight leg raising test or tension sign signifies pressure and/or inflammation of a nerve root. This is quite specific for active mechanical pressure of some type on the neural elements. However, one must realize that epidural or perineural fibrosis around a nerve root can cause a positive tension sign as well as a new herniated nucleus pulposus or spinal stenosis.

Roentgenographic Studies

Plain radiographs are the first studies to be considered. They should include standing lateral flexion-extension films of the lumbar spine. These plain roentgenograms are evaluated for the extent and level of previous laminectomies and for evidence of spinal stenosis. One should make sure that the laminectomy on the plain film corresponds to the neurologic picture. The lateral flexion-extension roentgenograms must be carefully assessed for any sign of instability; an unstable spine can be the result of a patient's intrinsic disease (such as spondylolisthesis) or a previous surgical procedure.

Computerized axial tomography (CAT scan) is employed with intravenous contrast to differentiate between scar tissue and a recurrent herniated disc. A herniated disc is avascular and will not enhance, or light up, with the injection of contrast material. Scar tissue, on the other hand, is vascular and will enhance on the scan. The CAT scan is most helpful in evaluating the possibility of and extent of spinal stenosis. Bony encroachment in the lateral recesses and foramina can be determined precisely with this study.

Contrast studies (myelograms) are reserved for those patients who demonstrate either a new neurologic deficit or a positive straight leg raising test. It is most helpful to have a set of films from before the previous surgery for comparison. Pain, in and of itself, is not adequate justification for myelography. Patients with a diagnosis of spinal stenosis or spinal instability who are to have surgery performed should also undergo a myelogram to rule out any additional pathologic features. Metrizamide, a water-soluble contrast agent, is the medium of choice for lumbar spine myelography. It is quite satisfactory for differentiating extradural neural compression from arachnoiditis. However, in many instances it is not useful for distinguishing between neural compression and extradural fibrosis.

DIFFERENTIAL DIAGNOSIS

To arrive at a specific diagnosis for the multiply operated lumbar spine patient, one must have a method of problem solving which is precise and unambiguous. This is presented in the form of an algorithm. The primary goal of the evaluation is to arrive at a specific diagnosis. As already stated, the physician is trying to separate the patients whose symptoms are secondary to scar tissue or other medical problem from those patients whose pain is secondary to a type of mechanical pressure on the neural elements.

There are many non-operative modalities available for treatment of the patient with recurrent pain after lumbar disc surgery. Unfortunately, most of these treatment regimens are palliative at best and usually offer only short term relief. Epidural steroids, transcutaneous nerve stimulation, facet rhizolysis, operant conditioning, bracing, antidepressant medication, and patient education are included in this group[1,3,5,8,10,11,13,15].

Table 1 summarizes the various pathologic entities and the signs and symptoms that need to be considered in these patients. Figure 1 is a graphic display of the information from Table 1 in the form of an algorithm. If one starts at the top of the algorithm with the broad universe of patients with a history of failed low back surgery, the first effort should be to differentiate those whose back or leg pain emanates from a non-orthopaedic cause (pancreatitis, diabetes, abdominal aneurysm) from those who have a mechanical problem. Thus, a thorough medical evaluation in this group of patients begins at the same time as the orthopaedic and neurosurgical evaluation.

If there is any indication of psychosocial instability (which includes alcoholism, drug dependence, depression, or compensation-litigation), a thorough psychiatric evaluation should be obtained. People with profound emotional disturbances and those in the midst of active litigation do not get any positive benefit from additional low back surgery[12]; even if they have a specific diagnosis, the psychosocial problem should be addressed first. In many cases, once a patient's underlying psychosocial problem has been treated successfully the low back disability will disappear.

After the medical and psychosocial problems are separated, the physician is left with a group of patients who have back and leg pain. This group is then divided into patients with specific mechanical problems and those who have symptoms secondary to scar tissue. The latter group will not be helped by surgery. The incidence of surgically treatable problems is much lower than that of scar tissue.

Herniated Intervertebral Disc

A herniated intervertebral disc can cause pain on the basis of any of three pathologic possibilities. First, the original herniated disc may not have been successfully removed. This can occur if a fragment of disc material was left in place, the laminectomy was not wide enough, or the wrong level was decompressed. These patients will con-

*DIFFERENTIAL DIAGNOSIS OF THE MULTIPLY-OPERATED BACK

History-Physical Radiographs	Original Disc Not Removed	Recurrent Disc At Same Level	Recurrent Disc At Different Level	Spinal Instability	Spinal Stenosis	Arachnoiditis
# Previous Operations						>1
Pain-Free Interval	None	>6 months	>6 months			>1 month but < 6 months
Predominant Pain (Leg Versus Back)	Leg Pain	Leg Pain	Leg Pain	Back Pain	Back and Leg Pain	Back and Leg Pain
Tension Sign	+	+	+			May Be Positive
Neurologic Exam	+ Same Pattern	+ Same Pattern	+ Different Level		+ after Stress	
Plain X-rays	+ If Wrong Level				+	
Lateral Motion X-rays				+		
Metrizamide Myelogram	+ But Unchanged	+ Same Level	+ Different Level		+	+
C.A.T. Scan					+	

Table 1: Differential diagnosis of the multiply operated back (Reprinted from "The Aging Lumbar Spine", by Sam W. Wiesel et al. Permission granted by W.B. Saunders Company).

tinue to have pain because of the mechanical pressure on and inflammation of the same nerve root. These people complain predominantly of leg pain, and their tension signs and neurologic and myelographic patterns remain unchanged from those preoperatively. The major differentiating feature is that these patients will give a history of no pain-free interval; they wake from their operations complaining of the same leg pain they had before surgery. This group will be aided by a technically correct laminectomy.

The second possible cause of continued pain is a true recurrent herniated intervertebral disc at the previously decompressed level. Patients with this problem complain of sciatica and show no change in their tension signs, neurologic examination, or myelographic pattern. The distinguishing characteristic here is that their pain-free interval is greater than six months, and usually they have sudden onset of pain. An additional operative procedure is indicated for this subgroup.

Finally, there may be rupture of an intervertebral disc at a completely different interspace from that repaired initially. Patients who have a new herniation generally will have a pain-free interval greater than six months and sudden onset of pain. Sciatica will predominate, and tension signs will be positive. Both the neurologic defect (if there is one) and the myelographic findings will be at different level than preoperatively. A repeat operation will yield very good results.

Lumbar instability

Instability of the lumbar spine will cause pain on a mechanical basis in the multiply operated back patient. The patient's intrinsic back disease such as spondylolisthesis, or an excessively wide bilateral laminectomy can be the etiology of the instability. Pseudarthrosis is included in this category since the pain caused by this entity is based on instability. Patients usually complain of back pain associated with activity (mechanical), and their physical examinations may be negative.

The key to diagnosis of patients with instability is the weight bearing lateral flexion-extension roentgenogram. Anterior-posterior (horizontal) translation of one vertebral body on another and/or reversal of the normal lordotic curve at a motion segment are the radiographic criteria for diagnosing segmental instability. These objective findings constitute a strong indication for spinal fusion or repair of a pseudarthrosis. Finally, the presence of a traction osteophyte should alert the physician to the possibility of the existence of spinal instability[6].

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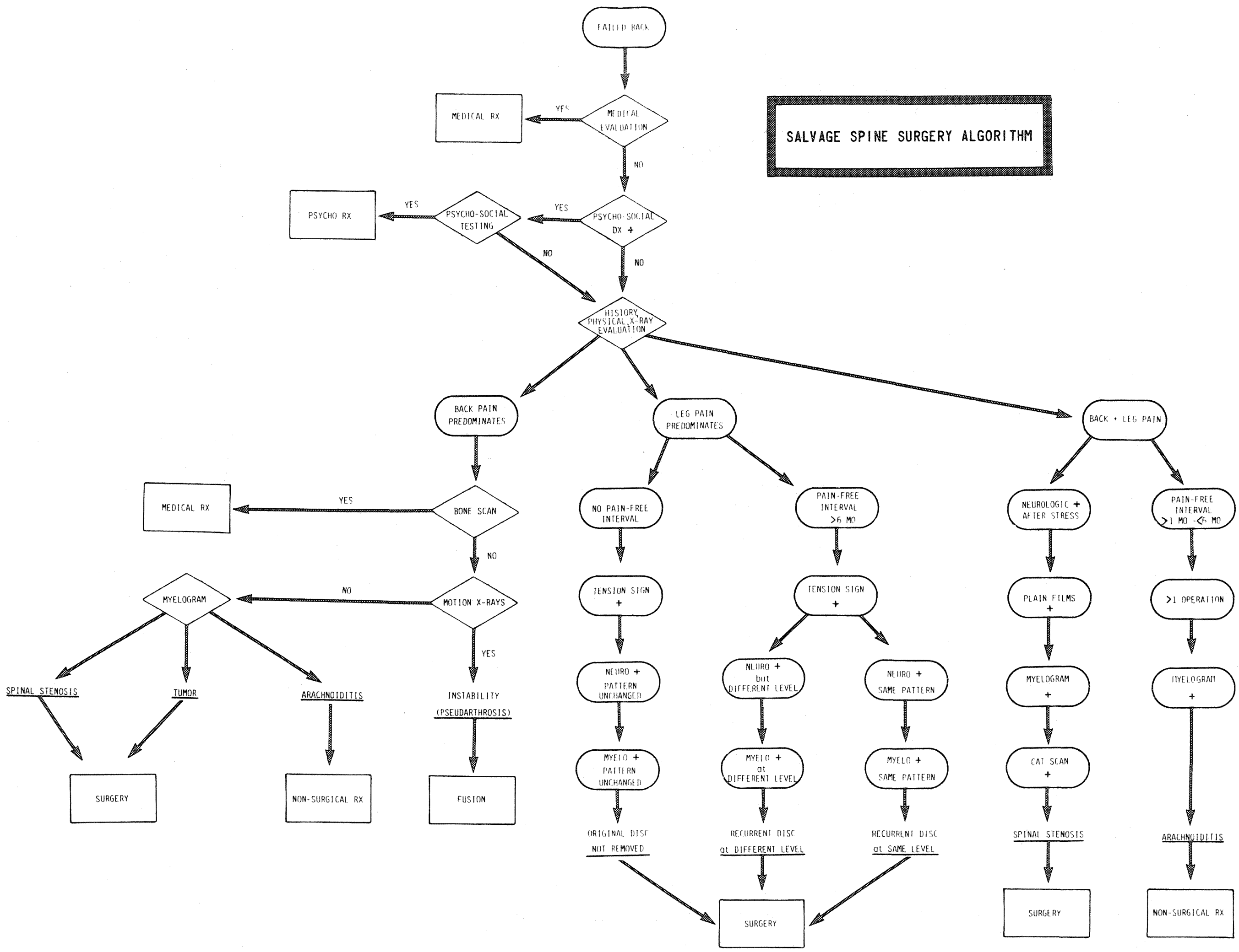

Fig. 1: Salvage spine surgery algorithm (Reprinted from "The Aging Lumbar Spine, by Sam W. Wiesel et al. Permission granted by W.B. Saunders Company).

Spinal Stenosis

Spinal stenosis can produce both back and leg pain on a mechanical basis. The etiology may be secondary to the patient's intrinsic back disease or a previous posterior spinal fusion. Physical examination often is inconclusive. However, a neurologic deficit may appear after exercise, with reproduction of the patient's symptoms; this phenomenon is termed a positive stress test.

The plain roentgenograms will display facet degeneration, decreased interpedicular distance, decreased sagittal canal diameter, and disc degeneration. A computerized axial tomogram will show bony encroachment upon the neural elements and is especially useful in evaluating the lateral recesses and foramina. A metrizamide myelogram is the most definitive test; it will demonstrate a block or significant narrowing of the dye column at the involved level. Spinal stenosis can coexist with some form of scar tissue. If there is definite evidence of bony compression, a laminectomy should be considered for a patient with continued pain. However, with scar tissue present the degree of anticipated pain relief is totally unpredictable. The patient must be made aware of this uncertainty because a laminectomy is a major surgical procedure and may be associated with significant morbidity.

Arachnoiditis

Arachnoiditis is an area of considerable concern in the postoperative patient who continues to have symptoms. There is no effective cure for true arachnoiditis, which can be strictly defined as an inflammation of the pia-arachnoid membrane surrounding the spinal cord or cauda equina[1]. This condition can be present in varying degrees of severity—from mild thickening of the membrane to solid adhesions which can obliterate the subarachnoid space and block the flow of contrast agents. Epidural scarring which may surround the cauda equina and/or individual nerve roots is a different pathological entity. It, too, may cause symptoms by producing an extradural defect.

Statistically, the histories of patients with arachnoiditis will reveal more than one previous operation, and their pain-free intervals will fall between one and six months. Usually they complain of both back and leg pain, in varying degrees. The physical examination will be inconclusive. The myelogram is definitive for the diagnosis of intradural scar tissue: non-visualization of the nerve roots within the dural sac and narrowing or blockage of the contrast column at the involved levels.

True arachnoiditis is not amenable to any form of surgical intervention. If surgery is attempted, the patient usually is made worse; therefore, non-surgical modalities should be employed. These patients should first be detoxified, then begun on as strenuous an exercise program as tolerated. Most of them will continue to have some chronic pain, for which Elavil on a long-term basis has proved helpful. The other modalities mentioned earlier should be employed as required.

SUMMARY

In conclusion, the physician dealing with the multiply operated lumbar spine patient needs to have an organized approach to evaluation. If one looks closely, the origin of the problem in most instances is a faulty decision to perform the original procedure. Further surgery on an "exploratory" basis is not warranted in any situation and will lead only to further disability. The surgeon should operate only when there are definite objective findings to substantiate the patient's subjective complaints.

The etiology of each patient's complaints must be accurately localized and identified. The patient's general medical status and psychosocial situation should be evaluated at the time of the initial consultation. Once the spine is identified as the probably source of symptoms, specific features should be sought in the patient's clinical history, physical examination, and radiographic studies. The number of previous operations, characteristics of the pain-free interval, and predominance of leg versus back pain are the major historical points. The presence of a tension sign and the neurologic findings are the focal points of the physical examination. Plain roentgenograms, motion films, metrizamide myelography, and computerized axial tomography all have specific roles. When all this information is integrated, the physician can separate patients with mechanical problems from those with some form of scar tissue.

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THE PALMAR RADIOCARPAL LIGAMENTS: A STUDY OF ADULT AND FETAL HUMAN WRIST JOINTS

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INTRODUCTION

It is commonly assumed that the gross anatomical features of the human body are fully documented and are more or less irrefutable. However, a brief scan through the literature concerning wrist ligaments reveals a surprising level of disagreement amongst authors. This holds especially true for the nomenclature of the ligaments connecting the radius and the carpal bones. Among the names assigned to the palmar carpal ligaments are the radial collateral ligament[9,10,19,22,24,27,28], superficial volar radiocarpal ligament[24], anterior, volar, or palmar radiocarpal ligament[9,10,16,19,23,24,27,28], deltoid ligament[24], radiate or arcuate ligament[23,27], radioscaphocapitate ligament[24], radiocapitate ligament[4,6,19], deep radioscapholunate ligament[25], radioscaphoid ligament[19], and the radioscapholunate ligament[6,24]. In addition, there are disagreements regarding the existence of structures, such as the radial collateral ligament, and failure to mention existing structures, such as a flat sheet of fibers connecting the distal radius to the lunate. These controversies may appear of no major consequence. However, the understanding of structure forms the foundation for understanding function. Therefore, a thorough, precise, and consistent description of carpal anatomy must percede an understanding of carpal function and pathomechanics.

Geoffrey Fisk stated "the integrity of the carpus appears to depend chiefly upon the volar radiocarpal ligamentous complex"[8]. Agreeing with Fisk's observation and seeking to eliminate much of the cited controversy, our investigation sought: 1) the detailed course of each major palmar radiocarpal ligament, and 2) the assignment of nomenclature possessing anatomic precision and clarifying position and course. Both adult and fetal human wrists supplied study material.

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MATERIALS AND METHODS

Over fifty adult, cadaveric wrists underwent investigation via three basic methods: gross dissection, microdissection, and histologic observation. Both palmar and dorsal approaches were made. Observations of the ligaments were noted and, when appropriate, photographed. Meticulous, piecemeal removal of the carpal bones in three specimens provided dorsal exposure of the entire palmar radiocarpal ligament. A Leitz stereoscopic dissecting microscope delineated fine details such as the insertion of two or more ligaments into a common region. Finally, serial sections of twenty-three fetal upper extremities from the Preparation Archives of the Department of Anatomy, University of Leiden, ranging from 23 to 230 mm C-R (crown-rump) length, were microscopically studied. Sagittal, coronal, and transverse sections were stained with either Azan or Hematoxylin and Eosin. Graphic reconstructions of various features of the wrists were made from the serial sections using the method developed by Tinkelenberg.

RESULTS

General Features of the Radiocarpal Joint

After incising the wrist joint capsule from a dorsal perspective and maximally palmar flexing the proximal carpal row to expose the radiocarpal joint, several general anatomic features are readily apparent in the organization of the palmar carpal ligaments (Fig. 1). A striking asymmetry exists between the ligaments coursing to the carpus from the radius and those to the carpus from the ulna-triangular

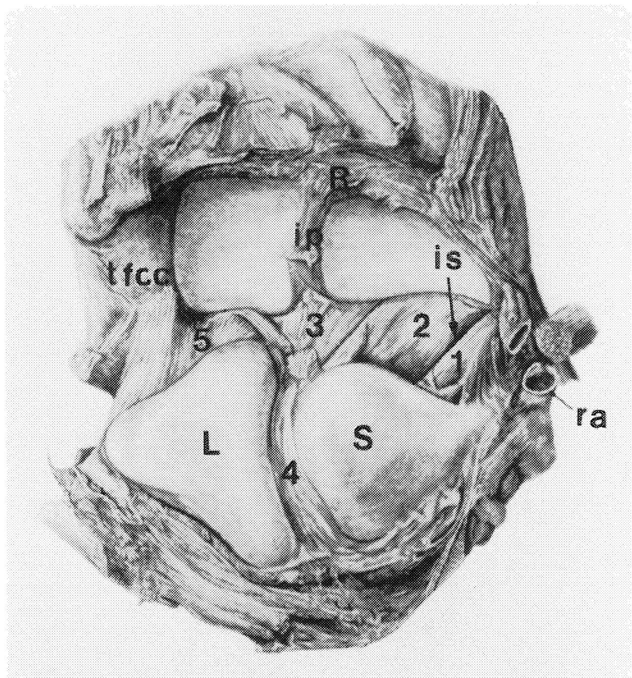

Fig. 1: Radiocarpal joint from a dorsal and distal perspective with the carpus palmar flexed. R = radius, S = scaphoid, L = lunate, tfcc = triangular fibrocartilage complex, ra = radial artery, is = interligamentous sulcus, ip = interfacet prominence, 1 = radioscaphocapitate ligament, 2 = long radiolunate ligament, 3 = radioscapholunate ligament, 4 = scapholunate interosseous ligament, 5 = short radiolunate ligament.

fibrocartilage complex (TFCC). The two large ligaments from the radius (radioscaphocapitate and long radiolunate) are of substantial size, with rounded dorsal surfaces protruding into the radiocarpal joint. Between these ligaments runs a sharply defined division, the interligamentous sulcus, which further emphasizes the relative size and individuality of these ligaments. In contrast, the ulnar TFCC undergoes a gradual transition palmarly to produce a flat sheet of fibers which progressively molds to the contour of the lunate and triquetrum. Intermittent divisions in the course of this flat ligamentous sheet form limited and shallow clefts filled with synovial villi.

The distal articulating surface of the radius comprises two articular facets: a lateral triangular facet for the scaphoid and a medial quadrangular facet for the lunate (Fig. 1). Separating these facets is the interfacet prominence. Nearly flush with the dorsal articular facets of the radius, the interfacet prominence is widest and projects farthest into the radiocarpal joint near the palmar margin of the radius. The prominence contrasts its fibrocartilagenous cover with the hyaline cartilage of the facets. The TFCC attaches to the ulnar margin of the radial articular facet for the lunate. The smooth transition from distal radius to TFCC is marked primarily by the contrasting appearance of its fibrocartilage composition compared to the facet's hyaline cartilage lining. When intact, the TFCC prevents communications between the distal radio-ulnar and radiocarpal joints[3].

The palmar view of the carpal ligaments differs remarkably from a dorsal view of the same structures (Fig. 2). After stripping the loose connective and vascular tissue lining of the carpal tunnel, a continuous array of collagen fibers is seen, without well defined ligaments. These fibers constitute the fibrous layer of the carpal joint capsule. As in a dorsal view, there is an overall tendency of these fibers to course toward the carpal midline. These fibers, contoured to the palmar geometries of the carpus, are continuous with the flexor retinaculum of the carpal tunnel. Careful microdissection of this fibrous layer reveals that it is not separate from the deeper substance of the palmar carpal ligaments. Rather, it binds the palmar surfaces of these ligaments into a continuous structure. Deeper dissection, disrupting the continuous, superficial fibrous layer, uncovers the divisions between the palmar radiocarpal ligaments as appreciated from the dorsal approach.

The proximal carpal row, composed of the scaphoid, lunate, and triquetrum form the distal boundary of the radiocarpal joint. Connecting these bones are the scapholunate and lunotriquetral interosseous ligaments (Fig. 1). These ligaments span transversely across the dorsal, proximal, and palmar interosseous joint margins, leaving the distal margin of the interosseous joints in free communication with the midcarpal joint. When intact, the scapholunate and lunotriquetral interosseous ligaments prevent communication between the radiocarpal and midcarpal joints[4].

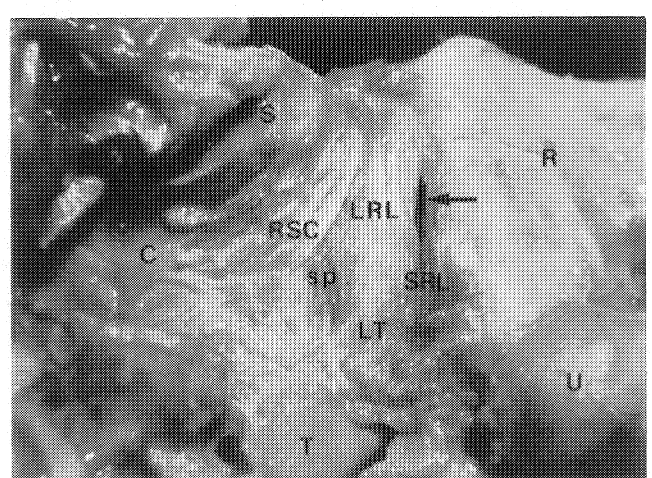

Fig. 2: Palmar view of the carpal region, after the removal of the transverse carpal ligament and the synovial lining of the carpal tunnel. R = radius, U = ulna, T = triquetrum, C = capitate, S = scaphoid (distal pole), LRL = long radiolunate ligament, RSC = radioscaphocapitate ligament (scaphocapitate portion), SRL = short radiolunate ligament, LT = lunotriquetral interosseous ligament, sp = space of Poirier. The arrow identifies the space where the radioscapholunate ligament penetrates into the radiocarpal joint.

Finally, each ligament described in this study is enveloped in a fibrosynovial sheath (Fig. 3)[6]. On their superficial surfaces, the ligaments are covered and interconnected by the fibrous layer of the joint capsule. On their deep, or joint surfaces, the ligaments are lined by the synovial layer of the joint capsule, except where they are covered by another ligament or bone. Thus, each ligament is truly an intercapsular structure, interposed between the fibrous and synovial joint capsule strata, and as such, the collagen fibers composing the ligaments are isolated from direct contact with the joint space proper.

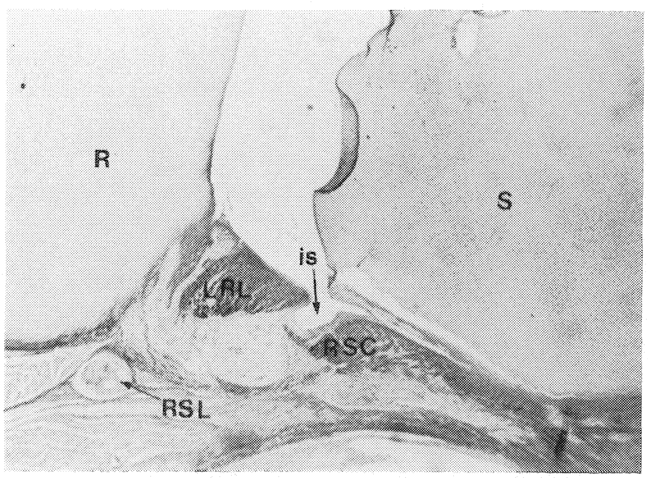

Fig. 3: Sagittal section through the wrist of an 11 cm C-R length fetus. R = radius, S = scaphoid, LRL = long radiolunate ligament, RSC = radioscaphocapitate ligament, RSL = radioscapholunate ligament, is = interligamentous sulcus. A layer of pale-staining synovial cells line the joint surfaces of the long radiolunate and radioscaphocapitate ligament inserts into the palmar surface of the proximal pole of the scaphoid. The radioscapholunate ligament, composed of neurovascular tissue, is seen passing parallel to the distal margin of m. pronator quadratus prior to entering the radiocarpal joint. Hematoxylin and eosin.

Radioscaphocapitate Ligament

The radioscaphocapitate ligament is the radial-most of the two large palmar radiocarpal ligaments (Fig. 1). It takes origin from a roughened area on the palmar surface of the radial styloid process. Those fibers originating from the extreme distal aspect of the radial styloid process course distally over a short distance to the radiopalmar surface of the waist of the scaphoid and form a functional and anatomic radial collateral ligament. Some of these fibers blend into the fibers of the dorsal scapho-trapezial-trapezoidal ligament. The remaining fibers of the radioscaphocapitate ligament course obliquely, distally, and ulnarly in the direction of the capitate, appearing to pass beneath the scaphoid's proximal pole. The radial-most fibers of this portion of the ligament insert progressively into the palmar surface of the distal pole of the scaphoid, where the ligament "bends" around the distal pole as the scaphocapitate articulation is approached (Fig. 5). The more ulnar fibers pass beneath the proximal pole of the scaphoid. Rather than inserting directly into the scaphoid, the synovial covering of the ligament near the scapholunate joint folds back onto itself to insert into the proximal pole of the scaphoid (Fig. 3). This further isolates the fibers of the ligament from the radiocarpal joint. Progressing distally beyond the proximal pole of the scaphoid, the radioscaphocapitate ligament fans out horizontally. The radial-most fibers of this part of the ligament blend with the fibers of the scaphocapitate ligament as they course toward the palmar surface of the body of the capitate. The bulk of the radioscaphocapitate ligament takes an arcuate course around the distal margin of the palmar surface of the lunate to form a ligamentous sling supporting, but not inserting into the head of the capitate (Figs. 4 and 5). These fibers

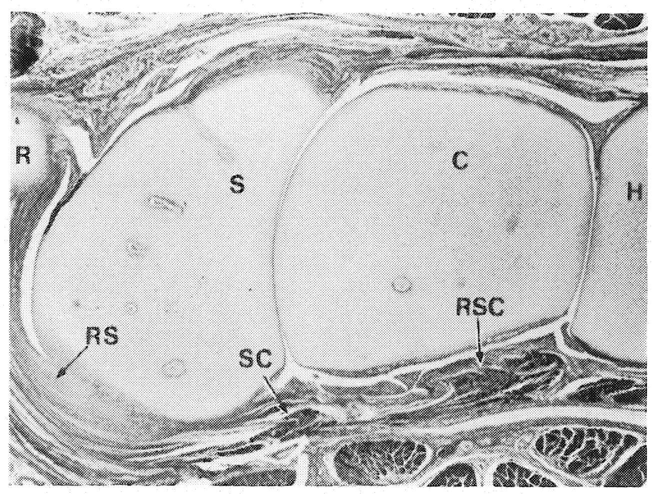

Fig. 4: Transverse section through a 17 cm C-R length fetal wrist. R = radial styloid process, S = scaphoid, C = head of capitate, H = hamate, RS = radioscaphoid portion of the radioscaphocapitate ligament, SC = scaphocapitate portion of the radioscaphocapitate ligament, RSC = radioscaphocapitate ligament merging with fibers from the TFCC to form the sling support for the head of the capitate. RS anatomically forms a collateral ligament, clearly inserting into the scaphoid. The head of the capitate is completely free from ligamentous attachment on its palmar surface. SC fibers are coursing medially and distally to insert into the body of the capitate. Hematoxylin and eosin.

interdigitate with fibers arching toward the midline from the TFCC. If a coronal section of the wrist is made at the level of the scaphocapitate articulation, only the distal-most fibers of radioscaphocapitate ligament is seen inserting into the capitate with fibers of the scaphocapitate ligament. The bulk of the radioscaphocapitate ligament passes palmar to the head of the capitate with essentially no insertion (Fig. 6). A few fibers from the portion of the radioscaphocapitate ligament forming the sling support for the head of the capitate deviate to a distal insertion into the body of the capitate (Fig. 5). Thus, there are three

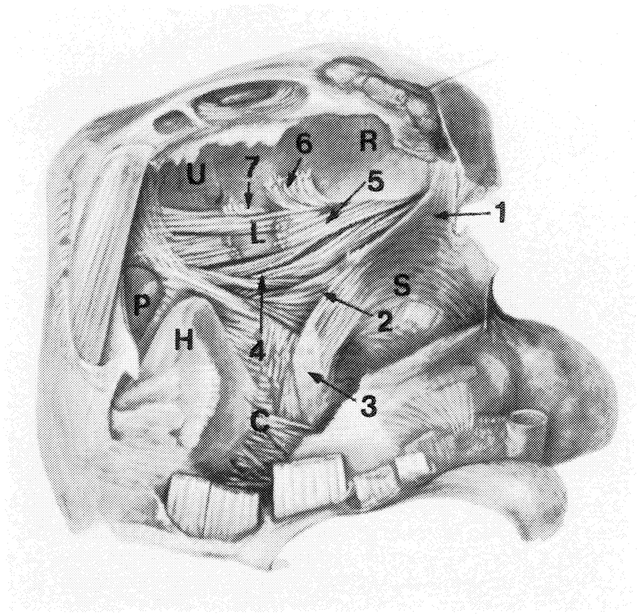

Fig. 5: Dorsal perspective of the palmar carpal ligaments after piecemeal excision of selected carpal bones. R = distal articulating surface of the radius, U = ulna/TFCC, P = pisiform, H = proximal pole of the hamate, L = space previously occupied by the lunate, S = space previously occupied by the scaphoid, C = space previously occupied by the capitate, 1 = radioscaphoid portion of the radioscaphocapitate ligament, 2 = radioscaphocapitate contribution to the sling support for the head of the capitate, 3 = scaphocapitate portion of the radioscaphocapitate ligament, 4 = space of Poirier, 5 = long radiolunate ligament, 6 = radioscapholunate ligament, 7 = short radiolunate ligament. Very few fibers originating from the radius insert into the capitate. Almost all of the fibers of the long radiolunate ligament insert into the lunate and do not reach the triquetrum. The sling support for the head of the capitate is composed of fibers from the radioscaphocapitate ligament and from the TFCC.

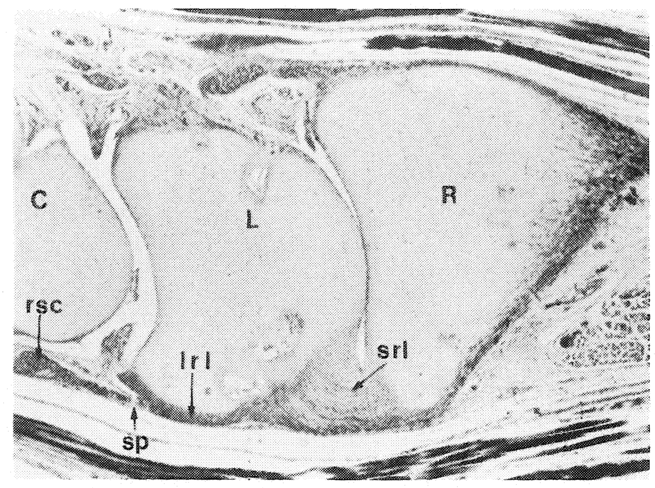

Fig. 6: Sagittal section through the wrist of an 11 cm C-R length fetus. R = radius, L = lunate, C = head of the capitate, srl = short radiolunate ligament, lrl = long radiolunate ligament, rsc = radioscaphocapitate ligament, sp = space of Poirier. The long radiolunate ligament has completely inserted into the palmar surface of the lunate, with only the fibrous layer of the joint capsule covering the lunate. The radioscaphocapitate ligament forms a supporting sling for the head of the capitate without inserting into it. The head of the capitate is completely devoid of ligamentous insertion. The space of Poirier, separating the fibrous layer of the joint capsule on the palmar surface of the lunate from the radioscaphocapitate ligament, is continuous with the interligamentous sulcus. Hematoxylin and eosin.

major components of the radioscaphocapitate ligament: radioscaphoid, radiocapitate, and the sling support for the head of the capitate. Throughout its course, the radioscaphocapitate ligament is separated from the long radiolunate ligament by the interligamentous sulcus (Fig. 3). This sulcus forms the space of Poirier at the level of the lunocapitate articulation (Fig. 6).

Long Radiolunate Ligament

The long radiolunate ligament is the ulnar-most of the two large palmar radiocarpal ligaments (Fig. 1). Immediately distal to its contiguous origin with the radioscaphocapitate ligament it is separated from that ligament by the interligamentous sulcus (Figs. 1, 3, and 7). The ligament courses obliquely and ulnarly toward the lunate, essentially parallel to the course of the proximal fibers of the radioscaphocapitate ligament. Near the scapholunate articulation, the synovial covering lining the joint surface of the long radiolunate ligament merges with the fibers forming the palmar components of the scapholunate interosseous and radioscapholunate ligaments. Directly beneath the scapholunate articulation, the deepest fibers of the long radiolunate ligament merge with the scapholunate interosseous and radioscapholunate ligaments in a similar fashion. Proceeding ulnarly, the long radiolunate ligament inserts completely into the radial margin and the radial half of the palmar surface of the lunate (Figs. 5, 6, and 7). Only the fibrous capsular layer forming the superficial aspect of the ligament continues ulnarly over the palmar surface of the lunate, ultimately contributing to the formation of the lunotriquetral interosseous ligament. At the level of their insertion, the distal-most fibers of the long radiolunate ligament are separated from the radioscaphocapitate ligament by the space of Poirier (Fig. 6). The proximal-most fibers of the long radiolunate ligament interdigitate with fibers inserting into the proximopalmar margin of the lunate from the short radiolunate ligament (Fig. 5). Just ulnar to the insertion of the bulk of the long radiolunate ligament into the lunate is a region of nutrient vessels penetrating the palmar cortex of the lunate.

Radioscapholunate Ligament

Although the radioscapholunate ligament is referred to as a ligament, in reality the radioscapholunate ligament is primarily a neurovascular bundle supplying the scapholunate interosseous ligament. The neural origin of this struc-

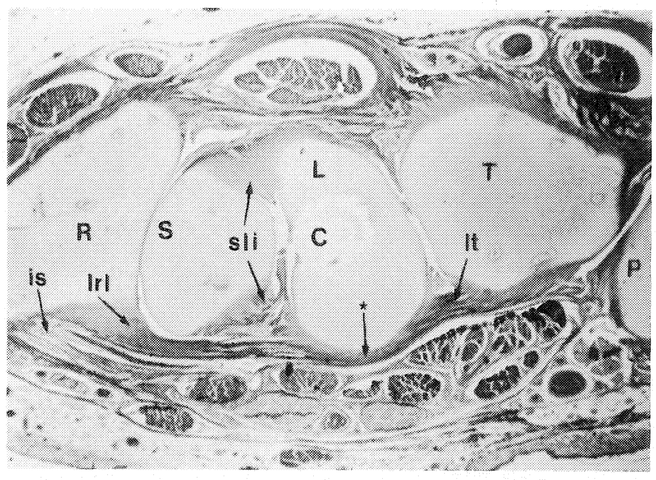

Fig. 7: Transverse section through the wrist of a 17 cm C-R length fetus. R = radius, S = scaphoid, L = lunate, C = head of the capitate, T = triquetrum; P = pisiform, lrl = long radiolunate ligament, sli = scapholunate interosseous ligament, lt = lunotriquetral interosseous ligament, is = interligamentous sulcus. The long radiolunate ligament supports the scapholunate interosseous ligament and inserts completely into the lunate. Only the superficial fibrous capsular layer covers the palmar surface of the lunate. Note the high degree of vascularity in the palmar scapholunate interosseous ligament, contributed by the radioscapholunate ligament. Hematoxylin and eosin.

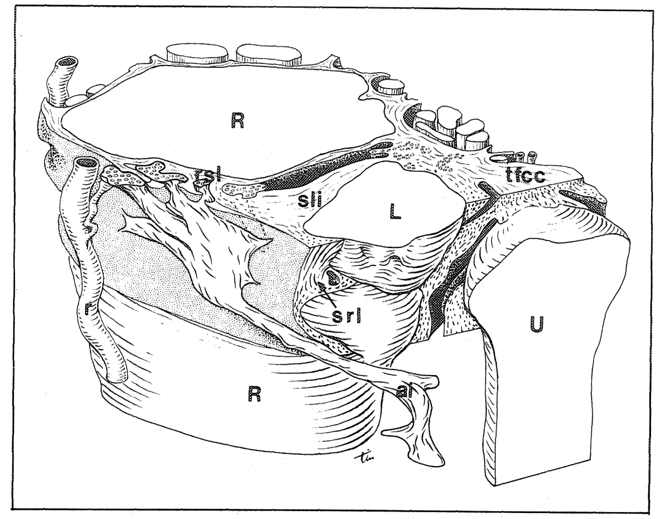

Fig. 8: Graphic reconstruction of serial sections from a 23 cm C-R length fetus. The perspective is from the palmar-ulnar direction, with the radial carpal extensor tendons shown at the top of the figure. R = radius, U = ulna, L = lunate, r = radial artery, ai = anterior interosseous artery, tfcc = triangular fibrocartilage complex, rsl = radioscapholunate ligament, sli = scapholunate interosseous ligament, srl = short radiolunate ligament. The radial artery and anterior interosseous artery give off branches with anastomose to form a common vascular supply for the radioscapholunate ligament. The radioscapholunate ligament penetrates into the radiocarpal joint between the short radiolunate ligament (shown) and the long radiolunate ligament (not shown).

ture is the anterior interosseous nerve. The vascular origin is from an anastomosis of branches from the radial and anterior interosseous arteries located near the distal margin of pronator quadratus (Figs. 3 and 8). The radioscapholunate ligament can be divided into five components: proximal and distal stems, radial and ulnar wings, and a junction region where the stems and wings converge (Figs. 1 and 9). The proximal stem integrates with the fibrocartilage forming the interfacet prominence on the distal surface of the radius. Within the proximal stem are one or more nutrient vessels which penetrate the cortex of the radius (Fig. 9). The distal stem courses obliquely, distally, and dorsally to form the proximal component of the scapholunate interosseous ligament, isolating the scapholunate articulation from contact with the radiocarpal joint. The vessels within the distal stem arborize within a short distance to supply the dorsal and palmar components of the scapholunate interosseous ligament (Fig. 9). Their vessels do not penetrate the cortices of either the scaphoid or lunate. The radial and ulnar wings present free edges to the radiocarpal joint and arc gently proximally to insert into the palmar margin of the distal radius (Fig. 1). The wings are directly continuous with the synovial layer lining the deep surfaces of the long and short radiolunate ligaments, and are heavily invested with small caliber vessels and probably represent synovial membrane. At the crux of the stems and wings is the junction region of the radioscapholunate ligament. The junction region can be traced anteriorly through a triangular region found between the distal radius and the long and short radiolunate ligaments (Fig. 2). From here, the vessels can be traced proximally to their parent arteries, enclosed with branches of the anterior interosseous nerve in a loose connective tissue core (Figs. 3 and 9). Although the vascular composition of the radioscapholunate ligament predominates, there is a fibrous component as well. This fibrous component is largely concentrated in the ulnar half of the ligament, integrating with the short radiolunate ligament (Fig. 5).

Short Radiolunate Ligament

The short radiolunate ligament is a relatively flat sheet of short fibers originating from the palmar margin of the distal radius, just palmar to the anterior facet for the lunate (Figs. 1, 5, and 9). It courses distally and dorsally to insert into the proximal margin of the lunate's palmar surface, immediately adjacent to the palmar extent of the articular cartilage covering the proximal articular surface of the lunate (Fig. 6). As with the other carpal ligaments it is lined with a synovial layer on its deep, or joint, surface. Just distal to the insertion of the fibers of the short radiolunate ligament are the nutrient vessels penetrating the palmar cortex of the lunate and the insertion of the long radiolunate ligament. The radial-most fibers of the short radiolunate ligament integrate with the radioscapholunate ligament, the palmar component of the scapholunate inter-

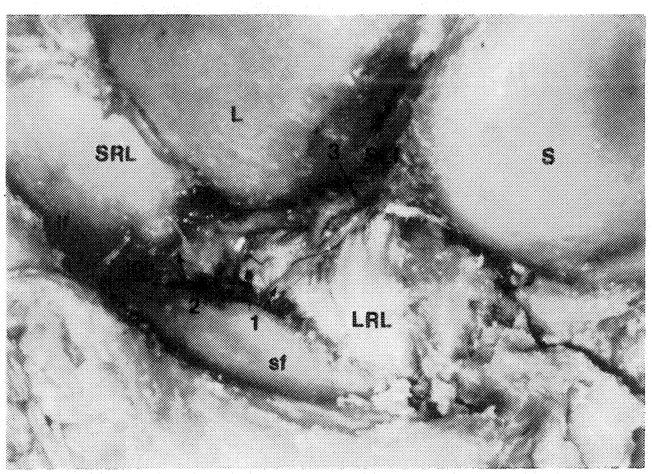

Fig. 9: Microdissection of an adult radioscapholunate ligament, viewed from a dorsal-proximal perspective. The dorsal surface of the radius is seen in the lower left. S = scaphoid, L = lunate, sf = scaphoid facet, lf = lunate facet, ip = interfacet prominence, LRL = long radiolunate ligament, SRL = short radiolunate ligament, SLI = radioscapholunate interosseous ligament, 1 = vessels from the anastomosis of branches of the radial and anterior interosseous arteries penetrating into the radiocarpal joint via the junction segment of the radioscapholunate ligament, 2 = vessels penetrating the cortex of the radius via the proximal stem of the radioscapholunate ligament, 3 = vessels supplying the scapholunate interosseous ligament via the distal stem of the radioscapholunate ligament. The microdissection consisted of removing loose connective tissue with few ligamentous bundles encountered. The vessels forming the radial and ulnar wings of the radioscapholunate ligament arborized to the level of capillaries very near their origins, precluding further dissection.

osseous ligament, and the long radiolunate ligament (Figs. 1 and 6). The ulnar-most fibers of this ligament are directly continuous with the ulnolunate component of the ulnocarpal ligament complex originating from the palmar margin of the TFCC (Fig. 1).

DISCUSSION

The substantial number of names assigned to the palmar radiocarpal ligaments leaves most readers confused and discouraged when pursuing an understanding of carpal mechanics. The present investigation was designed to reevaluate the descriptions of the anatomy of the palmar radiocarpal ligaments and to present the anatomy in as clear and graphic manner as possible. Before discussing specific points concerning the palmar radiocarpal ligaments, three general concepts will be emphasized. First, the authors feel that the term *palmar* is preferable to *volar* when describing features on the anterior surface of the hand and wrist, just as *plantar* is preferable when discussing an analogous region of the foot. Second, the palmar radiocarpal ligaments as a group are a major structural component of the wrist joint capsule. Each ligament, with the exception of the radioscapholunate ligament, forms the fibrous layer of the joint capsule and the deep surfaces of the ligaments are lined by synovial cells, thus forming the synovial layer of the joint capsule[6]. Therefore, the palmar radiocarpal ligaments are truly intracapsular ligaments, in contrast to the description offered by Mayfield et al., which divided these ligaments into capsular and intracapsular groups[19]. Third, there are no regions on the palmar surface of the carpus devoid of structures, as implied by most schematic illustrations of the carpus. The superficial surface of the carpus is covered exclusively by ligamentous tissue except where major neurovascular penetrations or tendon insertions occur.

The concept of collateral ligaments had been applied to almost all diarthroidal joints and has been applied controversially to the polyarthroidal wrist joint. A collateral ligament is more than a fibrous band passing along the side of a joint. It is a specialized structure uniquely oriented to generally allow motion in one plane, while stabilizing the joint and constraining motion of the joint in all other planes. Most major textbooks of anatomy, as well as recent publications by Taleisnik[24] and Mayfield et al.[19] describe radial collateral ligaments of the wrist, as originating from the radial styloid and coursing distally across the axis of the carpal flexion-extension motion to insert into the distal pole, or tuberosity, of the scaphoid. In contrast, Lewis et al.[16] and Kauer[13] have contended that there is no structure analogous to a collateral ligament on the radial side of the carpus. Additionally, Lewis[17] stressed that no such structures could be identified in the developing fetal wrist. Kauer[13], in developing his eloquent concept of active collateral ligaments formed by the extensor and abductor pollicis longus muscles, believed that during radial-ulnar deviation of the wrist the excursion necessary for a collateral ligament is too great to afford it any stabilizing properties, except in extreme positions of the joint. However, analysis of carpal bone kinematics provides insight into how the wrist can possess both a wide range of circumductory motions and functionally significant collateral ligaments. The major direction of rotation of all the carpal bones is the same during flexion-extension motions of the wrist, i.e., the proximal carpal row bones generally move in the same direction as the bones of the distal carpal row, albeit at different rates and with minor variations[1,2,10,16]. In contrast, during radial-ulnar deviation of the wrist, the proximal row bones continue to move principally in a flexion-extension direction, while the bones of the distal carpal row are moving in the same plane as the metacarpals, i.e., radial-ulnar deviation. Specifically, the scaphoid, lunate, and triquetrum palmar-flex during radial deviation of the wrist and dorsiflex during ulnar deviation of the wrist. Among other mechanical considerations, this mechanism theoretically allows for functional collateral ligaments attached at or near the axes of rotation of the proximal carpal row. A ligament attaching to the scaphoid in a collateral position could then be taut, hence functional, during all phases of wrist motion. Our present investigation unequivocally shows a significant fibrous insertion from the radial styloid to the radial surface of the scaphoid, which anatomically constitutes a collateral ligament. These fibers are, however, a part of the radioscaphocapitate ligament and do not form a discrete radial collateral ligament. This should not detract from the concept of active collateral stabilization developed by Kauer[13]. Rather, it emphasized that there are intrinsic ligamentous collateral stabilizers of the carpus in addition to extrinsic muscular forces. The stability offered by this intrinsic system is evident in the degree of carpal instability seen with avulsion fractures of the radial styloid, which would disrupt the course of the radioscaphoid portion of the radioscaphocapitate ligament[21].

Surprisingly few fibers of the radioscaphocapitate ligament actually insert into the palmar surface of the body of the capitate. This structure, previously called the radiocapitate ligament[4,6,19], is a primary stabilizer of the scaphoid and contributes to the formation of the sling ligament supporting the head of the capitate. The radial-most fibers of this ligament not only insert into the lateral surface of the scaphoid but also insert circumferentially around the entire distal pole of the scaphoid. Interdigitating with these inserting fibers are the origins of the scaphotrapezium and scaphocapitate ligaments. The only ligamentous insertions into the proximal pole of the scaphoid are the scapholunate interosseous ligament and a reflection of the synovial layer covering the radioscaphocapitate ligament. This arrangement allows a greater range of flexion-extension rotation of the scaphoid, but along with the curved geometry of the scaphoid at its waist, probably contributes to the predisposition of scaphoid fractures to occur at the waist, the most common location of scaphoid fractures[20]. The magnitude of ligamentous insertion into the distal pole of the scaphoid is demonstrated by the following. When a trans-scaphoid fracture occurs, the distal pole of the scaphoid generally remains in a normal position relative to the distal carpal row. If the trans-scaphoid fracture is accompanied by a rupture of the scapholunate interosseous ligament, the proximal pole of the scaphoid is then essentially free-floating. When scapholunate dissociation occurs without trans-scaphoid fracture, the scaphoid malrotates into palmar-flexion such that the proximal pole is elevated dorsally, implying a secure tethering of the distal pole of the scaphoid to the distal carpal row[21]. Thus, the significant ligamentous attachment to the distal pole of the scaphoid (radioscaphocapitate, scaphotrapezial, scaphotrapezoidal, and scaphocapitate ligaments) compared with the relative paucity of ligamentous attachment to the proximal pole of the scaphoid (scapholunate interosseous and radioscapholunate ligaments plus a reflection of synovium from the radioscaphocapitate ligament) essentially fixes the distal pole relative to the distal carpal row bones. Major ligamentous disruption must occur if scaphoid malrotation is to occur from a distal pole origin, whereas relatively few ligaments must be disrupted to produce scaphoid malrotation from a proximal pole origin.

The ulnar-most fibers of the radioscaphocapitate ligament contribute to the formation of a sling support for the head of the capitate by interdigitating with radially directed fibers from the triangular fibrocartilage complex and ulna. This arrangement was described by Landsmeer in his extensive study of fetal wrists[15]. These fibers do not directly insert into the capitate. The head of the capitate and proximal pole of the hamate, essentially free from ligamentous insertion, are together analogous to an articular ball in a ball-and-socket joint, with the distal surfaces of the scaphoid, lunate, and triquetrum forming a socket, as proposed by McConnaill[22]. The sling ligament formation provides a cushioned floor to restrain palmar displacement of the head of the capitate without limiting the articular surface area, hence without obstructing the range of motion of the midcarpal joint. This ligament formation is critical to normal midcarpal mechanics. In a wrist with volar-flexed intercalated segment instability (VISI)[18] or Stage II perilunate dislocation from a hyperextension injury[16], the space of Poirier between the lunate and the sling ligament formation is widened. This widening allows palmar displacement of the head of the capitate, which may contribute to malpositioning of the lunate in an abnormally palmar-flexed attitude.

Rather than becoming relaxed as the wrist radially deviates, as proposed by Mayfield et al., the radioscaphoid ligament could conceivably maintain a relatively constant tension. This is based on the kinematic observation that the scaphoid palmar-flexes during radial deviation of the wrist, hence palmarly displacing the radioscaphocapitate ligament as it passes under the waist of the scaphoid and attaches to the distal pole[1,2]. This palmarward rotational displacement may nearly equal the radial rotational displacement of the capitate during radial deviation, therefore generating little if any change in the three-dimensional origin-to-insertion length of the ligament. However, if the portion of the ligament interconnecting the scaphoid and capitate is disrupted, as described by Mayfield et al.[21], this length constancy relationship is disturbed and the scaphoid has a tendency to rotate into a abnormally palmar-flexed attitude, following the principles of intercalated segment instability described by Landsmeer[14]. An intact scapholunate interosseous ligament may attenuate this scaphoid rotation.

The long radiolunate ligament, previously referred to as the radiotriquetral ligament[4,6,19], is a primary stabilizer of the lunate and acts to prevent significant ulnarward displacement of the lunate during radial deviation of the wrist. Additionally, it provides a "floor" for the proximal pole of the scaphoid, thereby preventing a palmarward displacement just as the radioscaphocapitate ligament contributes to a sling support for the head of the capitate. This support does not inhibit the rotational range of motion of the scaphoid because the articular surface area of the scaphoid's proximal pole is not compromised by ligamentous insertion. The long radiolunate ligament also provides support for the scapholunate interosseous ligament, as shown by Berger and Blair[6]. The apparent continuity of the long radiolunate ligament and the palmar lunotriquetral interosseous ligament from a palmar perspective has given the impression of a single ligament connecting the radius to the triquetrum, hence the name radiotriquetral ligament. However, the palmar surface of the lunate is covered only by a thin layer of fibrous joint capsule and penetrating nutrient vessels. Therefore, the term radiotriquetral ligament should be discarded. In their investigations into the mechanism of carpal injury, Mayfield et al.[20,21] described a stage in progressive perilunate instability where lunotriquetral dislocation occurs with radiotriquetral ligament failure (PLI Stage III). The level of failure described is at the lunotriquetral joint, so the failure involves the lunotriquetral interosseous ligament just as scapholunate dissociation involves failure of the scapholunate interosseous ligament. The long radiolunate ligament is intact in both cases and provides stability to the lunate in concert with the short radiolunate ligament, while the contiguous bones dislocate relative to a fixed lunate and radius.

In the past decade, the radioscapholunate ligament has generated a surprising degree of controversy[6]. Questions have arisen regarding its attachment and whether or not it should even be classified as a ligament. Testut first described the deep radioscapholunate ligament as dividing into two bands for insertion along the palmar and proximal margins of the radial surface of the lunate[25]. Mayfield et al., referring to it as the radioscaphoid ligament, described its insertion into the proximal pole of the scaphoid, with secondary insertions into the lunate[21]. Taleisnik, using the term radioscapholunate ligament, described its insertion into the lunate and secondarily into the scaphoid and its covering the scapholunate joint proximally[24]. Landsmeer, choosing not to call this structure a ligament, described a vascular pole supplying the scapholunate interosseous ligament, based on observations made from serial sections of fetal wrist[15]. The adult dissections of Berger and Blair described the course of the ligament and found that radioscapholunate ligament indeed formed the proximal aspect of the scapholunate interosseous ligament in addition to inserting into the scaphoid and lunate[6]. The histologic sections uniformly confirmed Landsmeer's observations of a marked vascularity within the substance of the ligament[15], and refuted the theory of Williams et al. that the highly elastic properties of the structure were due to an unusually high elastin content, as no extravascular elastin tissue was detected[29]. However, it is possible that the increased elasticity of the structure reflects the mechanical properties imparted by the blood vessels, which are in general highly elastic. The present investigation reconfirmed the vascular nature of the radioscapholunate ligament. However, as Landsmeer observed, the vessels supply only the scapholunate interosseous ligament, and don't penetrate the cortices of either the scaphoid or lunate[15]. Only the proximal stem vessels penetrate bone cortex at the level of the interfacet prominence on the distal radius. Both fetal and adult specimens demonstrated a constant anastomosis of branches from the anterior interosseous and radial arteries; angiographic studies confirmed this common occurrence[11].

An intact scapholunate interosseous ligament has been felt to be critical to normal scapholunate, hence overall carpal, kinetmatics[12]. However, isolated sectioning of this ligament showed no acute significant changes in the motions or positions of the scaphoid, lunate, or remaining carpal bones[1]. This phenomenon may be related to initial stabilization of the scaphoid and lunate by contiguous ligaments, which may decompensate over time with repeated use of the wrist, leading to a progressive scapholunate dissociation and subsequent carpal instability. In all stages of perilunate dislocations, lunate dislocations, and scapholunate dissociations, not only is the scapholunate interosseous ligament ruptured, but the radioscapholunate ligament is disrupted as well[20,21]. This raises an interesting and potentially important clinical hypothesis. If the radioscapholunate ligament, currently shown to be the sole vascular supply of the scapholunate interosseous ligament, is disrupted along with scapholunate interosseous ligament failure, the blood supply to the interosseous ligament would be significantly embarrassed. Therefore, regardless of adequacy of reduction of the scapholunate dissociation, inadequate repair of the scapholunate interosseous ligament may exist secondary to inadequate vascular supply to the ligament. This would present as chronic progressive carpal instability due to scapholunate dissociation. This concept although in need of further substantiation, if valid, would necessitate radically different methods of treatment for scapholunate joint disruptions.

The short radiolunate ligament was not found in our extensive literature search. Its thickness and density suggest a major role in maintaining stability of the radiolunate articulation. After spanning the short distance between the radius and the lunate, it inserts next to the palmar margin of the proximal articular surface of the lunate. In this position, it could constrain the range of both palmar flexion and dorsiflexion as well as distal translation of the lunate.

The magnitude of ligamentous insertion into the lunate, including the long and short radiolunate, scapholunate and lunotriquetral interosseous, and dorsal radiocarpal ligaments, surpasses that of other carpal bones. This explains why the lunate undergoes less rotational displacement than any other carpal bone[1,2] and why tremendous ligamentous disruption would be necessary for a complete lunate dislocation to occur. However, according to Campbell et al.[7], closed and open reductions of lunate dislocations have better clinical results than open and closed reduction of perilunate dislocations, where presumably some ligamentous insertion into the lunate remains intact. An explanation of this phenomenon may be found in the central location of the lunate. If the lunate can be adequately reduced from a dislocated state, the contiguous bones may provide enough support to maintain reduction until ligamentous repair is complete.

Finally, a comment about the methods employed in this investigation will be made. Historically, most anatomical studies of adult extremities have relied on dissection techniques. Although the foundations of our anatomical understanding have been derived from these methods, gross dissection itself alters the anatomy of the specimen, sometimes leading to inaccurate conclusions. In the present study, gross dissections of the carpal ligaments were augmented by an extensive review of fetal wrist serial sections, which do not distort the in-situ anatomy of the specimen. The use of Tinkelenberg's method[26] allowed a three-dimensional reconstruction of features followed serially through multiple histologic sections. These reconstructions were then used to describe the deep anatomy of the wrist and to confirm observations made from the dissection studies. Additionally, our approach to observe the carpal ligaments involved removal of the carpal bones in a piecemeal fashion from a dorsal approach. This new perspective demonstrated the relationships of the carpal ligaments to themselves and the carpal bones. By combining all these techniques, a more complete and accurate description of the carpal ligaments was possible. It is also possible, but time consuming, to study adult bone-ligament complexes histologically, adding yet another dimension to an anatomical description[5]. The results gained from such a complete anatomical study would represent a worthwhile investment of time and effort and may lay the foundation necessary for a more complete understanding of normal and pathologic mechanics of these joint systems.

SUMMARY

This manuscript described the results of an extensive gross and microscopic anatomical study of the arrangement of the palmar radiocarpal ligaments, using human adult and fetal wrists. The four ligaments described were the radioscaphocapitate, long radiolunate, radioscapholunate, and short radiolunate ligaments. Salient features of each ligament are as follows.

Radioscaphocapitate Ligament

origin: radial styloid process

insertions:
1) radial aspect of the waist of the scaphoid
2) circumferentially around the distal pole of the scaphoid
3) integration with fibers from the triangular fibrocartilage complex to form a sling support for the head of the capitate
4) minor insertion into the body of the capitate

major functions:
1) stabilizes the scaphoid as a collateral ligament, preventing excessive lateral rotational displacement
2) stabilizes the scaphoid via distal pole insertions, preventing excessive dorsiflexion
3) provides a ligamentous support for the head of the capitate which does not impede rotational displacement

Long Radiolunate Ligament

origin: distal radius, just ulnar to the radioscaphocapitate ligament origin

insertion: radial margin of the palmar surface of the lunate

major functions:
1) stabilizes the lunate, preventing excessive ulnarward displacement
2) provides a ligamentous support of the proximal pole of the scaphoid which does not impede rotational displacement

Radioscapholunate Ligament

origins:
1) fibrous, from the region between the origins of the long and short radiolunate ligaments
2) vascular, from the anastomosis of branches of the radial and anterior interosseous arteries

insertions:
1) interfacet prominence on the distal surface of the radius
2) scapholunate interosseous ligament
3) palmar margin of the distal radius via synovial folds

major functions:
1) sole vascular supply to the scapholunate interosseous ligament, minor vascular supply to the distal radius
2) possible source of synovial fluid for the radiocarpal joint
3) minor stabilizer of the scaphoid and lunate

Short Radiolunate Ligament

origin: palmar margin of the distal radius, palmar to the lunate facet

insertion: palmar margin of the proximal articulating surface of the lunate
major function: stabilizes the lunate, preventing excessive dorsiflexion, palmar flexion, and distal displacement

Theoretical implications of traumatic disruptions of these ligaments were explored, all of which will require further laboratory and clinical analysis. Finally, the anatomical methods utilized in this investigation were discussed, with a major emphasis placed on the need to perform anatomic evaluations by combining a variety of approaches, each of which should strive to minimize disruption of the in-situ anatomical relationships.

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DENS FRACTURES
A MULTICENTER STUDY BY THE CERVICAL SPINE RESEARCH SOCIETY

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The treatment of dens fractures is controversial[1,3,5,6,9,10,14,15,16,19,21,22,23,25]. No single method of management has become universally accepted. Most authors agree that fractures involving the vertebral body can be treated non-operatively. The major controversy centers around fractures occurring at the junction of the dens and the body. Some strongly advocate surgical management[4,7,12,13,24] of this injury and others advocate non-surgical management[5,8,11,20]. Since clinical studies support both types of treatments, the surgeon may choose either. However, most of these studies involve relatively small numbers of patients.

No large, long-term study answers the question of the appropriate initial management of dens fractures. The Cervical Spine Research Society attempted to answer this question with a multicenter study.

Clinical Evaluation and Classification of Dens Fractures

Fractures of the dens are frequently overlooked due to a patient's unconsciousness, associated head trauma, intoxication, and other head injuries[16,18,24]. A high index of suspicion is frequently necessary to recognize these injuries[5]. Clinical symptoms, though present, are frequently nonspecific. Patients usually complain of posterior neck pain, but typically it is poorly localized. Examination reveals paravertebral muscle spasm with tenderness. Most patients have limited neck motion. Neural loss, if present, may range from high tetraplegia (with respiratory center involvement and medullospinal hematomyelia) to minimum motor and sensory weakness involving a portion of an upper limb due to minor loss of one or several roots[24]. The diagnosis is confirmed by radiographic studies. Since there is always potential danger of changing the head/neck relationship during the evaluation, the initial diagnosis may be difficult because one can not move the head for examination or roentgenograms. Gentle traction with the head neutrally positioned is advisable while anteroposterior, open-mouth, and lateral roentgenograms are made. Polytomography and computerized tomography may both be useful and necessary to establish the diagnosis[24].

Several classification schemata have been presented by various authors. Schatzker, et al.[23] classified dens fractures into high and low based on their relationship to the accessory ligament; however, they did not include fractures entering the centrum of the axis. This classification did not seem to be related to the outcome. Althoff[2] devised a classification which appears to have practical merits. He divided the injuries into four types. Type A is a fracture through the isthmus of the dens. Type B passes down into the most superior part of the body of the axis. A Type C fracture passes through the superior part of the body of the axis, and involves the medial part of one of the superior articular facets of the axis. Type D is a fracture which passes through the superior part of the body of the axis and involves the medial part of both superior articular facets of the axis. The most commonly used classification, however, is that of Anderson and D'Alonzo. Its acceptance appears to be due to its great clinical application. Anderson and D'Alonzo divided the injuries into three types. Type I is an oblique fracture of the tip of the dens and appears to be an unusual injury, which may not be of great clinical significance. Type II, a common injury, is a fracture of the junction of the dens with the central body of the axis or, less commonly, at a slightly higher level. The Type III fracture, slightly less common, is one in which the fracture goes deep into the body or centrum of the axis[4]. Several recent studies of fractures of the dens have used this classification scheme[7,12,20,24].

Anatomical considerations and vascular injury may explain the higher rate of nonunion in Anderson and D'Alonzo's Type II fractures as compared with Type III fractures[24]. Because of its clinical applicability as well as its anatomical significance, this classification schema would be the most useful for studying dens fractures. Therefore it was selected as the basic classification for this study. We, like several authors[5,23], have also considered additional factors such as direction, angle, and degree of displacement of the fracture fragments.

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Materials and Methods

All patients who sustained fractures of the dens were considered. Patients with pathologic fractures and fractures occurring in children less than ten years of age were excluded from final tabulations. Diagnosis was established by appropriate radiographic studies including standard anteroposterior, open-mouth, and lateral roentgenograms with the head in neutral position. Polytomography and computerized tomography were used to confirm the diagnosis when necessary.

Fractures were classified according to the schema of Anderson and D'Alonzo[4] based on the anatomic level of injury. Fractures were further described according to the displacement (direction, amount and angulation), degree of comminution at the fracture site, and adequacy of reduction.

Neurological examinations were performed and quantitated utilizing the Motor Index devised by Lucus and Ducker[17]. The Motor Index was documented immediately after injury and again at each follow up examination. Pain was quantitated on a ten point pain scale. Treatment modalities were carefully documented.

Stability and union were determined radiographically. Specific criteria for union included the evidence of trabeculation across the fracture site and no movement in lateral flexion-extension radiographs. Anteroposterior and/or lateral polytomography were utilized when necessary to establish or confirm union of the fracture. A fracture was considered stable if there was no evidence of displacement on lateral-flexion-extension radiographs regardless of union. Initial and follow up data forms were compiled on each patient by each participating member of the research society and then forwarded to the senior author for study compilation and analysis.

RESULTS

One hundred and sixty-four cases were evaluated. There was one Type I fracture, 106 Type II fractures, fifty Type III fractures and seven synchondrosis injuries in children. These seven fractures were excluded from the remainder of the study. Patients sustaining Type II injuries averaged 42.7 years of age with a range of fourteen to eighty-four years. Patients with Type III injuries averaged 43.9 years with a range of eleven to eighty-six years. Seventy-two per cent of the Type II injuries occurred in males and 28 per cent in females. Type III injuries were composed of 64 per cent males and 36 per cent females. Virtually all injuries occurred as a result of either a motor vehicle accident or a fall. Seventy per cent of Type II injuries and 72 per cent of Type III injuries were the result of motor vehicle accidents. In patients less than forty years old 89 per cent were the result of motor vehicle accidents, whereas, in those greater than forty years of age only 55 per cent were the result of a motor vehicle accident. Eighty-one per cent of all patients with falls resulting in dens fractures occurred in patients greater than age forty.

Mean AP translation in displaced fractures was 5.8 mm in thirty-six Type II fractures and 4.5 mm in eleven Type III fractures. Twenty-eight Type II fractures averaged an angular deformity of 13.3 degrees and twelve Type III fractures averaged 15.3 degrees of angulation. Sixty-one per cent of Type II and 89 per cent of Type III injuries were displaced in the anterior direction. Significant displacement was defined as greater than 4 mm of translation in the AP plane and/or greater than 10 degrees of angular deformity. Of Type II injuries with significant AP translation, 26 per cent developed nonunions and 13 per cent developed malunions, regardless of treatment. Patients with Type II injuries and angular deformities greater than 10 degrees had a 29 per cent nonunion rate, whereas, in those less than 10 degrees, 18 per cent had malunions. Significant AP displacement (> 4mm) in Type III injuries yielded a 40 per cent nonunion rate whereas a 22 per cent nonunion rate resulted from angular deformity greater than 10 degrees in Type III fractures.

Neurological involvement in Type II injuries included three patients with root involvement, four with greater occipital neuralgia, two with Brown-Sequard syndrome, three with hemiparesis, and seven with quadriparesis. Neurological involvement in Type III injuries included nerve root involvement in two patients, greater occipital neuralgia in four, hemiparesis in one and quadriparesis in three. Three patients had increased neurologic deficit following treatment.

Following the initial treatment of all Type II injuries, 64 per cent were united and 36 per cent were ununited. In Type III injuries, 72 per cent went on to union, 15 per cent were ununited, and 13 per cent were malunited.

Management of the fractures varied considerably. Treatment for Type II injuries included no treatment in seventeen, orthotics in two, posterior cervical fusion in twenty-seven, anterior cervical fusion in seven, halo vest or cast in thirty-eight, and skeletal traction alone in two. Anterior fusions included transoral and anterolateral approaches and generally were transfixed with a screw. All cases not treated originally or treated with an orthosis went on to nonunion. Sixty-eight per cent of patients treated with a halo device were united following the initial treatment. However, 26 per cent were ununited and 6 per cent were malunited. All patients treated with skeletal traction united. However, these required a minimum of six weeks in traction. One patient with an anterior cervical fusion went ununited and one patient had an increased neurological deficit postoperatively requiring replacement of the anterior screw. Ninety-three per cent of patients treated with a posterior cervical fusion united. There was one nonunion, and there was one patient who had an increased neurological deficit postoperatively. This required decompression and fusion.

Patients sustaining Type III fractures were managed as follows: there was no initial treatment in three cases; eleven were managed with an orthosis; five were treated with bedrest, utilizing sandbags to stabilize the head followed by an orthosis; eight were maintained in skeletal traction; fourteen were treated with a halo device; two were treated with anterior cervical fusions; and four were treated with posterior cervical fusions. All of the initially untreated fractures went ununited. Eighteen per cent of the patients treated with an orthosis went ununited and 36 per cent developed malunions. All patients treated by bedrest, anterior cervical fusion, or posterior cervical fusion developed solid union. One patient treated with skeletal traction had a malunion. Of the fractures treated with a halo device, 86 per cent united, one developed a nonunion, and one patient displaced the fracture while in the halo device and required surgical fusion.

Thirty-one patients with Type II injuries required further treatment including skeletal traction in one case, anterior cervical fusion in nine, and posterior cervical fusion in twenty-one. All of these united solidly. Ten patients with Type III injuries required further treatment following their initial management which included one halo device, three anterior cervical fusions, and six posterior cervical fusions. All of these patients obtained solid union.

COMPLICATIONS

Four patients with Type II injuries died suddenly following their injuries. Two additional patients died during follow up, one secondary to metastatic carcinoma, and a second patient died postoperatively from respiratory failure following an anterior cervical fusion. Two patients with anterior screw fixation of the dens had migration of their internal fixation device with one patient developing an eye palsy postoperatively. One patient treated with an anterior cervical fusion and another treated with a posterior cervical fusion had increased neurological deficit following surgery. Three patients managed with the halo device had significant displacement of the fracture alignment while in the device. Complications in patients sustaining Type III injuries include one patient who died twenty-four hours following injury due to a cardiopulmonary arrest. This patient was treated with a halo device. Four patients treated with an orthosis went on to malunion and two patients had nonunions. One patient treated with a halo device had significant displacement of the fracture while in the device.

DISCUSSION

The management of dens fractures remains controversial. Type II fractures appear to be particularly troublesome with 36 per cent of the patients in this series developing nonunion following initial treatment. Type III injuries have been considered relatively innocuous; however, in our series, 15 per cent developed nonunions, and 13 per cent developed malunions. Therefore, careful attention to the Type III injuries is also essential. The halo device can be used successfully in almost 70 per cent of Type II fractures. Posterior cervical fusions had the highest success rate for managing Type II injuries with over 93 per cent uniting initially. However, there may be significant complications with surgery. This study has clearly shown that an orthosis alone is not sufficient for managing a Type III injury since this treatment yielded 18 per cent nonunions and 36 per cent malunions. All patients with either Type II or Type III injuries with initial nonunion were successfully managed with further treatment. The majority of these were managed by posterior cervical fusion. However, one patient was successfully managed in skeletal traction and one patient in a halo device.

Displacement appeared to be a significant factor affecting the outcome of treatment. Type II injuries with greater than 4 mm of AP translation had a 26 per cent nonunion and a 13 per cent malunion rate. Twenty-nine per cent of patients with Type II injuries angulated more than 10 degrees went ununited. Similarly in Type III injuries 40 per cent of those displaced greater than 4 mm went on to nonunion and 22 per cent of those angulated greater than 10 degrees went on to nonunion and 11 per cent to malunion.

Many patients in this series had no early treatment because the diagnosis was not made initially. All of these patients presented with symptomatic nonunions. The diagnosis must be suspected in the elderly individual or child who falls and complains of neck pain. In addition, one must carefully look for this injury in the multi-system trauma patient following a motor vehicle accident or in the intoxicated patient who is injured. Radiographs must be carefully scrutinized and repeated if symptoms persist. If the index of suspicion is high and plain radiographs are normal, particularly in the patient with neurologic deficit and neck pain, further radiographic evaluation may be indicated. Polytomography and computerized axial tomography have been the most helpful.

Initial management of the dens fracture patient requires adequate radiographic and neurologic evaluation. In addition, other spine or associated injuries must be evaluated and treated as necessary. All patients with Type II or Type III injuries are initially stabilized in traction, preferably skeletal, followed by the definitive treatment.

CONCLUSIONS

Based on our multicenter study of dens fractures the following conclusions were reached:

1) The Anderson and D'Alonzo classification of dens

fractures appears to be useful. In addition, the translatory displacement and degree of angulation of the fracture appear to be significant prognostic factors.

2) Anderson and D'Alonzo Type II and Type III injuries were the most common in this series.

3) Type II injuries have a significant rate of nonunion following initial treatment.

4) The halo device was successful in managing Type II injuries in 68 per cent of cases, whereas a posterior cervical fusion was successful in 93 per cent. However, the surgical complications are potentially more serious.

5) Type III injuries are not benign. There is a significant rate of malunion and nonunion in patients treated with an orthosis alone. Patients in our series were successfully managed with skeletal traction, the halo device, or surgery. The halo device is the safest and most reliable form of therapy for the Type III injury.

6) Patients with Type II injuries having significant displacement should be considered for surgical stabilization. Patients managed with posterior cervical fusion had a higher success rate and lower complication rate than those managed with anterior stabilization.

7) The majority of dens fractures resulted from motor vehicle accidents. A patient involved in a serious motor vehicle accident should be evaluated for this possibility. Elderly patients and children who fall and complain of neck pain, and intoxicated patients who sustain further injury should also be evaluated for a dens fracture. A high index of suspicion is the key to proper diagnosis and the initiation of appropriate treatment.

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RADIAL HEAD RESECTION FOR ISOLATED RADIAL HEAD FRACTURES— A LONG TERM FOLLOW-UP

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INTRODUCTION

Radial head resection for displaced, depressed, or comminuted radial head fractures is widely practiced [3-5,13,14,15,17,18,23,27,34,36-38,42]. However, some authors have cautioned against resection because of sequelae that may arise at the elbow and the distal radio-ulnar joint. These problems include proximal migration of the radius and degenerative changes at the elbow and distal radio-ulnar joint. Radial head implant arthroplasty and open reduction and internal fixation have been advocated to avoid these problems[11,16,20,22,24,25,30,31,40]. The efficacy of radial head resection for isolated radial head fractures, at long term follow-up, varies in the literature[8,28,39,42]. This is unfortunate, as this information is important when discussing with patients the results of radial head resection, and when considering alternative procedures. This study reviews the long-term follow-up of radial head resection for isolated radial head fractures, in an attempt to improve our understanding of this form of treatment.

MATERIALS AND METHODS

Seventeen patients, eleven males and six females, with isolated closed radial head fractures, were evaluated eight to forty-six years (average 18.6 years) after radial head resection. Age at injury ranged from sixteen to seventy-seven years (average 40.3 years) with age at follow-up being from forty through eighty-nine years (average 58.9 years). The evaluation included an interview, chart review, physical examination, and standardized radiographs. The same person (D.S.) examined both upper extremities and recorded active range of motion for elbow flexion and extension, wrist flexion and extension, radial and ulnar deviation, and forearm pronation and supination. Grip strength was measured with a JAMAR dynamometer (Asimow Engineering Co., Los Angeles, California). The results from three successive trials were averaged. Pronation and supination strength was evaluated with the Cybex II Dynamometer. Strength data were normalized by the method of Morrey, et al.[33]. Strength, then, is presented as a percentage of a predicted value which is based upon that measured in the contralateral (dominant or nondominant) extremity.

Radiographic evaluation included anteroposterior (AP) and lateral views of both elbows, posteroanterior (PA) and lateral views of both wrists in the position recommended by Palmer[35] with and without grip. Elbow arthritis was graded using the criteria of Swanson[40]. The method was also adapted for assessing arthritic changes in the distal radio-ulnar joint. We assigned points for each grade of arthritis (Grade I = one point, Grade II = two points and Grade III = three points) to permit a calculation of an arthritis index. We measured ulnar variance using two methods: 1) that recommended by Palmer using a template of concentric circles (Fig. 1)[35], and 2) the method of perpendiculars. This method is completed by drawing a line at the distal ulnar aspect of the radius which is perpendicular to the longitudinal axis of the radius and then measuring the distance between the line and the end of the ulna (Fig. 2). The angle between the longitudinal axes

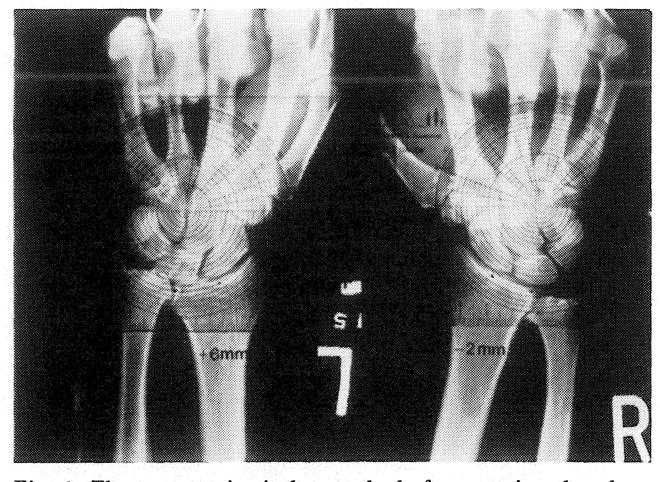

Fig. 1: The concentric circles method of measuring the ulnar variance. A circle is best fit to the subchrondal bone of the radius, and the distance between that circle and the distal end of the ulna quantitates ulnar variance.

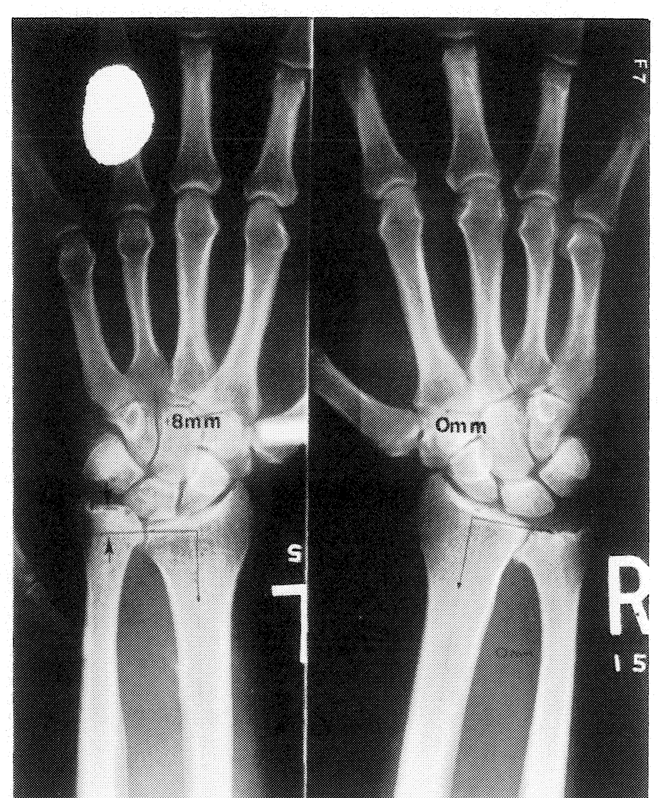

Fig. 2: The method of perpendiculars for measuring ulnar variance. A line is constructed at the distal ulnar aspect of the radius which is perpendicular to the longitudinal axis of the radius. The distance between this line and the end of the ulna quantitates ulnar variance.

of the humerus and the forearm determined cubitus valgus. In this method, the forearm axis is determined by a line from the center of the neck of the radius through the head of the ulna (Fig. 3).

Fig. 3: The angle between the longitudinal axis of the humerus and the forearm quantitates cubitus valgus. The forearm axis is determined by a line from the center of the neck of the radius through the head of the ulna.

RESULTS

Most patients described a fall on their outstretched hand resulting in their fracture. The interval between injury and surgery ranged from a few hours to nine days in fourteen patients, four months in one, and eight months in two. Interim treatment varied from nothing to the application of a long arm cast. Operative reports were available for fourteen patients. Thirteen reports described a comminuted radial head or a large depressed fragment. The other report described an enlarged, flattened head in a patient seen eight months after his fall. Damage to the capitellum articular cartilage was noted in four elbows. One patient underwent two unsuccessful, subsequent procedures about ten years later in an attempt to improve forearm rotation by resecting a radio-ulnar synostosis. Postoperative treatment was variable as elbow motion was started one day to four weeks (average 12.1 days) after surgery.

The time between surgery and return to an occupation or housework ranged from two days to three months (average 4.6 weeks) in fourteen patients. Two patients had to modify or change occupations. One was a housewife who needed help to lift heavy objects, and the other was a heavy laborer who developed elbow pain and weakness ten years after resection. Three patients had to modify their hobbies. No patient changed occupation or deleted hobbies because of wrist symptoms alone.

When queried about symptoms, four patients related weather changes to very mild rest pain. Two patients complained of very mild elbow pain with flexion and extension, and one patient complained of pain with gentle forearm rotation. Resisted elbow flexion and extension produced very mild pain in six patients and intermittent, mild pain in two. Resisted forearm rotation produced rare, mild pain in four patients and intermittent mild pain in three. Prolonged use of the elbow resulted in very mild pain in two patients and intermittent mild pain in three. Patients who experienced pain had more radiographically advanced arthritis (1.3) than those without pain (0.86). Patients with elbow pain had decreased normalized strengths when compared to patients without elbow pain (Table I). No patients complained of wrist pain at either rest or any activity level.

Table I

Normalized Strengths Relative to Elbow Pain

Patients	Grip	Pronation	Supination
No Pain	−3.8	+0.5	−7.5
Pain	−9.9	−9.6	−13.5

Values denote percent changes.

Three patients noted activity related elbow swelling, and one patient noted wrist swelling. Three patients complained mildly of decreased elbow motion. No patient complained of decreased wrist motion.

The active ranges of motion data for elbow, forearm, and wrist, for both normal and operated extremities, are presented in Table II. The minimum and maximum values indicate the range of observed data. A comparison of the averaged values for normal and operated extremities indicate few differences, except for forearm pronation-supination values. Of those patients undergoing delayed surgery, only one (eight months post-injury) had an extension loss of −18 degrees, while two other patients (seven and eight months post-injury) had essentially normal elbow motion. Limited wrist motion, in those few cases in which it occurred, was not associated with ulnar variance, increased cubitus valgus, arthritis, or decreased strength.

Forearm pronation-supination values, as indicated in Table II, were most decreased on the operated side. Supination was decreased 15 degrees, which is more than the 7 degree decrease in pronation. If the patient with proximal radio-ulnar synostosis is deleted, supination averaged 77 degrees (a 10 degree decrease) and pronation averaged 86 degrees (a 2 degree decrease). Loss of supination was associated with other clinical observations. Patients with supination limited 30 degrees or more had increased elbow arthritis (1.7) compared to those without loss of supination (0.8). Of the six patients with more than 30 degrees loss of supination, five experienced pain, while only four of the remaining eleven patients experienced pain. Patients with decreased supination had an averaged increase in cubitus valgus of 13.7 degrees, while patients with nearly normal supination had an increase of only 6.2 degrees.

Table II

Active Ranges of Motion, in Degrees

	Normal			Operated		
	Min.	Max.	Aver.	Min.	Max.	Aver.
Elbow						
Flexion	130	155	137	125	145	136
Extension	5	−5	0	0	20	−3.7
Forearm						
Pronation	70	90	88	0	90	81
Supination	80	90	87	0	90	72
Wrist						
Flexion	45	75	63	45	75	62
Extension	45	75	57	40	80	57
Radial Deviation	8	45	28	5	50	26
Ulnar Deviation	20	55	40	20	50	39

Cybex testing without normalized data yielded an average pronation strength loss of 10.0 per cent and with normalized data a loss of 5.3 per cent. Decreased pronation strength did not correlate with length of time from injury to surgery, length of postoperative immobilization, increased ulnar variance or increased cubitus valgus. However, those patients who demonstrated decreased normalized pronation strength tended to have a slightly higher averaged grade of arthritis (1.1) than those patients with normal pronation strength (0.8). Six of nine patients with decreased strength experienced pain, while only two of six patients with normal strength experienced pain.

Cybex testing without the normalized data yielded an average supination strength loss of 14.6 per cent and with normalized data a loss of 11.3 per cent. Those patients who demonstrated decreased normalized supination strength also had an averaged higher grade of arthritis (1.1) than those with normal strength (0.75). More patients in the decreased strength group experienced pain than did patients in the normal strength group. Patients with supination limited 30 degrees or more had markedly decreased normalized supination strength (−22.6 per cent) than patients with essentially normal range of motion (−4.8 per cent). Loss of supination strength did not correlate with the time from injury to surgery, length of postoperative immobilization, increased ulnar variance, or increased cubitus valgus.

Elbow arthritis was graded using Swanson's radiographic criteria[40]. Five patients demonstrated mild (Grade I) arthritic changes in the elbow. In the operated elbow, two patients had no evidence of arthritis; eleven had Grade I changes; three had moderate changes (Grade II); and one had gross deformity (Grade III). Those patients with elbow pain, with supination decreased 30 degrees or more, or with decreased pronation or supination strength had higher average grades of elbow arthritis. Decreased grip, although associated with pain, was not associated with arthritic changes in the elbow.

Distal radio-ulnar arthritic changes were evaluated using a similar radiographic grading system. In the normal wrist, two patients had mild changes and one was not evaluated because of a previous Darrach procedure done following a Colles' fracture. In the distal radio-ulnar joint of the operated extremity, seven patients had mild changes, and one had moderate changes.

Cubitus valgus averaged 19 degrees (range:4-35 degrees) in the operated side compared to 10 degrees in the normal side. One patient had 5 degrees less valgus on the operated side than the normal side. All other patients had increased cubitus valgus and were distributed as follows: 0-5 degrees (five), 6-10 degrees (five), 11-20 degrees (five), greater than 20 degrees (one). Six patients with increased cubitus valgus of greater than 10 degrees had longer follow-up (average 25.6 years) and tended to have limited supination of 30 degrees or more.

All patients demonstrated an increased ulnar variance, to a more positive position. Using Palmer's method[35], without grip ulnar variance increased 1.88 mm. With grip, the variance was increased 2.03 mm. The method of perpendiculars provided averaged values which were slightly higher. Without grip the averaged increased ulnar variance was 2.07 mm. With grip, the averaged value was 2.40 mm. Patients with increased variance over 2.0 mm were all male laborers with an average follow-up of 22.4 years.

DISCUSSION

Early resection for isolated comminuted radial head fractures is generally recommended[9,15,18,23,27,34,38,42]. Gaston[15] recommended surgery within twenty-four hours, and Speed[38] and Murry[34] stated that surgery should be done as early as possible to avoid complications. Charnley, however, felt the physician cannot properly assess the need for resection until two weeks after the injury[10]. Buxton[7] and Alder and Shafton[1] extended the period of observation from six to eight weeks before making a decision for resection. Stephen's long-term review found that those patients resected within six weeks of injury had good or fair results[39]. Fourteen patients in our series were resected within nine days, the majority within one to three days. Only one of the three patients operated on late had significantly limited extension of 18 degrees, which was an improvement over preoperative limitation of 35 degrees. Two other patients with limited elbow extension (15 and 20 degrees) were resected within two days. Two of the three patients with radial heads resected late, for pain, continued to experience rare, mild pain.

Few authors have commented on occupation or hobby changes after surgery, or length of time from surgery to return to work. Hein stated that the "lost time factor is of utmost importance". He found that the average disability after radial head resection was 8.5 weeks[17]. "Time off work" in Mason's series averaged five weeks for Type II fractures treated conservatively and 8.5 weeks for those patients treated by radial head resection[23]. Patients with Type III fractures treated by radial head resection averaged 9.5 weeks before returning to work. Wagner's series, which included twenty-four resections, revealed that all patients resumed their former occupation[42]. Arner, et al., found that the mean period of incapacitation from work was ten weeks in patients undergoing surgery for radial head fractures[3].

Many of the patients in our series, who were farmers or farm wives, stated that they could not stay off work for any extended time and had little choice but to return to work. This motivation factor may account for our relatively low average time off work of 4.6 weeks.

Post-resection immobilization in most series has ranged from days to weeks. Meekison[27] and Gaston[15] recommended starting motion as soon as the patient is awake, or within pain limitations. Two to three weeks of immobilization was recommended by Sever[37], Jacobs and Kernodle[18], and Carstam[8]. Post-resection immobilization in our series ranged from less than twenty-four hours to four weeks with an average of 12.1 days. We found limited extension of 15 and 20 degrees in two patients, immobilized for three weeks and four weeks, respectively. This suggests that extended immobilization may interfere with regaining full extension. We had too few patients to correlate limited pronation and supination motion with length of post-resection immobilization.

Pain following radial head resections has been discussed by many authors. King's review of thirteen patients, resected for various pathologic conditions, presented nine patients without complaints, three patients with mild to moderate pain, and one with clicking[19]. Murray followed twenty-three patients for an average of three and one-half years after radial head resection and found sixteen patients with symptoms[34]. Jacobs and Kernodle stated that none of their patients with resections had any discomfort when checked at six months[18]. Pain was not a prominent feature in Mason's series[23]. Wagner stated that both conservative and operated cases complained of elbow discomfort at some time with weather changes and heavy use of the arm. He also found, at five years follow-up, that neither group had complaints when full motion was present, and all patients with restricted motion complained of discomfort when attempting to move the joint through full motion[42]. Arner stated that insignificant discomfort was recorded in nine patients with restrictions[3]. Stephen found minimal elbow symptoms in seven patients, minor symptoms in three, and major symptoms in two following resection[39]. Over half of Mikić and Vukadinović's patients' elbows were asymptomatic. Fourteen patients (23.3 per cent) had mild symptoms, six (10 per cent) had moderate symptoms, and six patients (10 per cent) had severe symptoms[28]. We agree with most authors that many patients experience some form of pain following resection. In our series patients describe pain as either a rare, mild pain, or an intermittent, mild pain. We do not feel that pain was a major sequelae of radial head resection. We agree with Morrey, et al., that patients with pain tend to have more advanced arthritis and decreased strength[33].

Limited elbow motion is not uncommon following radial head fractures treated by resection. Thirteen of Murray's twenty-six patients had greater than 10 degrees loss of elbow motion[34]. Meekison's review of 110 radial head fractures showed that only three patients of thirty-two treated nonoperatively gained complete extension, and extension loss averaged 15 degrees. Seventy-eight patients treated by radial head resection in his series had only a 5 degree loss of extension[27]. Carstam's thirty-one patients with head resection averaged 17 degrees extension loss and 7 degrees flexion loss[8]. Mason reported an average loss of 20 degrees of extension in resected Type II's and 25 degrees in resected Type III's[23]. Wagner compared motion following resection at one and five years and found little change. Sixteen of his twenty-four patients had full elbow motion, five lost 10 degrees extension, and three lost 20 degrees of extension[42]. Elbow motion following resection in our series was fairly consistent with that of Meekison[27]. Averaged flexion and extension deficits of 1 degree and 3.7 degrees, respectively, did not produce significant symptoms or a functional impairment. The excellent motion in our series may again be related to our patient's motivation and determination to return to normal activities.

Forearm pronation and supination has not been as well discussed by previous authors as elbow flexion and extension. Carstam, in thirty-one patients with resected heads, found an average pronation-supination loss of 41 degrees[8]. Pronation and supination were each limited 15 degrees in Mason's resected Type III's, but pronation and supination were without limitation in Type II fractures[23]. Sixteen of twenty-four patients in Wagner's series had full pronation and supination, five patients lost 10 degrees, and three patients lost 20 degrees[42]. Stephen found an average pronation deficit of 15 degrees[39]. Mikić and Vukadinović also recorded impaired pronation and supination in thirty-five of sixty patients[28]. Our results agree that forearm rotation is limited with an average pronation loss of 7 degrees and an average supination loss of 15.3 degrees. Patients with supination loss of greater than 30 degrees tended to experience more pain (five of six patients), increased arthritis, increased cubitus valgus, and decreased supination strength. Too few patients had limitations of pronation motion to permit any associations. Only the patient with radio-ulnar synostosis complained of limited forearm rotation, but compensated by changing selected activities to her contralateral hand.

Strength following radial head resections has been evaluated by Morrey, et al. Using normalized methods on thirteen patients post-resection, they found less than a 10 per cent loss of elbow flexion strength, and approximately 18 per cent loss of pronation, supination, and grip strengths. Strength loss correlated best with arthritis and pain, but not proximal radial migration[33]. Stephen found an averaged flexion power decrease of 20 per cent, and a pronation power decrease of 15 per cent[39]. Our normalized results indicate that the major strength loss was in supination (−11.3 per cent). This loss tended to be more marked in patients with supination limited 30 degrees or more and in those patients with elbow pain. Few associations could be made with decreased pronation or grip strength.

Elbow arthritis was frequently identified following radial head fractures in Carstam's nine year follow-up. However, he could not find a significant difference in the incidence of arthritis relative to the fracture type or method of surgical treatment[8]. Mason noted little elbow arthritis regardless of treatment for radial head fracture[23]. Wagner compared radiographs at one and five years after radial head resection and found no evidence of progressive arthritis[42]. Only two of twenty-five patients in Bakalim's series of resections had arthritis. Stephen found eleven of twelve patients with elbow arthritis; none of which was severe[43]. Thirty-one of sixty patients in Mikić and Vukadinović's series had mild or moderate arthritis, but none severe[28]. Morrey et al., found no definite association between the severity of arthritis and loss of motion or strength[33]. In our series, patients with pain and those lacking 30 degrees or more of supination tended to have a higher average grade of arthritis.

Radio-ulnar synostosis following resection was noted by King in two of thirteen patients[19], Bakalim in two of twenty-five patients, and Mikić and Vukadinović in four of sixty patients. Our patient, who synostosed in a functional position, had few complaints relative to limited forearm rotation.

Brockman, in 1930, recognized subluxation of the distal radio-ulnar joint following radial head resection[6]. Lewis and Thibodeau reported seven cases in 1937[21], and King noted that eleven of his thirteen patients had subluxation[19]. Curr and Coe correlated distal radio-ulnar subluxation or dislocation with many conditions including radial head resections[12]. Twenty-five of forty-four patients in McDougall and White's series of radial head resections developed subluxation, most of which were asymptomatic[26]. Carstam noted very few symptomatic patients, and they averaged 2.5 mm of proximal radial displacement[8]. Albert recommended resection of the distal ulna when the disrupted distal radio-ulnar joint became symptomatic[2]. Taylor and O'Conner had thirty-seven of fifty-eight patients with resections develop distal radio-ulnar subluxation; twenty-nine of these were symptomatic. However, the authors were unable to correlate degree of displacement with symptoms[41]. Fourteen of thirty-six patients treated by radial head resection and three of forty-eight patients treated conservatively for radial head fractures by Radin and Riseborough developed subluxation from 1-4 mm. Only three of these wrists were symptomatic, and, like Taylor and O'Conner, they were unable to correlate degree of displacement with symptoms[36]. Three of sixteen patients reviewed by Bakalim had asymptomatic subluxation of 3-5 mm[4]. Average subluxation in Stephen's study was 2.3 mm, but he did not comment on symptoms[39]. Twenty-eight of Mikić and Vukadinović's patients (47 per cent) had distal radio-ulnar subluxation, which was most often in laborers and was associated with limited pronation and supination. They concluded that proximal migration of the radius is an important disadvantage of radial head excision[28]. Morrey et al., concluded just the opposite from Mikić and Vukadinović as the magnitude of proximal migration of the radius did not correlate with the functional result. This led Morrey, et al., to question the rationale of using a prosthetic radial head to prevent migration. Our average increased ulnar variance (averaging both methods used) of 1.97 mm without grip and 2.21 mm with grip is consistent with most reports. We, like McDougall and White[26], Taylor and O'Conner[41], and Mikić and Vukadinović[28], found that most of our patients with variance over 2 mm were male laborers with longer average follow-up (25.6 years). This agrees with Lewis and Thibodeau's[21] and McDougall and White's[26] theories of displacement, in which the loss of bony and ligament support, the pull of muscles, and the strain which the forearm experiences may stretch the interosseous membrane, allowing proximal displacement of the radius. We concur with Morrey, et al., that the degree of acquired ulnar variance is not directly associated with symptoms or functional impairment. This observation questions the indication for implants which are intended to, if effective, prevent proximal migration of the radius.

Many authors have reported increasing valgus of the elbow following radial head resection. Miller[29], Carstam[8], and Stephen[39] reported 5 to 6.6 degree increases following resection. Mikić and Vukadinović in their series of sixty patients found these increases to be as follows: 0-10 degrees (four), 10-30 degrees (thirteen), and greater than 30 degrees (one). They believed that the increased valgus could explain ulnar nerve symptoms in four of their patients. They suggested that the disordered biomechanics could be prevented by radial head prosthetic replacement, thus preventing ulnar nerve symptoms[28]. Increased cubitus valgus alone following head resection did not produce significant elbow symptoms or jeopardize function.

In summary, the long term follow-up of radial head resection for isolated radial head fractures indicates that the procedure yields very satisfactory clinical results. Some patients experienced mild, intermittent elbow pain, but none experienced wrist pain. Motion and strength losses were limited and of little clinical significance. Operated extremities demonstrated, by radiographic criteria, increased elbow and wrist arthritis, cubitus valgus, and positive ulnar variance. These results must be considered relative to the long term results for any alternative treatments for the isolated radial head fracture.

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ORTHOPAEDIC EDUCATION RESEARCH AND PRACTICE IN THE INFORMATION EXPLOSION

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Twenty years ago, training to become an orthopaedic surgeon was a rather straightforward process with a moderate number of applicants meeting little competition. Four years of exposure to trauma, children's disorders, degenerative conditions and hand problems, supplemented by reading *Campbell's Operative Orthopaedics* and a few other standardized texts, prepared the trainee for a broad practice covering the spectrum of orthopaedic surgery. Similarly, twenty years ago, receiving a college degree in fields such as business, engineering, education, etc., prepared individuals to reach the top. However, in the subsequent decade immense accumulations of knowledge have precipitated revolutions within educational institutions—including medical specialty education. These changes will continue to produce profound changes in orthopaedic research as well as community orthopaedic practice.

The Information Explosion:

The almost unfathomable growth in knowledge over the last twenty years has been to a great extent due to the computer and its ability to organize and store information. The prodigious capacity of computers is based on the silicon chip. Future computers based on a bio-chip (biological chip), under simultaneous development in several advanced nations, will dwarf the capacity of today's supercomputers, thus allowing for steepening of the exponential information growth curve. Developers state that perfection of a chip computing at the molecular-size level will allow the information stored in all the world's present computers to be maintained in an information block the size of a sugar cube.

Information Overload and Medical Education:

The knowledge explosion has produced new bio-materials, complicated joint implants, operative arthroscopy, mechanically superior internal fixation devices, complex scoliosis instrumentation, electrical treatment of fracture nonunions, micro-reimplantation, and many other useful yet perplexing devices and procedures. Each development is made possible by basic and applied research, all greatly speeded by computerization. As a result, no orthopaedic program can train all residents to the depths of each orthopaedic subspecialty. Furthermore, no orthopaedic practitioner can master the entire discipline.

The Fellowship Era:

Orthopaedic residents are now exposed to each subspecialty only to a depth which a brief rotation will allow. A few outstanding training programs provide ample experience in all subspecialties; however, in most, adequate exposure to all areas is impossible. Thus when establishing a practice, a recent graduate must decide whether to practice the entire spectrum of orthopaedics to a level of complexity consistent with his residency training or to train further in a subspecialty. This dilemma has led to the spontaneous but rapid appearance of the "fellowship era" in orthopaedic surgery.

Perceptive orthopaedic residents, after viewing their own orthopaedic mentors and attending instructional courses, note that those who are creating orthopaedic advances have limited their research or practice to a single area. As a result, the subspecialties have developed a level of knowledge in a single area which is greatly valued by their academic peers, orthopaedic colleagues, and patients. Furthermore, increasingly sophisticated consumers often insist on care by a subspecialist. The most sophisticated of consumers, e.g. an orthopaedic surgeon with a knee injury, commonly bypasses the "local orthopod" and flies to a distant center for a magical outpatient arthroscopic repair by an expert who treats only knees. Thousands of lay consumers, partially educated by the media, are following suit.

Many current subspecialists have developed their expertise without fellowship training through fortuitous early exposure to a high volume in a limited area (e.g., hip disease). This pathway is rarely available to current orthopaedic trainees because of a near saturation of the orthopaedic market. Thus, taking an additional year of subspecialized orthopaedic training seems the only practical avenue for development of subspecialty expertise. Established practitioners recognize the marketing advantage of subspecialization and are basing the future competitiveness and viability of their practice on hiring fellowship trained colleagues.

These evolving patterns suggest that the "fellowship era" in orthopaedic surgery is based on marketing decisions and the need to remain current with the massive information growth. The lay public demands an "expert". As is true of subspecialization and division of labor in all endeavors, this consumer demand is greatest in large population centers. Clearly "renaissance man" orthopaedists will fare best in smaller cities removed from major referral areas.

The information explosion is producing rapid change in major university-based orthopaedic residencies. In many programs, four out of five residents take postgraduate subspecialty fellowships in fields such as pediatric orthopaedics, hand surgery, joint reconstruction, and sports medicine, with a few choosing advanced education in research areas (biomechanics, biochemistry).

Because the fellowship era has evolved only recently, no regulations or controls exist over the quality and number of fellowships. Only recently have ACORE (Advisory Council for Orthopaedic Residency Education) and individual subspecialty organizations explored fellowships and their possible impact on resident education.

Most successful fellowship programs are one-year programs combining research and clinical training, including operative experience. Most are offered in the same training centers where orthopaedic residents are educated. At the completion of the year a fellow should have gained the knowledge and experience to provide subspecialty care. Obviously, the development of high-level competence requires subsequent practice in a disciplined environment with a high patient volume. With the surplus of orthopaedic surgeons in many parts of North America, a high-volume practice may be impossible to establish rapidly; thus an individual's fellowship training may not be fully utilized. The growth of this pattern raises questions regarding the number of subspecialty training positions offered and their effect on quality of care (volume dilution may equal quality dilution).

Fellowships and Orthopaedic Manpower:

Because of the national concern about overproduction of both general orthopaedic surgeons and subspecialists, fellowships should be considered within the overall framework of orthopaedic manpower. One advantage of fellowship training is that it increases the overall length of orthopaedic training and thus provides a one-year delay in the arrival of a new graduate into the oversupply of practicing orthopaedists. A more meaningful correction would occur if major training centers combined the expansion of fellowship programs with a decrease in the number of orthopaedic residents admitted for residency each year. Such a transfer from resident education to fellow education would maintain the training center manpower, yet would decrease the overall number of orthopaedists trained. The evolution would be an appropriate response to society's demand for fewer, but better-trained surgical specialists. The number of surgical specialists produced cannot be determined by patient care workload demands in training institutions. The economic cost of such a policy — with resultant overproduction of specialists — is far too great. Additional orthopaedic manpower required by growing service workloads in both city-county and private training hospitals need to be met through additional orthopaedic staff, family practice residents, nurse practitioners, physician assistants, and other physician extenders, rather than orthopaedic residents.

The Information Explosion and Orthopaedic Training Centers:

The knowledge explosion has been a double-edged sword for orthopaedic research. Great technical advances allow dedicated orthopaedic surgeons and their laboratory colleagues to perform more sophisticated research with rapid clinical application, a clear benefit to the profession and society. Unfortunately, science at the molecular level has left most M.D. researchers at a competitive disadvantage. The National Institutes of Health have documented a rapid change in the distribution of research grants, favoring Ph.D. investigators over M.D. investigators the last ten years. The trend is accelerating and unlikely to change since the knowledge explosion fuels subspecialized research, which in many areas can be led only by Ph.D. investigators, trained in their own subspecialized areas. Successful orthopaedic departments develop collaborative efforts between clinician-researchers and Ph.D.'s.

Furthermore, the financial reward differential between the development of technology (research) and its application (surgeon implanting the latest porous-coated joint implant) is currently so large that orthopaedists who have the temperament, training, and skills to do either basic research or clinical practice usually choose the latter.

The Information Explosion and Community Orthopaedic Practice:

Again the effect will be double-edged. Rapid development and testing of new technology will provide methods for scientifically proven, effective intervention in a greater number of orthopaedic conditions. Practicing orthopaedists will be positioned at the interface between the lengthy, laborious development and the final application of new technology.

The computer will make continuing education more available, easing the burden of staying current. Patient billing, accounting, and business procedures will be greatly expedited.

Along with these gains come certain liabilities. As described earlier, the information explosion will make career decisions concerning "type of practice" more difficult. Change is always difficult and the middle-aged general orthopaedist, especially in a competitive metropolitan area, may find life in the computer-aided "fast lane" traumatic. Once competent in all aspects of knee surgery, he or she may find his or her practice suddenly diminished by newly arrived, seemingly entrepreneurial "sports-medicine trained" orthopaedists who perform only outpatient knee surgery. The proliferation of subspecialists may leave less adaptive individuals with a shrinking practice, limited to minor trauma and mild degenerative conditions.

Additionally, since the knowledge explosion also includes social scientists, lawyers, etc., additional changes may face the practitioner. Patients will demand "high technology" and their attorneys will use sophisticated worldwide computer searches to assure that both the selection and application of the surgical procedure were faultless. Errors in application by the general orthopaedists may be scrutinized by subspecialty standards.

Furthermore, government and private health insurance social scientists and psychologists, within the context of a physician surplus, will analyze hospital and surgeon charges on a cost-benefit ratio. Intervention (surgery) will be paid for only if the benefit to the individual (and society) can be documented. Competitive bidding, made possible by a surplus of surgeons, will allow the insurers to determine, for the first time, the true market value of surgical care. Do surgeons really need a higher "per hour" fee for "installation" versus the history, physical examination and pre-op judgement time? Some suggest that the surgical procedure itself is innately rewarding, and that open, competitive bidding will not support the high "per hour" fee earned by surgeons.

Thus, as in the academic sphere, orthopaedic practitioners can anticipate both great gains and potential setbacks in the information era.

Summary:

The information explosion, currently revolutionizing western culture, is producing rapid changes in orthopaedic surgery. Already, a high percentage of orthopaedic residents seek further subspecialty training to prepare themselves for what they rightfully perceive as a more complex, competitive future.

Future orthopaedic residents may be faced with a basic "undergraduate education" (residency of three or four years) followed by one or two years of optional "graduate school" (specialty training). The percentage that seek subspecialty training will depend on future information growth, consumer demand, economic factors, and even medico-legal considerations.

Although initially threatening, change always provides an opportunity for improvement. If growth in fellowships can be coupled with a decrease in the number of orthopaedic residents trained yearly, educators can transform the emerging "fellowship era" into a solution to the problem of overproducing orthopaedic surgeons. This method would meet society's need for fewer but better-trained surgical specialists.

The information explosion serves as a double-edged sword for the medical center orthopaedists by providing technology for rapid advances, but also fueling growth in understanding which allows only the most agile M.D. investigators to survive in a sea of Ph.D. competitors. Orthopaedic departments employing both M.D. and Ph.D.s who work together should remain productive in fulfilling an academic department's role of developing orthopaedic biology and technology.

The orthopaedic practitioner's role of applying new technology places him or her in the rewarding position of interfacing between science and application to the patient. Although these rewards should increase in the information era, there may also be negative features. Scientific study, made possible by sophisticated computers and an alliance of social scientists and legal experts, will analyze treatment effectiveness, safety, complications, cost-benefit analysis, and value of "surgical versus nonsurgical" time expenditure to a depth not previously possible. Furthermore, rapid changes, even within a subspecialty, have the potential for quickly making all but the most adaptive individuals obsolete. The successful practitioner will rely on his or her interpersonal skills with patients and aggressive continuing education to remain competitive. He or she may consider developing a subspecialty interest, as well as selecting future partners with fellowship training who can broaden the capabilities of the practice group. The basic orthopaedic temperament, whose major features include optimism and adaptability, is well suited for survival.

KNEE LIGAMENTS: A NEW VIEW

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INTRODUCTION

Few areas within orthopaedic surgery have more contradictory observations and conclusions, or more controversial opinions than the treatment of knee ligament injuries. Basic researchers in the area have concentrated on delineating the mechanical (i.e., structural) function of individual ligaments and support structures under controlled loading or displacement conditions. Although this work has provided an evolving picture of individual ligament function, these concepts don't radically vary from intuition or the summation of empirical evidence. Clinical researchers, on the other hand, have concentrated on relatively short-term (i.e., usually less than five years) follow-up of individual surgical procedures. The usual goals of such procedures are to restore function and to avoid the development of degenerative arthritis. The consensus of this work generally suggests that most surgical procedures provide good results (i.e., improved function), thus achieving at least one of the goals.

In considering some clinical observations I have made and some recent experimental work, I began to question my view* of ligaments; a view created by the basic and clinical research.

In this precis I will discuss my observations about knees and their ligaments; then I will analyze what I consider to be some assumptions, questions, and problems associated with the current "mechanistic" view of knee ligaments. Considering recent, relevant observations, I will suggest an interpretation of these which provides an alternate point of view and new research directions. While the observations aren't original, my synthesis intends to be.

OBSERVATIONS

My first observation is the existence of all the contradictory, basic, and clinical findings on knee ligaments[1-3]. Let me cite just two cases. The first case is the considerable disagreement on the mechanical (i.e., structural) function of the knee ligaments. Patients can have a torn anterior cruciate ligament without an anterior drawer sign. Conversely, most surgeons have observed normal knees with anterior drawer signs as well as injured knees with drawer signs yet with seemingly intact anterior cruciate ligaments at the time of surgery. Furthermore, Johnson et al.[2] have pointed out that seven studies report that the accuracy of the anterior drawer test ranges from 0 to 100 percent. Most would agree that the anterior drawer test should be a reasonable, even if imperfect, mechanical test for the anterior cruciate ligament based on anatomy, location, and an Aristotelian view of nature. How can such a wide range of discrepancy exist? A second case is the enormously variable functional response to knee ligament injuries. Patients with seemingly minor amounts of instability sometimes have considerable functional disability, while some patients with considerable instability have few functional problems. Thus, while a gross correlation between instability and functional disability may exist, the relationship is prone to considerable scatter. Is this scatter really due to "biologic variability" of a mechanical function?

The second observation is that patients tend to have the greatest functional impairments the first few years following knee ligament injury, and then do well long-term. McDaniel and Dameron[4] noted that 72 percent of patients with unrepaired but surgically documented tears of the anterior cruciate ligament returned to strenuous sports, and 42 percent had no restrictions with an average follow-up of 9.9 years. At an average of fourteen years, 75 percent of the patients continued in strenuous sports, and the incidence of giving way decreased[5]. Johnson et al.[6] noted that 25 percent of patients in a rehabilitation program removed themselves from a surgical waiting list because pain and function improved over a period of a few months. What would the percentage be if one waited five years? I submit that most patients would probably withdraw from the list. I am not suggesting that surgery should be delayed five years when indicated, but rather that over time something improves, and that the "something" is not likely an improvement in mechanical stability. Relatively few knee-injured patients complain of functional problems after five to ten years. One plausible explanation includes patient acceptance of functional limitations, but I doubt that this is the complete explanation since the ultimate functional limitations are minimal. Why does mechanical instability not uniformly create long-standing functional deficits?

*I shall use the term "view" as some would use the term "theory"; either implies only an interpretation of observations which may be considered "proven" or "accurate" to a greater or lesser extent, depending upon the preponderance of evidence.

The third observation made by myself as well as other reconstructive surgeons: relatively few patients having total knee replacements have ever had a major knee injury. In one series at the Mayo Clinic, only one of eighty-three patients had "post-traumatic arthritis"[7]. Cracchiolo et al. reported eight of 211 (3.8 percent) patients with a history of trauma before total knee replacements[8]. Engelbrecht et al. reported 75 of 998 (7.5 percent) patients with post-traumatic arthrosis[9]. In Funk's series, 8.5 percent of patients in his clinic undergoing total knee replacement "had a history compatible with significant ligamentous injury"[10]. (His figure may be exceptionally high, since that practice is widely known for its expertise in sports medicine.) Funk concluded "ligament injury is a relatively minor etiologic factor in the overall problem of severe degenerative arthritis of the knee". Furthermore, Kelsey[11] estimated 1.9 million new knee sprains for 1975-1976, and Hori et al.[12] estimated that 40,000 total knee replacements were performed in the United States in 1976. If one assumes that less than 10 percent (i.e., less than 4,000 of these total knee replacements) were performed for degeneration secondary to old ligament injury, and that the incidence of ligament injury now is similar to twenty to forty years ago, then few ligament injuries (i.e., 0.2 percent with these figures) result in total knee replacement. The author recognizes that these figures may be "soft". Factors tending to increase the percentage of ligament injuries leading to total knee replacement include: patients forgetting old injuries (although they would not likely forget a significantly disabling injury), surgeons forgetting to ask for or record a history of injury, or a much higher incidence of knee ligament injuries today than twenty to forty years ago. (Owing to the emphasis in physical fitness today, it is likely that injuries do occur with greater incidence, but even if it were ten times higher, which is unlikely, only 2 percent of all ligament injuries would ultimately require total knee replacement.) Factors tending to reduce the percentage of knee-ligament-injured patients requiring total knee replacement include: many knee ligament injuries are never seen by a physician and do not appear in any statistics; the reported injuries may have been more severe than isolated ligament injuries and may have included meniscal tears or articular cartilage injuries; and vague definitions of "trauma" are often used, so that the figures may also include fractures. The inescapable conclusion is that few knee ligament injuries lead to severe and disabling degenerative changes. This suggests to me that these patients usually develop only mild to moderate degenerative changes, and that these changes are ordinarily neither progressive nor severe. Klunder et al.[13] showed no difference in the incidence of knee arthrosis in ex-football players compared to controls, even though more football players had knee injuries. The degenerative changes in knee-injured patients (the existence of which are well documented) therefore, seem to behave substantially different than those seen in patients with typical primary osteoarthrosis. Why is one condition progressive and the other non-progressive when available evidence suggest that the two conditions have similar gross, histologic, and chemical cartilage changes?

The fourth observation is that within the thirty to forty years since knee ligament surgery has been widely practiced, there has emerged no convincing documentation that treatment per se or choice of treatment affects either the incidence or severity of degenerative changes. No truly long-term follow-up studies on surgically reconstructed knees exist, and even the natural history of untreated ligament tears is unknown. (By "long-term" in this context I mean a study with an average follow-up of at least ten to twenty years, the minimum period of time needed to determine whether or not one treatment, compared to another, really reduces the incidence of clinically significant degenerative changes.) Furthermore, there are few clinical follow-up studies of knee ligament injuries in the range of five to ten years[4,6]. The inherent limitations of such studies with or without controls hamper their completion. Furthermore, in a society that expects, indeed demands, intervention for real or perceived abnormalities, clinicians study interventions, rather than non-intervention. Additionally, professionals do what they enjoy doing and what they are trained to do: surgeons operate and few choose to explore non-operative treatments. Proof of efficacy becomes the burden of practitioner who chooses not to intervene, rather than on the one who does. Not surprisingly, no study documents the efficacy of treatment in preventing degeneration. However, so few attempts to compare operative with non-operative treatment does surprise me. If epidemiologically valid studies were available, would they be able to demonstrate a difference in large groups of patients treated by virtually any method?

These four observations have created considerable conceptual difficulties for me; they certainly do not conform to the conventional view. While considerable clinical opinion may vary with these observations, little hard scientific exists to refute them. Therefore, I felt compelled to arrive at some reasonable explanations.

PROBLEMS WITH CURRENT MECHANISTIC VIEWS

Most clinicians and basic researchers view normal ligaments as exclusively or principally passive (i.e., non-contractile) structural elements. Almost all laboratory and clinical work (including knee ligament reconstructive surgery) is based on such a notion. This view is also consistent with the idea that mechanical instability per se is the cause of functional disability. A mechanistic view may be assumed until sufficient evidence appears to refute it. The difficulties in reconciling seemingly contradictory laboratory and clinical observations based on this view will be magnified in proportion to the incorrectness of the assumption.

One can cite many explanations for seemingly contradictory and irreconcilable laboratory and clinical observations and conclusions about knee ligaments: biologic variability, different experimental or clinical techniques, lack of objective clinical measures, inaccuracies of in vivo stability testing owing to soft tissues, difficulties in conducting long-term follow-up studies of patients with knee ligament injuries. The list is almost endless. However, other possibilities cannot be discarded out of hand: that our view or model of ligaments is wrong; that we are considering the wrong parameters and making the wrong measurements; that we have been unable to see and synthesize the obvious. It is such alternative explanations for the discrepancies that I wish to explore. Several of these explanations hit at the heart of the underlying assumptions of science while others are more directly relevant to the clinical and basic research on knee ligaments.

The first issue addresses the role of determinism with regards to knee ligaments. A deterministic system dictates that a given perturbation or set of stimuli always produces the same behavior. On the other hand, stochastic systems explain behavior based on probabilities rather than certainties. While strict determinancy is a cornerstone of science, evidence is accumulating that it may not always be an appropriate one. The inability of deterministic theories to correctly predict system behavior has been most clearly demonstrated by particle physicists, and by biologists challenging the relevance of strictly deterministic theories[14-15]. Determinism would imply that knee ligaments will behave in a single and predictable way. Is this true of the behavior we observe for either individual joints or groups of joints? Have we observed all of the relevant parts, parameters, and behaviors to even answer this question?

The second issue is related to the first: Is the reductionist approach reasonable with complex biologic systems? Reductionism assumes that any system behaves according to the sum of its parts and, therefore, may be analyzed by reducing the entire system to a series of parts. Holism, or emergence theory, on the other hand, assumes that the whole system has properties or behavior not attributable to any given part or parts, and, therefore, the system cannot be analyzed by reducing it to a series of subsystems. If ligaments have more than a passive structural role, then won't the reductionist approach yield incorrect, inconsistent, or incomprehensible answers to our questions?

Another fundamental problem is the formulation of a view of reality based principally on "abnormal" observations rather than on "normal" observations. Clearly abnormal conditions give us many clues to the normal, but equally clear should be the difficulty attributing an abnormality to a single cause, function, or part of a complex system. The clinician's view of ligaments is based in large part on generalizations about patients having the greatest functional impairment following injuries. Many, if not most patients with knee ligament injuries never see a doctor and never have significant problems. Only a fraction of those who seek medical advice are ultimately referred to an orthopaedic surgeon (e.g., the patients in the study of McDaniel and Dameron[4]). An even smaller percentage see a knee specialist (i.e., those doing the research, those making the printed observations, and those most influential in formulating our views). The reported observations and the generalizations about treatment may be valid for the selected abnormal cases; however, they may not be representative for all patients with knee ligament injuries, and the relevance of those observations to normal knee ligament function is questionable. Thus, we must exercise caution in developing a view of normal ligament function based on observations of patients with abnormal ligaments. (This is not to imply, however, that those observations are not useful ones on which to base the design of surgical procedures; there can be little doubt that most of the patients reported in the carefully documented study of Johnson et al.[6] benefited from surgery.)

How have researchers explained the discrepancies and contradictions in their own data and between their conclusions and those in the literature? "Biologic variability" is the most common explanation. This explanation appears anti-deterministic. Although not wed to a deterministic viewpoint, I believe this explanation to be inadequate for a wide range of observations, explanations, and conclusions about knee ligaments.

One explanation for the variable surgical results is that ligaments always heal with scar rather than new ligamentous tissue. The amount of scar may vary, and the distance between ligament ends may vary, but extra-articular ligaments will always heal with scar, as will intra-articular ligaments, when they do heal. This scar likely never has chemical or structural properties identical to the original tissue. Additionally, scar has unpredictable long-term properties: sometimes stretching, and sometimes contracting. Limited motion is common following reconstructive surgery and anecdotal clinical evidence suggests that stretching of surgically repaired ligaments occurs in some cases. Thus, the formation of unpredictable scarring could be considered as one possible explanation of variable clinical results, but it can only be considered as a possibility until scar of variable quality and quantity can be shown to correlate with the variable results.

A NEW VIEW

Accumulating evidence challenges the generally accepted mechanistic view of ligaments. If this is so, the implications are profound: doctors will have to reconsider their treatment approaches, and scientists will have to reconsider their research plans. What observations and evidence suggest that the major role of ligaments is "nonstructural"?

The first observation is one made by Lewis and Shybut that during level walking and trotting the medial collateral ligament of the dog is not significantly strained[16]. Isolated observations should be interpreted cautiously, but if this observation is confirmed, it indeed suggests, that at least for normal activities, ligaments have little or no passive mechanical role. According to Lewis and Shybut, stability in normal situations may be provided by the joint geometry and muscles.

A second important observation is the demonstration of mechano-receptors in the anterior cruciate ligament of animals by Freeman and Wyke[17] and others and recently in humans by Schultz et al.[18]. It is very unlikely that these receptors would be present (assuming the Aristotelian view) unless they had some critical function such as signaling joint position. Furthermore, the work of Grigg and his colleagues over the past ten years suggests that capsular mechanoreceptors are sensors for reflex arcs controlling muscular contraction[19-22].

Third, an enlarging body of opinion fueled by evidence from shorter-term uncontrolled studies, such as reported by Jokl et al.[23], support the concept that non-operative treatment is just as effective as surgical treatment for most patients. Assuming that their patients are comparable to those in various surgical series (a point for which they provide some evidence), their study implies that the functional result of ligament injuries may be independent of the form of treatment since their results were similar to those in surgical series.

Finally, there are the recent suggestions of Levine et al.[24] and others, that degenerative arthritis may be related to the release of an inflammatory neurotransmitter peptide, called "Substance P". In Levine's study, the severity of experimental arthritis was related to both the level of Substance P in the joint and the richness of innervation of the joint. Furthermore, an antagonist to Substance P reduced the severity of experimental arthritis. This notion, while not directly related to ligaments, may be related to the observation that persons with knee ligament injuries develop an apparently mild and relatively non-progressive form of degenerative joint disease which might be distinguished from the typical progressive osteoarthrosis by the absence of Substance P.

These new observations suggest that ligaments function as sensors for the nervous system, and that the nervous system plays a much larger role in normal knee function than formerly believed. There is little doubt that ligaments provide sensory input to the central nervous system. How much this input contributes to reflex muscle control and functional joint stability and how the nervous system is related to recovery following injuries are the principal issues needing resolution. The neurosensory function may dominate during normal activities, and the passive structural role may assume prime importance during injuries or unnatural acts, such as football.

This alternate, or neurosensory, view of ligaments, if not explanatory, is at least consistent with the four observations I have discussed. First, the apparently contradictory data and conclusions in the knee ligament literature; second, the observation that patients with knee ligament injuries do not have long standing functional disability; third, that patients having total knee reconstructions rarely have had major knee ligament injuries and, conversely, that patients with knee ligament injuries rarely develop significant enough degenerative changes to warrant total knee reconstruction; and fourth that the long-term result of knee ligament injuries may be unrelated to the form of current treatments.

Let me speculate on how this view may explain the four initial observations. The first observation may be explained simply by the failure to recognize the predominant role of the ligaments as sensory transducers, and instead studies are based on their minor role as passive structural elements. If the passive role is minor, biologic variability of mechanical behavior assumes far less importance. It is also possible that the ligament systems have properties independent of their sensory and structural roles. As the number of functions of a system increases, the chance that a strictly reductionist experiment can be accurate decreases, since it is increasingly difficult to separate and distinguish functions and behavior. Thus, our mechanical experiments alone tell us nothing about the interactions of the mechanical and neurosensory functions of ligaments, and our "mechanical" observations may appear contradictory because we are observing the wrong behavior, or only a portion of the correct behavior.

The second observation (i.e., lack of major functional disability from knee ligament injuries) may be explained in at least two ways: First, reinnervation of scar tissue over time, and second, retraining of the brain to compensate for lost sensory input. Assuming that the neurologic role of ligaments is the principal one, critical sensory input would be lost following an injury. Scar tissue might develop new neurons and nerve endings over a period of time, and replace the lost sensory transducers. The neural repair would be local unless retrograde axonal degeneration took place. Then, a repair over a period of months or even years would be possible, since the axons themselves would not be damaged. The second possibility is that even though scar tissue might not develop new transducers, the brain may begin to pick up or process sensory signals from surrounding tissues, such as joint capsule, muscle and skin. Over a period of time, this new input may restore more or less normal reflex control as the brain is retrained to utilize them. Similar phenomena occur after nerve injury and after muscle transfers, and some therapists are beginning to develop knee rehabilitation programs based on this concept[25]. Certainly, such a theory is consistent with the observation that the greatest functional deficits occur the first few years following a ligament injury. Poor restoration of innervation or lack of retraining might explain longstanding functional deficits in a small percentage of patients.

The third observation may also be explained with this new view. If reinnervation or retraining occurs after ligament injury, then progressive degeneration might be avoided since regained neural control by either or both mechanism would diminish the functional instability and its potentially deleterious effects. Furthermore, the knee-injured patient without an abnormally rich innervation or abnormal release of Levine's substance P, would not necessarily develop a typical form of progressive arthrosis.

The final observation is also readily explainable with a neurosensory view of ligaments, since the results of treatment would be dependent on regaining reflex muscle control, through either reinnervation or retraining, rather than through restoration of mechanical stability. It would be unlikely that reinnervation and retraining would be related to whether or not a knee was treated surgically, at least using current techniques.

It seems to me, then, that a neurosensory view of ligaments explains available observations better than a strictly mechanical view. In this view, ligaments are not isolated anatomic structures, but rather parts of a complex system including capsule, nerves, muscles, and perhaps even bone and cartilage, in which each potentially plays an interrelated functional role. While I am not aware of any evidence which clearly contradicts such a theory it is obviously critical to accumulate evidence to either support or refute such a view. We must identify the nature of the neural role of ligaments in the context of system behavior. The nature and functioning of the capsular reflex arcs needs to be elucidated. We must determine whether return of motor control is related to the successes and failures of our treatments, both operative and non-operative. Patients at risk for long-term functional disability, whether of neurologic or mechanical or combined origin, need to be distinguished from those who are not. All of these issues, as well as related ones will require input from the engineer/scientist, as well as the surgeon, physiologist, and anatomist. It is possible that the approach I am suggesting will ultimately prove to be the wrong one, but even in that case, the new work will guide and suggest other new approaches.

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LUMBAR DISC HERNIATION—A TEN-YEAR FOLLOW-UP

Chemonucleolysis vs. Open Discectomy

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Abstract

This is a 10 year follow-up longitudinal case study of two treatment groups. Group I (85 patients) was treated with chymopapain and Group II (71 patients) was treated with open discectomy.

The study questionnaire contained six well accepted pain measures. Validity studies demonstrated these measures to be adequate reflections of the patient's condition and that all six measures were significantly related (Pearson's r, $p < .003$). The chymopapain and discectomy groups were not distinguishable on the basis of these pain outcome measures. An additional test of the relationship between pain outcomes and body mass (Kg/M^2) demonstrated that discectomy patients who reported greater pain had significantly greater body mass, ($p < .004$).

Recurrence rates did not differ significantly, but there was a trend for discectomy patients to report higher recurrence rates at both the 1- and 10-year periods. Superiority of one treatment over the other could not be unequivocally demonstrated.

Regardless of treatment modality, patients who returned to work between 6 and 12 weeks after treatment, but prior to complete recovery reported significantly greater pain at 10-year follow-up ($p < .04$). Patients who returned to work within 6 weeks of treatment but prior to recovery demonstrated a similar trend. However, for patients who had not recovered within 12 weeks of treatment, no differences were seen in long-term results, regardless of whether or not they had returned to work. Treatment satisfaction was similar but chymopapain patients were much more likely than discectomy patients to recommend the treatment to a friend ($p < .01$).

It has been 50 years since Mixter and Barr[13] first operated on a herniated nucleus pulposus, and 20 years since Lyman Smith[18] first injected chymopapain into the nucleus pulposus of a human. Controversy and disagreement concerning the efficacy of these two treatments continues. In most cases of ruptured lumbosacral herniations, non-operative treatment is preferred. If recovery is delayed, surgical intervention in the form of open discectomy or closed percutaneous chymopapain injection may be considered.

The issue of chymopapain versus open surgery in the treatment of disc herniation remains unsettled. Although some authors have reported comparable results[11], others have reported less favorable results for chymopapain[3,9,20]. Hakelius[5], Nashold and Hrubel[14], and Weber[21] did not report any significant difference between the final results of surgical and nonsurgical treatment at 5-, 10-, and 20-year observations.

Numerous publications report treatment results of sciatica and low back pain. There are, however, no studies comparing the long term effects of chymopapain to laminectomy and discectomy in the treatment of herniated disc.

This study compares the long term results (i.e., 10-year post-treatment) of two treatment modalities for lumbar and lumbosacral disc herniation. Questionnaires were sent to patients who had undergone open discectomy. Outcome measures included indices of current pain and disability. Progress variables included speed of recovery, duration of recovery, recurrence rate, and treatment satisfaction. We hypothesized that no major differences between the treatment groups would be found based on the outcome measures, but we did expect differences across some of the progress measures. Chymopapain patients were expected to report more rapid recovery, greater recovery duration, and lower recurrence rates than discectomy patients. Finally, the relationship between treatment modality and return to work was explored.

Study Population

The study population was composed of two groups. Group I consisted of chymopapain patients treated by three orthopaedic surgeons at the Rush Presbyterian St. Luke's Medical Center, Chicago, Ill. Uniform records were kept on these patients using the Baxter-Travenol experimental protocol. Group II was a composite of open discectomy patients treated by four orthopaedic surgeons at the University of Iowa Hospitals in Iowa City, Ia. Most of these patients were from the State of Iowa. Standard hospital records were kept on these patients.

Criteria for inclusion in this series were: 1) Positive straight leg raising on the affected side; 2) Positive reflex changes on the affected side; 3) Positive motor and/or

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sensory changes; 4) Minimum three months conservative treatment; 5) Positive myelogram, consistent with history and physical findings; and 6) Minimum of 10-years since original treatment. Patients who had undergone previous lumbar spine surgery or chemonucleolysis, or who had other spinal pathology, including infections, tumor, spondylolysis, and spondylolisthesis were excluded. Generalized arthropathy or a neurologic disorder, including a cauda equina syndrome and bladder dysfunction, were also cause for exclusion.

Inclusion criteria were satisfied by 156 chymopapain patients and 100 discectomy patients. Twelve of the chymopapain and nine of the discectomy patients were deceased, and 56 of the chymopapain (36%) and 20 of the discectomy (22%) could not be located. Of the remaining 88 chymopapain patients who were reached, 85 (97%) responded. Of the remaining 71 discectomy patients, all responded.

Instrumentation

The study questionnaire included three distinct yet related measures: 1) outcome measures—indicators of the patient's current condition (i.e., 10-years post-treatment); 2) progress measures — indicators of the course of the patient's back condition over the 10-year period; and 3) work measures—a special classification of progress measures dealing with the patient's occupation history over the 10-year period.

The questionnaire contained several well accepted pain outcome measures[4,8,9,10,12,16,17]. Progress variables included relief of back and/or leg pain following the original treatment, recurrence of pain, and history of additional treatments including surgery. Recurrence was defined as a second surgical procedure at the same level as the original treatment. Work indicators included return to work, speed of return to work, job changes, and level of physical activity required on the job.

Results

Demographic variables for the chymopapain and discectomy groups are summarized in Table 1. The two groups were remarkably similar. The main difference was that the chymopapain group was better educated and less likely to be laborers.

Outcome Measures

Validity studies of the pain outcome measures (i.e., Pain Thermometer[16,17], Pain Status[4,8,9,10], and Disability Score[12]) were done to assure that the measures were accurate reflections of the patient's condition. Table 2 summarizes the intercorrelations among the six outcome measures. The high intercorrelations among the six pain outcome measures provided support for the notion that the six outcome measures assess related or similar things.

As a second validity assessment, patients in the treatment groups were combined and a one-way MANOVA was done to assess the relationship between the six outcome measures and treatment satisfaction. Treatment satisfaction should be positively correlated with pain relief. Results indicated a strong satisfaction main effect, Wilkes Criterion $F_{6,53} = 4.00$, $p < .003$. Follow-up univariate tests indicated significant main effects for each criterion and examination of the means indicated that, in each case, patients satisfied with their treatment reported significantly lower pain than patients less satisfied with their treatment. The univariate tests and appropriate descriptive statistics are summarized in Table 3.

Results of the one-way MANOVA assessing the relationship between the six pain outcome measures and treat-

Table 1

Summary of Demographic Variables by Treatment Modality

Demographic Variable		Treatment Modality: Chymopapain	Treatment Modality: Discectomy
Age:	Mean	41.9	40.5
	Range	32-56	28-57
Height (Meters):	Mean	1.70	1.71
	Range	1.50-1.98	1.50-2.08
Weight (Kilograms):	Mean	79.41	80.45
	Range	50.80-147.40	47.80-136.10
Follow-up Interval (Years):	Mean	10.5	10.0
	Range	10-13.5	10-11.3
Sex:	Male	45.9%	35.2%
	Female	54.1%	64.8%
Post High School Training		52.9%	39.2%
Laborer as a Profession		54.1%	84.5%
Carry Workmen's Compensation		8.2%	12.6%

Table 2

Intercorrelations Among the Six Pain Outcome Measures

		Pain Thermometer		Pain Status		Average Pain I		Average Pain II		Visual Analogue Scale		Disability Score
P. T.		1.00										
	N		156									
P. S.		0.83		1.00								
	N		134		134							
A.P. I		0.56		0.77		1.00						
	N		68		68		68					
A.P. II		0.69		0.80		0.90		1.00				
	N		61		61		61		61			
V.A.S.		0.55		0.70		0.73		0.77		1.00		
	N		69		68		68		61		69	
D. S.		0.51		0.67		0.59		0.68		0.72		1.00
	N		69		68		68		61		69	69

Table 3

Summary of follow-up Univariate MANOVAs Assessing the Relationship Between the Outcome Measures and Treatment Satisfaction

Outcome Measure	Source	df	SS	F	P
Pain Thermometer	Treatment Satisfaction	1	35.88	41.01	.001
	Error	152	132.96		
Pain Status	Treatment Satisfaction	1	37.06	46.14	.001
	Error	131	105.23		
Avg. Pain I	Treatment Satisfaction	1	3966.36	7.32	.009
	Error	65	35226.81		
Avg. Pain II	Treatment Satisfaction	1	4842.97	8.19	.006
	Error	1	34293.21		
Visual Analogue Scale	Treatment Satisfaction	1	5.29	12.29	.001
	Error	66	28.38		
Disability Score	Treatment Satisfaction	1	504.28	16.45	.001
	Error	66	2023.31		

Descriptive Statistics

Outcome Measures[1]	Treatment Satisfaction					
	Satisfied			Dissatisfied		
	M	S	N	M	S	N
Pain Thermometer	1.75	0.92	128	3.04	1.00	26
Pain Status	1.89	0.88	108	3.24	0.97	25
Avg. Pain I	36.89	22.34	45	53.27	24.18	22
Avg. Pain II	33.95	25.05	38	52.59	22.96	22
Visual Analogue Scale	−0.21	0.64	46	0.39	0.68	22
Disability Score	8.19	5.07	46	14.01	6.43	22

1. All six pain outcome measures have been scaled so that large values imply greater pain/disability.

ment modality (chymopapain vs. discectomy) were not significant, Wilkes Criterion $F_{6,54} = 1.18$, $p < .34$. Thus, the chymopapain and discectomy groups were not distinguishable on the basis of the pain outcome measures at 10-year follow-up.

An additional test was done to determine, whether body mass (i.e. body weight in kilograms divided by the square of body height in meters — (Kg/M^2) was related to the outcome measures. Results indicated a significant interaction between treatment modality and pain thermometer and between treatment modality and pain status, $F_{3,147} = 4.73$, $p < .004$, and $F_{3,126} = 3.34$, $p < .025$, respectively. Discectomy patients who reported great pain had significantly greater body mass than all other patients, including all of the chymopapain cases. Descriptive statistics for these analyses are reported in Table 4. Pain status versus body mass is present in Figure 1.

Progress Measures

Results relating progress measures to treatment modality are summarized in Table 5. Treatment modality was found to be dependent on the duration of pain before seeking additional treatment. The chymopapain group was more likely than the discectomy group to endure their pain (68.4% of the chymopapain vs. 49.2% of the discectomy patients endured their pain for more than 7 years before seeking additional treatment). The chymopapain and discectomy groups did not differ significantly from each other on any of the other six criteria.

Although no statistically significant differences in recurrence rates were observed, there was a trend indicating higher recurrence rates both in the short and long run for discectomy patients (18.3% of discectomy vs. 11.8% of chymopapain patients had a recurrence within the first year of treatment, and 38% of discectomy vs. 31.8% of chymopapain patients had a recurrence by 10-year follow-up).

Other trends in the data suggested that the chymopapain patients recovered more quickly (70.9% of the chymopapain vs. 61.4% of the discectomy patients reported recovery within six weeks), had a recovery of longer duration (64.6% of the chymopapain vs. 51.5% of the discectomy patients reported a recovery period of more than 7 years), and were slightly more likely to have frequent episodes of back pain (57.1% of the chymopapain vs. 51.5% of the discectomy patients reported an average of more than 15 episodes of back pain per year). These trends suggest a potential superiority of chymopapain over discectomy treatment, or alternatively, that the chymopapain group had a larger proportion of marginally affected back pain patients compared to the discectomy group. This latter interpretation is supported by the high number of episodes per year reported by the chymopapain group.

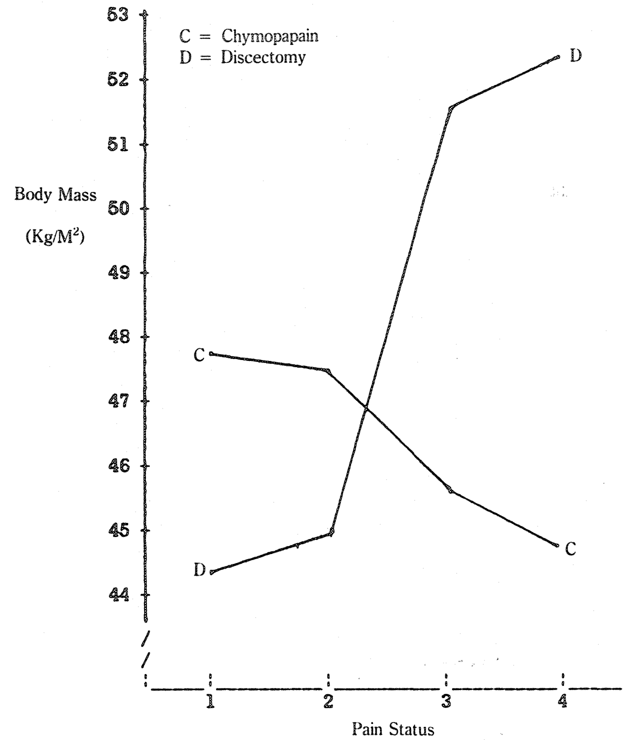

Fig. 1: Graphic Representation of the Treatment Modality by Pain Status Interaction for the Body Mass Criterion

This number of episodes is only possible if the episodes are of short duration. Similarly, the apparent willingness of chymopapain patients to endure the pain for more than seven years suggests a pain of lesser intensity. In summary, the trends in the progress measures do not provide support for chymopapain over discectomy treatment.

Work Measures

Differences in treatment modality across the work measures are summarized in Table 6. Again, the similarities between the two groups were more remarkable than the differences. The likelihood of returning to work and retaining the same job was quite similar for both treatment modalities (90.4% vs. 87% and 75.3% vs. 78.9% for the chymopapain and discectomy groups, respectively). Regarding speed of recovery, chymopapain patients were quicker returning to work than discectomy patients (41.8% of chymopapain vs. 30% of discectomy patients returned to work within six weeks of treatment). Interestingly, of the few patients who changed jobs, the chymopapain patients were more likely than discectomy patients to switch to a job not requiring manual labor (63.6% vs. 36.4%, respectively).

Assessing the effect of returning to work we combined Speed of Recovery (a progress measure) and Speed of Returning to Work (a work measure) to create three com-

Table 4

Summary of Descriptive Statistics for the Treatment Modality by Outcome Measure Interactions of the Body Mass Criterion

Criteria	Outcome Measure[1]		Chymopapain M	Chymopapain S	Chymopapain N	Discectomy M	Discectomy S	Discectomy N
Body Mass								
	Pain Thermometer	1	48.01	8.63	39	44.36	5.13	30
		2	44.92	6.67	19	45.73	7.79	21
		3	46.22	10.98	13	49.32	8.89	15
		4	44.31	12.19	13	58.39	10.88	5
	Pain Status	1	47.75	8.64	21	44.31	5.72	23
		2	47.26	8.52	24	44.97	6.93	27
		3	45.50	7.47	9	51.57	9.37	10
		4	44.81	10.41	11	52.16	9.97	11

1. Larger Pain Status and Pain Thermometer scores indicate greater pain.

Table 5

Summary of Progress Measure Results

Progress Measures		Chymopapain	Discectomy	X^2	df	P
Speed of Recovery	N	85	63	4.38	4	.36
1. No Recovery		10.1%	11.4%			
2. 12 + weeks		7.6%	4.3%			
3. 6-12 weeks		11.4%	22.9%			
4. 2-6 weeks		29.1%	31.4%			
5. Immediately		41.8%	30.0%			
Duration of Recovery	N	79	66	2.64	3	.45
1. .5-1 year		13.9%	19.7%			
2. 1-3 years		11.4%	13.6%			
3. 3-7 years		10.1%	15.1%			
4. 7+ years		64.6%	51.5%			
Duration of Pain before Seeking Additional Treatment	N	79	61	9.20	2	.01
1. 0-2 years		25.3%	27.9%			
2. 2-6 years		6.3%	22.9%			
3. 7+ years		68.4%	49.2%			
No. of Back Pain Episodes Since Treatment	N	84	68	0.81	2	.67
1. 0-4 per year		25.0%	25.0%			
2. 5-14 per year		17.9%	23.5%			
3. 15+ per year		57.1%	51.5%			
Recurrence Rate	N	85	71	0.28	1	.60
1. Within 1st year		11.8%	18.3%			
2. By 10 year follow-up		31.8%	38.0%			
More than 1 Hospitalization	N	84	71	0.45	1	.83
		15.5%	15.5%			
No Additional Treatment	N	83	69	0.79	1	.78
		47.0%	49.3%			

posite variables. Each composite had two levels. Composite A considered patients who returned to work within six weeks. Patients who were well by six weeks were assigned a value of 1 and patients who were not well by six weeks were assigned a value of 0. A person was defined as "well" when they reported complete relief of their back and/or leg pain (sciatica). Composite B was comprised of patients returning to work between six weeks and three months. Again patients who were well were assigned a value of 1 and patients who were not well were assigned a value of 0. Composite C included patients who reported being well three months or more after treatment. Patients who returned to work after three months were assigned a value of 1 and patients who returned to work

Table 6

Summary of Work Measure Results

Work Measures		Treatment Modality: Chymopapain	Treatment Modality: Discectomy	X^2	df	P
Returned to Work	N	83	69	0.44	1	.51
		90.4%	87.0%			
Speed of Return to Work	N	79	70	5.12	4	.28
1. More than a year		10.1%	11.3%			
2. 6 months - 1 year		7.8%	4.3%			
3. 3 - 6 months		11.4%	22.9%			
4. 6 weeks - 3 months		29.1%	31.4%			
5. less than 6 weeks		41.8%	30.0%			
Retained Same Job	N	85	71	0.28	1	.60
		75.3%	78.9%			
New Job Requirements	N	11	11	2.82	3	.43
1. No Manual Labor		63.6%	36.4%			
2. Minimal Manual Labor		27.3%	27.3%			
3. Moderate Manual Labor		9.1%	27.3%			
4. Heavy Manual Labor		—	9.1%			

Table 7

Summary of the Relationships between the Composite Scores and Treatment Modality

Composite: Treatment Recovery	Composite: Back Working			Treatment Modality: Chymopapain	Treatment Modality: Discectomy	X^2	df	P
A			N	33	19	0.00	1	.99
Not Well	: 0-6 weeks	(0)		21.2%	21.1%			
Well	: 0-6 weeks	(1)		78.8%	78.9%			
B			N	23	20	0.96	1	.33
Not Well	: 6-12 weeks	(0)		17.4%	30.0%			
Well	: 6-12 weeks	(1)		82.6%	70.0%			
C			N	12	10	2.94	1	.08
3-12 Months	: < 3 Months	(0)		33.3%	70.0%			
3-12 Months	: > 3 Months	(1)		66.7%	30.0%			

before three months were assigned a value of 0. Thus, composites A and B assessed patients speed of recovery conditioned on speed of returning to work, and composite C measured patients speed of returning to work conditioned on speed of recovery.

Table 7 summarizes the distribution of the three composites across treatment modality. Consistent with most of the previous findings, composites A, B, and C were found to be independent of treatment modality. That is, for each composite, the classification of a patient was a 0 or a 1 was not related to treatment modality; for all three composites, chymopapain patients were just as likely or unlikely to be a 0 as discectomy patients.

A series of two-way MANOVAS was done to assess whether or not treatment modality and each of the composite variables might be useful constructs for explaining the pain outcome and progress measures. No overall treatment modality by composite interactions were found for the pain outcome measures for composites A, B, or C, Wilkes Criterion $F_{5,6} = 2.17$, $p < .21$, $F_{6,7} = 0.31$, $p < .60$, $F_{6,1} = 5.82$, $p < .31$, respectively. However, there was an overall significant Composite B Main effect, Wilkes Criterion $F_{6,7} = 4.31$, $p < .04$. Table 8 summarized the significant univarite follow-ups. Examination of the mean differences indicated the main effect to be in the same direction for all three criteria. Those patients returning to work between 6 and 12 weeks, reported significantly greater pain at 10-year follow-up if they returned to work before they were well. Although significant differences were not observed for Composite A, mean differences across treatment modality were in the same direction.

Significant interactions between Treatment Modality and Composites A and C were observed for the progress measures, Wilkes Criterion $F_{6,40} = 1.97$, $p < .10$, and $F_{6,7} = 5.23$, $p < .03$, respectively. No significant effects for Composite B were observed. For Composite A, the univarite follow-up analyses indicated significant Treatment Modality by Composite interactions for the Duration of Recovery, and Duration of Pain before seeking additional treatment criteria, $F_{1,45} = 5.14$, $p < .03$, and $F_{1,45}$

Table 8

Summary of Significant Results for Relationships between Composite B and the Outcome Measures

Outcome Measure	Source	df	SS	F	P
Avg. Pain I	Composite B	1	2230.59	8.43	.0109
	Error	15	3967.88		
Avg. Pain II	Composite B	1	1793.07	4.49	.0524
	Error	14	5586.93		
Visual Analogue Scale	Composite B	1	1.89	7.77	.0132
	Error	16	3.89		

Descriptive Statistics

Composite B		Outcome Measures[1]								
Treatment Recovery	Back Working	Avg. Pain I			Avg. Pain. II			Visual Analogue Scale		
		M	S	N	M	S	N	M	S	N
Not Well:	6-12 weeks (0)	48.33	11.25	6	44.16	19.08	6	0.11	0.28	6
Well:	6-12 weeks (1)	24.36	18.26	11	22.30	20.46	10	−0.57	0.56	12

1. For all outcome measures, high values imply greater pain and/or disability.

Table 9

Summary of Discriptive Statistics for the Treatment Modality by Composite A Interaction for the Progress Measures

Criteria[1]	Composite A		Treatment Modality					
			Chymopapain			Disectomy		
	Treatment Recovery	Back Working	M	S	N	M	S	N
D. R.[2]	Not Well:	0-6 weeks (0)	3.71	0.48	7	2.00	1.73	3
	Well:	0-6 weeks (1)	3.38	1.10	26	3.53	0.91	15
D. P.[3]	Not Well:	0-6 weeks (0)	2.67	1.37	7	1.25	0.50	4
	Well:	0-6 weeks (1)	3.56	1.00	26	3.67	0.72	15

1. Larger criteria scores imply positive aspects of recovery.
2. D. R. = Duration of Recovery
3. D. P. = Duration of Pain before Seeking Additional Treatment

= 6.71 $p < .03$, respectively. Examination of the patterns of means indicated both interactions to be of the same form. Follow-up simple effects tests indicated that for both interactions, discectomy patients at the 0 level on the composite variable had significantly poorer prognosis compared to all other patients. These patients had shorter durations of recovery and were likely to wait shorter periods of time to seek additional treatment than discectomy patients at the 1 level on the composite and all of the chymopapain patients. Descriptive statistics associated with these analyses are reported in Table 9. The pattern of means in the treatment modality by composite A interaction for the duration of recovery criterion is presented in Figure 2.

For composite C, the univariate follow-up analyses indicated marginal significance for the treatment modality by composite interaction for the duration of pain before seeking additional treatment criteria, $F_{1,12} = 4.03$, $p < .068$. However, there was no data to suggest poorer progress in recovery when patients returned to work prior to relief of back and/or leg pain more than 12 weeks following treatment. Overall, the extremely small number of patients fitting this classification makes meaningful interpretation difficult.

Discussion

This study compared the results in two treatment groups with similar back and/or leg pain. Group I patients were treated with chymopapain, and Group II patients were treated by open discectomy. Longitudinal studies of this type have a number of inherent difficulties. First, retrospective analysis is often difficult. In this study, the record keeping systems at both hospitals minimized these problems. Secondly, finding patients after 10 years and getting them to respond to questionnaires is no small task. Although

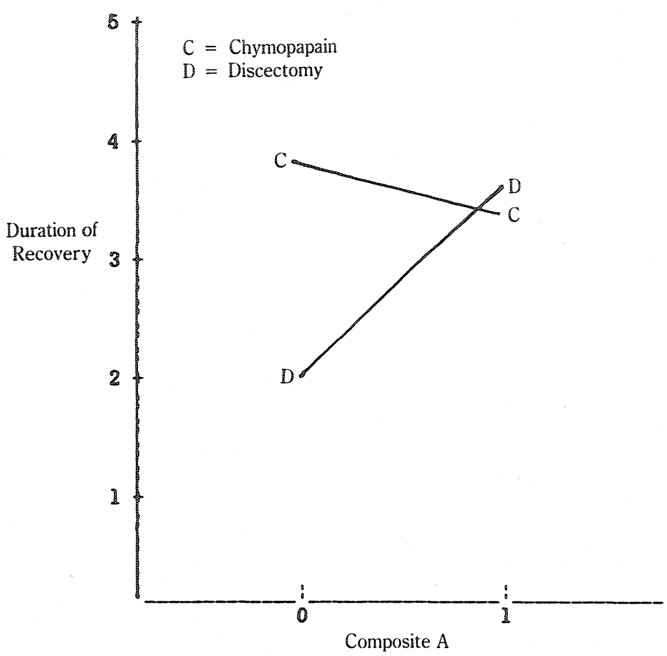

Fig. 2: Graphic Representation of the Treatment Modality by Composite A Interaction for the Duration of Recovery Criterion

we achieved a questionnaire return rate of 98% in this study (97% for chymopapain and 100% for discectomy patients), these numbers do not reflect the fact that we could not locate 29.7% (76/256) of the identified patients. Thirdly, the use of questionnaires has its own set of problems. Patients often skip questions resulting in incomplete data, and perhaps more importantly, patients may incorrectly recall information concerning the progress of their recovery over a 10-year period. Inconsistent responses were eliminated from subsequent analyses. Finally, studies of this nature are not randomized and, therefore, treatment differences do not necessarily imply treatment effects. This point is identical to the old saying that "correlation does not imply causality." Even with these limitations, the results of this study suggest several potentially important points.

The questionnaire used in this study contained several well accepted pain outcome measures. These measures adequately reflect the patient's condition according to validity studies showing linear relationships between each of six outcome measures. The validity hypothesis, that patients satisfied with their treatment would report less pain than patients dissatisfied with their treatment, was supported. Consistent with our original hypothesis, the chymopapain and discectomy groups were not distinguishable on the basis of the pain outcome measures.

An additional test assessing the relationship of pain outcome measures with body mass (Kg/M^2) resulted in a surprising finding. Discectomy patients who reported greater pain at 10-year follow-up had significantly greater body mass.

Differences in progress measures were observed. Chymopapain patients were found to wait significantly longer periods of time before seeking treatment. Of particular interest was the relationship between treatment modality and recurrence rate (i.e., the need for a second treatment within one year of original treatment). The literature has reported average recurrence rates of approximately 10% (range 0-30%) following discectomy[2,19], while recurrence rates following chymopapain injection are unknown. Although differences in recurrence rate were not statistically significant, there was a trend indicating higher recurrence rates at both 1 and 10 years for discectomy patients. Other trends in the progress measures suggested that chymopapain patients recovered more quickly, had a longer duration of recovery, and were more likely to have frequent episodes of back pain. These significant findings and trends suggest a potential superiority of chymopapain over discectomy treatment. This interpretation is not unequivocally supported by the data and advocacy of one of these treatments over the other on the basis of these findings would be at best premature and at worst irresponsible.

No hypotheses were made concerning treatment modality and work-related measures. Although the chymopapain and discectomy groups were quite similar on many of these measures, there was a trend indicating that chymopapain patients returned to work more rapidly than discectomy patients. However, rapidity of returning to work in and of itself is not particularly significant information. The effects of returning to work before or after treatment recovery are of much greater interest.

Three composites combining speed of recovery and speed of returning to work were created to more carefully investigate this issue. Consistent with most of the previous findings, these composites were found to be independent of treatment modality. That is, chymopapain patients and discectomy patients did not differ significantly in the proportions of patients who returned to work before or after recovery. However, these composites proved useful as predictors of the long term effects of returning to work before or after recovery. The patients who returned to work between 6 and 12 weeks of treatment and before recovery from surgery reported significantly greater pain at 10-year follow-up. A similar pattern was observed for patients who returned to work within six weeks of treatment, but these trends were not statistically significant. There was no relationship between outcome and return to work in patients who had not recovered by twelve weeks. Thus, it would appear that returning to work at twelve weeks does not have deleterious long term effects even if recovery is not yet complete. For patients who returned to work within six weeks of treatment, treatment modality and recovery interacted to predict duration of recovery. Discectomy patients who returned to work before recovery reported significantly shorter durations of recovery than other discectomy patients, while duration of recovery was not related to recovery status for the chymopapain patients. Thus, for discectomy patients more than for chymopapain patients, duration of recovery may be more intimately related to rapidity of returning to work.

In closing, let us consider treatment modality in relation to patient satisfaction with treatment. Although it has been demonstrated that treatment satisfaction was related to long term pain outcome measures it remains to be seen whether or not treatment modality was related to satisfaction with treatment. Results indicated no significant differences in treatment satisfaction or in willingness to repeat the treatment. In comparing the pattern of satisfaction responses across treatment modality, the discectomy patients responded in a reasonably consistent manner, although more patients reported that they would repeat the treatment than reported satisfaction (84.3% would repeat while only 80.3% were satisfied), discectomy patients were relatively reluctant to recommend the treatment to a friend, only 71.3% would recommend the treatment to a friend. On the other hand, for chymopapain patients, 90.3% would recommend the treatment to a friend although only 85.5% reported that they were satisfied with the treatment and only 79.5% would repeat the treatment. In light of these findings, one can only speculate about the quality of friendship among the chymopapain patients.

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CRANIAL SETTLING

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I. INTRODUCTION

Rheumatoid involvement of the cervical spine, a well documented entity both clinically and roentgenographically[4,7,14,22], results from the same inflammatory and destructive process that occurs elsewhere in the body. The synovial hypertrophy within the small joints of the cervical spine leads to bony erosions and ligamentous disruption with resultant instability. This instability is most pronounced in the upper cervical spine at the occipito-atlanto-axial complex, although the lower cervical spine is also frequently involved.

In 1890, A.E. Garrod[7] first described cervical spine involvement in patients with rheumatoid arthritis. The percentage of rheumatoid patients with radiographic changes is quite variable depending upon the study and the chosen roentgenographic features. Conlon et al.[5] noted an incidence of 88 per cent neck pain in rheumatoid patients, 50 per cent of whom displayed roentgenographic changes. Pellicci et al.[15] studied 106 symptomatic patients of whom 43 per cent presented with roentgenographic abnormalities, and at a six year follow-up this increased to 70 per cent. The three roentgenographic lesions most commonly described include atlantoaxial subluxation, subaxial subluxation (second to seventh cervical vertebrae), and cranial settling.

The terminology regarding displacement of the dens into the foramen magnum is confusing[6]. Terms that have been used interchangeably include superior migration of the odontoid process[15,18], downward luxation of the atlas on the axis[20], vertical subluxation of the axis[21], upward translocation of the dens[16], atlantoaxial impaction[22], and basilar[19] or pseudobasilar invagination[9]. We feel that the term cranial settling most simply and accurately describes the underlying abnormality. Because the bony erosions involve the occipital condyles and lateral masses of the atlas, the cranium moves downward (settles) relative to the dens; the dens does not change position.

The incidence of cranial settling is less than that of atlantoaxial subluxation. Atlantoaxial subluxation appears roentgenographically in 19 to 71 per cent of patients, whereas cranial settling is present in only 5 to 32 percent[8]. Again, these percentages vary, depending upon patient selection and roentgenographic features. The potential complications from cranial settling are greater than those from atlantoaxial subluxation, although cranial settling usually coexists with some degree of atlantoaxial subluxation. The potential for progression in patients with cranial settling is 33 to 50 per cent compared to a potential for progression of 20 per cent in patients with atlantoaxial subluxation[8].

We reviewed twenty-seven patients with cranial settling, fourteen of whom underwent surgical stabilization. Specifically, we investigated: 1) the various roentgenographic features previously described for measuring cranial settling as well as developing our own method; 2) associated roentgenographic findings such as atlantoaxial subluxation, subaxial subluxation, and erosions of the dens; 3) the success of surgery is achieving the goals of therapy, i.e. relief of pain, stabilization or improvement of the neurologic status, and prevention of progressive settling; 4) the relative safety of surgery; and 5) the relationship between roentgenographic and clinical findings.

II. MATERIALS AND METHODS

We reviewed the charts and roentgenograms of twenty-seven rheumatoid patients with cranial settling who had presented to either the orthopaedic or neurosurgical service in the past ten years. Fourteen of the patients underwent surgery; whereas thirteen were followed nonoperatively.

All charts were reviewed for clinical presentation; symptoms of pain and neurologic status were retrospectively classified in the manner described by Ranawat et al.[18] (Tables 1 and 2) with some modifications. All roentgenograms were measured to determine the degree of cranial settling according to the methods of McGregor[12], McRae[13] and Ranawat[18], as well as our new method (Fig. 1). Measurements on plain roentgenograms and tomograms were adjusted for magnification factors to yield actual dimensions.

Because measurements were made from plain roentgenograms and tomograms, we tested a ratio of measurement which would negate magnification factors. This method is similar to Ranawat's in that it expresses the relationship between the ring of the atlas and the dens (ring/dens ratio). It is possible to measure the ratio if the ring of the first cervical vertebra, the tip of the dens, and the base

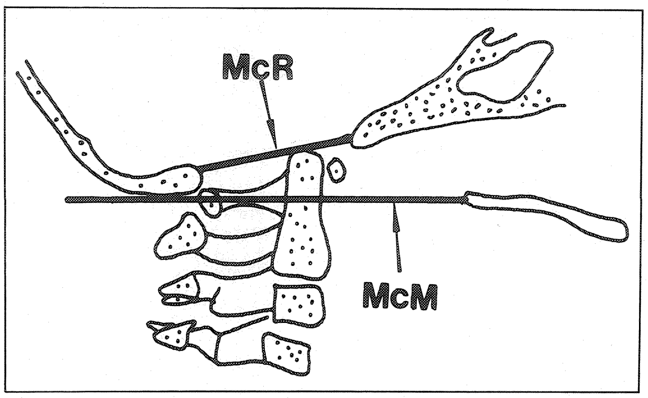

Fig. 1-A

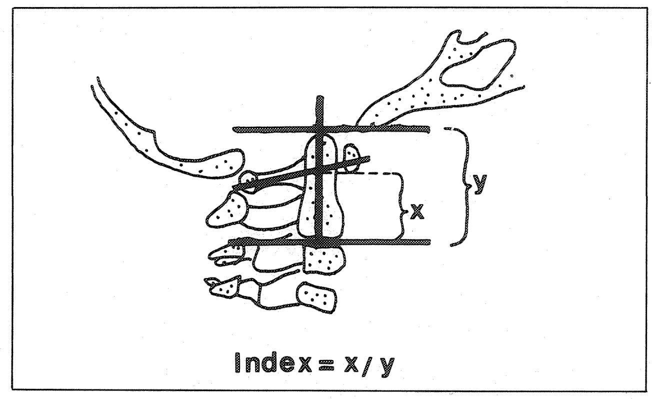

Fig. 1-B

**Fig. 1: A. McR is McRae's line and McM is McGregor's line.
B. Ring/dens index.**

Table 1

Pain Classification

Grade	Definition
0	None
1	Mild (intermittent, relieved by nonnarcotic analgesics)
2	Moderate (intermittent, relieved by collar and/or narcotic analgesics
3	Severe (constant and disabling)

Table 2

Neural Involvement Classification

Class	Definition
I	No neural deficit
II	Subjective weakness, hyperreflexia, dysesthesia
IIIA	Objective weakness, long tract signs, brain stem compression (ambulatory)
IIIB	Objective weakness, long tract signs, brain stem compression (nonambulatory)

of the second cervical vertebrae are visualized. The sagittal axis of the first cervical vertebrae is outlined from the center of the anterior arch to the center of its posterior ring. A second line is marked from the midbase of the second cervical vertebra to the tip of the dens. The distance from where the two lines intersect to the base of the second cervical vertebrae divided by the total height of the dens determines the ratio. This ratio was determined in thirty normal cervical spine lateral flexion/extension roentgenograms and averaged 80 per cent (range seventy-five to eighty-five). As with Ranawat's method, this ratio does not address the changes occurring at the atlanto-occipital junction, although we observed that collapse here usually is insignificant if no collapse has occurred between the first and second cervical vertebrae. Roentgenograms were also measured for atlantoaxial subluxation, subaxial subluxation (slippage of one vertebrae on another by 15 per cent or more of the width of the lower vertebrae) and erosion of the dens (Table 3).

Table 3

Dens Erosions

Type	Definition
0	None
I	Mild (posterior scalloping at level of transverse ligament)
II	Moderate (circumferential bone loss — "penciling")
III	Severe (marked shortening with circumferential loss)

Surgical Group (N = 14)

This group consisted of thirteen females and one male, with an average age at surgery of 59.8 years (range thirty-seven to eighty-two). Eight were ARA classification III, whereas three patients each were ARA class II and IV. Rheumatoid arthritis had been present for 19.6 years (range four to thirty-two), with eight patients seropositive, one seronegative, and five unknown. The patients were symptomatic prior to surgery on an average of thirty months (range three days to 12.5 years). Four patients initially were followed in our nonsurgical group after cranial settling was diagnosed, but eventually underwent surgery. The remaining ten patients underwent surgery soon after diagnosis.

Neck pain was the most common presenting symptom (79 per cent), followed by occipital pain (57 per cent) and weakness (50 per cent). Two patients presented with recent inability to ambulate and one patient presented in respiratory distress. Four patients were noted to have cranial nerve abnormalities, most often cranial nerves V, IX, X, and XII. One patient had involvement of cranial nerves III, IV, and VI.

Traction preceded surgery in each case for an average of 13.2 days (range three to thirty-seven days). All patients improved symptomatically in traction; neurologic status also seemed to improve, although this was not always well documented in the chart. Two patients underwent transoral odontoidectomy; all fourteen patients underwent posterior occipit to axis fusion with bone graft, and twelve were augmented with methylmethacrylate. Postoperative immobilization ranged from immediate use of a four poster brace or soft collar (eight patients), to continued traction for two to eighteen days followed by a four poster brace (five patients), and halo cast for six months followed by a four poster brace (one patient). Eleven patients underwent clinical and roentgenographic examination within the last six months prior to the study, two were contacted by phone and one was deceased. The average length of follow-up was twenty-two months (range five to sixty months) for the thirteen surviving patients.

Nonsurgical Group (N = 13)

This group consisted of ten females and three males, with an average age at the time of diagnosis of 57.2 years (range twenty-seven to seventy-five years). Four were ARA classification II, five were class III, and four were class IV. Rheumatoid arthritis had been present for 20.2 years (range two to thirty-four years), with five patients seropositive, four seronegative and four unknown. Neck pain was present in only 54 per cent of this group, all mild in nature. Thirty-eight per cent complained also of mild occipital pain. Four patients (31 per cent) in this group were asymptomatic, and cranial settling had been diagnosed on routine preoperative cervical roentgenograms. Treatment varied from no collar use to full-time collar use (one patient).

Six patients underwent clinical and roentgenographic examination within the last six months, three were contacted by phone, and four were deceased. The average length of follow-up was forty-two months (range seven to 120 months) for the nine living patients.

III. RESULTS

Surgical Group

One patient was deceased. Eleven of the thirteen living patients (85 per cent) experienced less neck pain as compared to preoperative levels, and two patients with mild neck pain remained unchanged by surgery. No patient's pain worsened after surgery.

Six of the thirteen patients' (46 per cent) neurologic status improved following surgery, whereas seven patients (54 per cent) experienced no improvement. No patient deteriorated neurologically following surgery. The three living patients who presented with neural Class III all improved to Class II; two of these patients have remained in Class II, whereas one patient is Class III-B again (according to the patient's wife). The one patient who died presented with neural Class III-B; at the time of her death (three months postoperatively), her neurologic status was unchanged.

We attempted to review at least four different sets of roentgenograms on each patient: one set preoperatively without traction, one set while in traction, one set soon after surgery (zero to twenty-eight days postoperatively), and one set at follow-up.

As compared to preoperative roentgenographic measurements, traction decreased the amount of cranial settling in eight of the fourteen patients (including the one deceased patient), whereas six patients did not benefit from traction. Excluding the deceased patient, of those seven who benefited from traction, only three patients maintained any correction. Three patients lost this correction either at surgery or within the first month postoperatively, and one patient slowly lost correction over several months and then stabilized at her preoperative baseline.

Of those seven patients who benefited from traction, two patients deteriorated to below preoperative measurements. In those six patients who did not benefit from traction, four patients remained the same, i.e. did not change from preoperative levels, whereas one has deteriorated to below preoperative level and stabilized, and one patient's measurements were equivocal.

At surgery, the degree of cranial settling in nine patients is outlined in Table 4. Four of the surgical patients required special measurements for cranial settling ("reverse" measurements) which will be discussed later. Ten of the fourteen patients displayed five millimeters or less of atlantoaxial subluxation, three had between five and ten millimeters, and one subluxed greater than ten millimeters (11.5 mm). Only one patient out of the fourteen had significant subaxial subluxation (i.e. greater than 15 per cent slippage), and this particular level was fused at the same time as the occiput to axis fusion.

Table 4

Cranial Settling Measurements*
(surgical group)

Method	Preop	Postop
McGregor's	8.5mm (5.0-14.5mm)	—
McRae's	2.0mm (−1.0-6.5mm)	1.5mm (−2.0-5.5)
Ring/Dens Ratio	57% (30-70%)	57% (45-66%)
Ranawat	5.5mm (0-9.5mm)	—

*These measurements include 9 patients only. Four surgical patients required special measurements, and one patient that was deceased at follow-up was excluded.

All the patients displayed some erosion of the dens. Six patients displayed Type I erosions, six displayed Type II, and two had Type III erosions.

All surgeries consisted of a posterior fusion from the occiput to the axis with the only variance consisting of the source of graft (iliac crest, rib or spinous processes) and the use of methylmethacrylate (twelve cases). Also, most patients underwent decompression prior to fusion. The decompression consisted either of removal of the posterior ring of the atlas or enlargement of the foramen magnum posteriorly by removing part of the occiput, or both. The most common procedure (ten cases) utilized iliac crest graft with methylmethacrylate. The average time for this procedure was three hours (range 2.5 to 4.25 hrs) with an average blood loss of 880 cc.

Complications included three intraoperative dural tears (during occipital decompression), one pleural tear (at the harvesting of a rib graft), three occipital skin breakdowns secondary to the occipital support of a four poster brace, one prolonged, severe headache, one superficial wound infection (*Staphylococcus aureus*), one unexplained episode of respiratory distress two weeks postoperatively requiring tracheostomy, and one death three months postoperatively in a patient with multiple medical problems including congestive heart failure, pneumonia, urinary tract infection, and upper GI bleeding.

Nonsurgical Group

No significant differences exist between this population and the surgical group relative to age at diagnosis, duration of disease, ARA classification or the presence of the rheumatoid factor. As mentioned previously, four patients (24 per cent) of the seventeen originally in this group progressed to a point requiring surgery. Four patients were deceased; the cause of death was cardiac arrest in one (no autopsy), and septic shock in another (no autopsy). The cause of death is unknown in the other two.

Of the nine patients interviewed or examined at follow-up, six patients were having only mild pain and three no pain. Five patients were neural Class II (subjective weakness), and four patients were neural Class I. None of these progressed clinically over the follow-up period.

The degree of cranial settling at the time of diagnosis is outlined in Table 5. Follow-up roentgenograms revealed progressive cranial settling in only one patient. Atlantoaxial subluxation was less than five millimeters in eight patients, and greater than five millimeters in only one. Initially seven patients exhibited no evidence of subaxial subluxation; at follow-up, three of these patients developed subaxial subluxation at one or two levels. One of the two patients with subaxial subluxation initially also progressed from two to three levels of involvement.

Erosions of the dens were absent in one patient (Type O), mild in seven patients (Type I), and moderate in one (Type II).

Table 5

Cranial Settling Measurements (nonsurgical group)

Method	At Diagnosis
McGregor	11.5mm (4.5-21mm)
McRae	1.5mm (−4.5-12mm)
Ring/Dens Ratio	58% (44-79%)
Ranawat	8.0mm (2.5-15mm)

IV. DISCUSSION

Rheumatoid arthritis can be a severely crippling disease. Moderate to severe forms of the disease are associated with a decreased life expectancy compared to the general population, although cervical spine instability or luxations alone do not influence life expectancy[20]. The most potentially lethal lesion in the rheumatoid cervical spine is cranial settling. The neurologic loss may begin insidiously and go unrecognized until significant deficit suddenly appears[1]. Rana et al.[16] felt that urgent neurologic syndromes were more likely in patients with cranial settling. Twenty-five per cent of the patients in his series (two out of eight) with cranial settling came to surgery; this compares to 52 per cent in our series.

Our study population is comparable to Ranawat's[18] and Conaty's[4] groups with regard to age at time of surgery and average duration of rheumatoid disease. We did not find any sex predilection for development of cord compression as Weisman et al.[22] reported.

Roentgenographic determination of cranial settling is often difficult because of the frequent osteopenia and destructive changes on plain roentgenograms[18]. Smith et al.[20] recognized cranial settling, but chose to assess it subjectively as they were unable to devise a satisfactory method of measuring lesions. Weisman et al.[22] utilized McGregor's baseline, but when faced with severe erosions of the dens, they would note the relationship of the ring of the atlas to the dens and the body of the axis, but made no attempt to quantitate this relationship. McGregor's baseline requires identification of the hard palate (which is often not present on routine studies or tomograms) and the tip of the dens (often not discernible on plain roentgenograms). Our study showed measurements with McGregor's baseline to be the most varied.

McRae's line is probably the most meaningful method because it looks directly at the foramen magnum and its relationship to the dens. However, this is often difficult to measure without tomograms.

Ranawat's method is the easiest measurement on routine screening roentgenograms, but in more severe cases of cranial settling, the cortical rings of the pedicles are not easily visualized. This method relies least on tomograms.

The major advantage of the ring/dens ratio is to allow the accurate comparison of measurements from plain roentgenograms to tomograms, and theorectically, from study to study. Like Ranawat's method, it is limited because it reflects only the relationship within the atlantoaxial complex. In most instances, this is not a major problem. However, judging the efficacy of traction, depends on the relationship between the foramen magnum and the atlantoaxial complex, and not just changes within the complex itself. In severe cases where the ring of the atlas has descended to the level of the body of the axis or below, the ring of the atlas and the axis may move in unison. Therefore, if one were to use only Ranawat's method or the ring/dens ratio, the true efficacy of traction in severe cases would be overlooked, and one would be unable to follow a patient's roentgenograms for evidence of progression. Although a subjective judgement of cranial settling can be made, some quantitative measurement is necessary for patient follow-up.

In those two patients with autoamputation of the upper half of the dens, as well as in those two patients who underwent transoral odontoidectomy, the ring/dens ratio and McGregor's and McRae's baselines are no longer viable methods of gauging cranial settling. In these rare instances, we need a means of measuring disease progression. We arbitrarily used the midbase of the body of the axis as our point of reference, and measured its perpendicular distance beneath (or above) either McGregor's or McRae's baseline (a "reverse" measurement). This was effective in monitoring the efficacy of traction as well as the postoperative progression of settling. No single method of measurement is universally applicable, and the method of measurement needs to be individualized.

Postoperatively, if the posterior ring of the atlas had been removed, the sagittal axis of the ring could change dramatically, thus significantly altering Ranawat's line and the ring/dens ratio measurements without an actual change in the degree of cranial settling.

The treatment goals in cranial settling (surgical or conservative) are pain alleviation, termination and possibly reversal of neurologic deterioration, and prevention of further anatomic deterioration. Our experience is similar to Ranawat et al.[18]. The posterior occiput to axis fusion successfully alleviated pain (85 per cent improved with no patient experiencing increased pain) and halted neurologic deterioration (46 per cent with improved neurologic status, 54 per cent unchanged, and no patient with neurologic deterioration). However, we are less successful at preventing further anatomic deterioration. Four patients (31 per cent) at follow-up were worse by roentgenographic measurements as compared to preoperative measurements; one of these patients underwent initial transoral odontoidectomy. Contrary to Brattstrom's observation that reduction during skull traction is insignificant or nonexistent[2], traction diminished the amount of settling in eight of our original fourteen patients (57 per cent), but less than half of them maintained any correction.

It is not entirely clear why deterioration occurred, although it may partly be due to postoperative immobilization. We have moved away from postoperative halo traction and halo vests with the use of intraoperative methylmethacrylate and have utilized four poster braces initially. This obviously places greater demands on the methylmethacrylate to maintain surgical correction prior to incorporation of the bony fusion mass. We are in agreement with Bryan et al.[3] that the methylmethacrylate should only act as an internal splint until the graft coalesces into a solid arthrodesis. Four poster braces may not be adequate enough support despite use of methylmethacrylate, especially in that patient who undergoes a combined anterior (transoral) and posterior procedure. Yet, if we return to halo vests and its associated problems in debilitated rheumatoid patients, one of the benefits gained from the use of methylmethacrylate is lost. However, methylmethacrylate may always be advantageous when the bone is porotic and additional internal support is needed.

Another possible cause for deterioration on roentgenogram is that we are correcting the settling problem with a posterior fusion when the destruction and bony erosions are more anterior. Thus, the lever arm is quite long from the fusion mass to the front of the skull.

Despite roentgenographic deterioration, no patient exhibited symptomatic or neurologic deterioration. This is consistent with the nonoperative experience, i.e. despite roentgenographic progression in 81 per cent of their patients, Pellicci et al.[15] noted only 36 per cent had neurologic progression. This may be due to a number of factors. Since most patients underwent surgical decompression (transoral odontoidectomy, excision of the posterior ring of the atlas, and/or posterior enlargement of the foramen magnum), this might explain the lack of neurologic or symptomatic deterioration, despite recurrence or progression of anatomic settling. This study is only a short term follow-up, and it is still unclear if these patients will deteriorate any further.

We agree that roentgenographic evidence of severe cranial settling may be present in a relatively asymptomatic patient[15,21]. However, neural Class III do not necessarily have severe cranial settling.

The surgical procedure itself, occiput to axis fusion with iliac crest or rib bone grafting and methylmethacrylate augmentation, is relatively safe. Our only postoperative death came at three months and occurred in a debilitated patient with multiple medical problems.

Atlantoaxial subluxation was significant (greater than 5.0 mm) in five of the fourteen operative patients (36 per cent) and in one of the nonoperative patients (8 per cent).

Pellicci et al.[15] observed that the development of cranial settling in a patient with preexisting atlantoaxial subluxation is a bad prognostic sign. Consistent with Matthews[10] and Weisman[22], our study demonstrates a decrease in atlantoaxial subluxation with progressive cranial settling. Subaxial subluxation was present in only one patient (7 per cent) in the surgical group, whereas it was present in eight patients (62 per cent) in the nonsurgical group. Rana et al.[16] noted subaxial subluxation in association with cranial settling in three of his eight patients (38 per cent). Moderate to severe dens erosions were more frequent in the surgical group. Rana identified dens erosions in five of his eight patients[16], and describes "hook" erosions along the posterior aspect of the dens at the level of the transverse ligament. The two patients with complete erosion of the upper half of the dens presented as neural Class III. Such severe erosions of the dens imply active, destructive disease and predictably these patients are at risk to develop significant neurologic syndromes.

V. CONCLUSIONS

Despite attempts to determine the natural history of cervical spine changes in rheumatoid patients[15,20], we were still unable to predict the development or progression of cervical changes. Surgery thus far has been reserved for those patients with severe symptoms or neurologic changes. Ideally, the day will come when we can accurately predict the progression of this disease and favorably intervene (surgically or nonsurgically) prior to clinical deterioration.

In summary, we conclude that:

1) The natural history of cervical spine changes is still unpredictable and therefore we recommend surgery only in those patients with functionally limiting pain or objective neurologic changes.

2) No one method of measuring cranial settling on roentgenograms is universally applicable. A combination of measurements is preferable and needs to be consistently applied to a given patient in order to accurately assess disease progression.

3) We offer a new method of measuring cranial settling which allows for the comparison of plain roentgenograms to tomograms. As with the other methods, it has its limitations.

4) Surgery predictably alleviates pain and stabilizes or improves neurologic status.

5) Surgery is safe.

6) Preoperative traction decreases pain and may also improve neurologic status.

7) Although correction of cranial settling in preoperative traction wasn't maintained, surgical decompression may explain the preservation of a successful result.

8) Patients with Type III erosions of the dens are at risk to develop severe neurologic syndromes.

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LONG TERM FOLLOW-UP OF EXCISION ARTHROPLASTIES OF THE HIP

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Introduction

In 1818 a British physician, Mr. Anthony White, first performed a femoral head and neck excision for septic hip arthritis in a nine year old boy[1]. The procedure, however, was popularized by another British physician, G.R. Girdlestone; Girdlestone first reported his technique in 1928 for treatment of hip tuberculosis. Fifteen years later he described the procedure in detail for treatment of hip sepsis[8]. His technique consisted of a transverse lateral approach with removal of a large wedge of the gluteus medius, minimus, and maximus including the greater trochanter. Removal of the femoral head and neck exposed the acetabulum. All acetubular cartilage and the superior rim of the acetabulum was removed. Occasionally a medial approach, excising a wedge of the adductors and pectineus and sparing the neurovascular structures, was used. Healing was by secondary intention[6]. "If the operation is well done relief from illness and distress is dramatic. The great gaping wound becomes a narrow scar"[8].

J.S. Batchelor, in 1948, described a two stage procedure which he felt was indicated for primary and secondary degenerative arthritis as well as septic arthritis. He performed a femoral head and neck resection through a Smith-Peterson approach followed by a subtrochanteric angulation osteotomy of the femur three to five weeks later. He stabilized this osteotomy with an eight hole, pre-bent Lane plate[2]. Milch, in 1955, combined this procedure into one stage using a Blount-Moore blade plate for fixation of the angulation osteotomy[20]. Milch concluded that 92 per cent of his patients had good pain relief and a high percentage had good functional results.

In 1950 Taylor published a series of 93 femoral head and neck resections through an anterior approach without subtrochanteric femoral osteotomy. Most patients had primary osteoarthritis, and 83 patients reported a good result with a remarkable degree of stability. His summary concluded, "The more formidable operation of cup arthroplasty may prove to be superior in younger patients with osteoarthritis".

As techniques for cup and hemi-arthroplasties became more refined, the excision arthroplasty with or without angulation osteotomy assumed the role of a salvage procedure. Additional papers published in the 1960's and early 1970's demonstrated femoral head and neck resection to be a predictable and satisfactory procedure for septic arthritis and unreconstructable hips[22,23,27]. Shepherd concluded from her data in 1960 that angulation osteotomy markedly increased rehabilitation time and did not provide consistent pain relief as did a simple femoral head and neck resection[27]. Murray et al. shared her opinion[22]. Murray et al. and Parr et al. also obtained good results without acetabular modification[22,23]. During the second decade of total hip arthroplasties, indications are being expanded to include younger patients, more difficult reconstructive problems, and previously infected total hip replacements. Some of these patients will need repeated revisions and may, because of lack of bone stock or infection, come to excision arthroplasty. Although antibiotic containing cement has improved exchange procedures, the failure rate is still between 20 and 30 per cent[3,5].

Studies of excision arthroplasties for infected hip replacements have shown variable results. Some authors feel the results in these patients are worse than in excision arthroplasties for other indications[19,20], but no study comparing the two groups has been reported. Our personal observation is that these patients function better than the results in the literature would indicate. This retrospective study investigates the following: results of excision arthroplasties done for various indications; the need to remove cement for healing to occur; the effects on drainage on function; leg length discrepancy and its relation to postoperative traction and function; the effects of trochanteric osteotomies and acetabular modification; and patient satisfaction.

Materials and Methods

From 1950 to 1983 at the University of Iowa Hospitals and Clinics, we saw and/or followed 49 patients who had an excision arthroplasty of the hip. An additional 14 patients were identified by Dr. Richard Johnston, a former staff orthopaedic surgeon at University of Iowa Hospitals whose practice in Des Moines, Iowa is limited largely to total hip arthroplasties. Of these 63 patients, 11 patients had died, 5 declined participation in the study, 5 were lost to follow-up, and 3 had been converted to total hip replacements with insufficient data for inclusion in the study. Data was therefore obtained from 39 patients by a combination of examination by the author (DAL) (24), chart review (15), phone conversation (15), and radiographs (36) (supine AP pelvis and true lateral of the involved hip). Five deceased patients had adequate records and relatives available for phone interviews; these cases were added to the 39. We collected data which included such physical characteristics as leg length discrepancy (measured from anterior superior iliac spine to medial malleolus), wound drainage, strength, motion, ambulation, radiographic features, and patient assessment. Data from phone interviews included history, work record, ambulation aides, function, pain, and satisfaction. All hips had an Iowa Hip Rating. The Iowa Hip Rating scale (IHR) provided an objective measurement of the patient's function[17]. The scale includes a 35 point function category, a 35 point pain category, and 10 point categories for gait, deformity, and motion.

The 44 patients with 46 excision arthroplasties were divided into two groups. Group A consisted of 27 patients (14 males and 13 females) with 29 excision arthroplasties after infected total hip replacements. Group B consisted of 17 patients (eight males and nine females) with 17 excision arthroplasties for all other causes.

Of the Group A patients, 14 had right, 11 had left, and two had bilateral excision arthroplasties. The average age at time of excision arthroplasty was 63.3 years with a range from 35 to 79 years. The average age at follow-up was 69.8 years with a range from 41 to 86 years. Follow-up averaged 68 months (5.7 years) with a range of one year to 12 years 4 months. The original diagnoses were primary osteoarthritis (16), post traumatic osteoarthritis (7), congenital dislocated hip (2), aseptic necrosis (1), rheumatoid arthritis (1), cerebral palsy (1), and septic arthritis (1). Eighteen patients had one prior surgery, three had two prior surgeries, six had three prior surgeries, and two had four prior surgeries.

The total hip components, infected tissues, and as much cement as possible were removed from all Group A patients. Operative time averaged 2.4 hours, and blood loss averaged 2300 cc's. Eleven greater trochanteric osteotomies were performed with reattachment and seven posterolateral femoral troughs were made to facilitate cement removal. Closure was primary in 26 hips and secondary in two patients. Cultures obtained at the time of surgery were positive in all patients. Thirteen cultures grew Staph. aureus, eight Staph. epidermidis, two alpha strep, one beta strep, one bacteroides sp., one proteus, and three were mixed infections (pseudomonas aeruginosa and alpha strep, Klebsiella pneumonia and peptostreptococcus, and Staph. epidermidis, and peptostreptococcus). All were treated with appropriate antibiotics for periods ranging from one month to two years. Postoperative skeletal traction was used in five hips for three to eight weeks (average 5.8 weeks), balanced suspension was used in 12 hips for two to three weeks (average 2.3 weeks), and Buck's traction was used in 12 hips for short duration (two to five days). Physical therapy after traction included progressive ambulation, weight bearing, range of motion, and strengthening exercises. Time spent in therapy ranged from five days to one month with an average of 2.2 weeks.

Group B, with five excision arthroplasties on the right and 12 on the left, had an average age at time of resection of 50.5 years with a range from 12 to 75 years. The average age at follow-up was 62.2 years with a range from 39 to 87 years. Follow-up averaged 142 months (11.8 years) with a range from one to 63 years. Eight patients originally had femoral neck or head fractures, three had septic degenerative joint disease, two had hip dislocations with subsequent aseptic necrosis, and one each had rheumatoid arthritis with protrusio acetabuli, primary osteoarthritis, arthrogryposis, and acetabular fracture with secondary osteoarthritis. Four patients had primary excision arthroplasties, four had one prior surgery, seven had two prior surgeries, one had four prior surgeries, and one had five prior surgeries.

At the time of excision arthroplasty all implants, hardware, and/or infected tissue were removed. Operative time averaged two hours (11 patients), and estimated blood loss averaged 1000 milliters. A trochanteric osteotomy with reattachment was performed in one patient. Closure was primary in 15 patients and secondary in two. Cultures obtained at surgery grew nothing in seven patients, Staph. aureus in six, pseudomonas aeroginosa in one, TB in one, and mixed Staph. aureus and Staph. epidermidis in one. One patient was treated for septic arthritis as a child and the culture results are unknown. Use of appropriate antibiotics in those patients with positive cultures ranged from the perioperative period to six months. One patient has received several courses of antibiotics over the years for recurrent flares of infection. Postoperative Buck's traction was used for a short duration in 12 hips, skeletal traction for three months in one hip, and hip spica casts in two patients (one for three months and one for six months). Physical therapy after traction included range of motion and strengthening exercises followed by weight bearing. Time spent in therapy ranged from one to three weeks with an average of 12 days.

Results

Group A contained a range of IHR's from 55-90 with an average of 74. The two patients with bilateral excision arthroplasties had an average IHR of 63. Excluding these four hips and the hips of four other patients who stated they were limited by other medical problems, the average IHR for the group was 78. The IHR's in the following sections will also exclude these patients. The range in the function category of the IHR was 13-35 with an average of 25.9. The range in the pain category was 10-35 with an average of 28.9. The averages of the gait, deformity, and motion categories were 5.2, 8, and 5.8, respectively.

The six patients younger than 60 years of age at excision arthroplasty have IHR's of 79. Six patients were older than 70 years of age and their average IHR was 75. The higher rating for younger patients is not statistically significant.

Group B contained a range of IHR's from 55-86 with an average of 73. Four patients were limited by medical problems other than their excision arthroplasty. Excluding these four patients the average IHR was 76.5. Sectional breakdown of the IHR's for Group B will also exclude these patients. The function category range was 10-35 with an average of 25. The pain category range was 20-35 with an average of 28. The gait, deformity, and motion categories averages were 5.3, 7.9, and 6.2, respectively. Two patients had an excision arthroplasty as a primary procedure. Their average IHR was 78.5; the average IHR of the 11 patients with secondary excision arthroplasties was 76. The numbers are too small for statistical correlation. Four patients were less than 50 years of age at the time of excision arthroplasty. Their average IHR was 81.5. Six patients were greater than 60 and had an average IHR of 78.5. Three patients were less than 50 at the time of follow-up and their average IHR was 84. Five patients were older than 70 and their average IHR was 75. These figures suggest that younger patients may function better.

Physical Characteristics

Heights and weights were obtained on 22 patients in Group A and 13 patients in Group B. Nine patients (41%) in Group A and seven patients (54%) in Group B were significantly overweight according to actuary tables. The IHR average for the overweight patients in Group A was 74 compared to 80 in other patients. In Group B the IHR's were 71 and 79, respectively.

Deformity

In Group A, the leg length discrepancy ranged from 2-11 cm with an average of 5.7 cm. Shoe lifts were prescribed for all 25 patients with unilateral excision arthroplasties and averaged 3.8 cm. Three patients chose not to wear the prescribed lift even though their limb discrepancies were 7, 5, and 2 cm. The average discrepancy for those treated in traction was 5.5 cm, for those in balanced suspension 4.7 cm and for those in Buck's traction 5.9 cm. The differences are not statistically significant. The IHR for seven patients with less than a 5 cm discrepancy was 78.6. The IHR for seven patients with more than 5 cm was 79.3. The difference is not significant.

In Group B leg length discrepancy ranged from 2.5-13 cm with an average of 5.7 cm. The patient with the 13 cm discrepancy had septic arthritis as a child and subsequent destruction of the proximal femoral epiphysis. Excluding her, the average was 5.3. Shoe lifts averaged 4.4 cm and two people with discrepancies of 5.4 and 2.5 cm chose not to wear shoe lifts. The IHR of five patients with less than a 5 cm discrepancy was 78. The eight patients with a 5 cm discrepancy or greater had an IHR of 75.5. The difference is not significant.

Drainage

Twenty-eight of 29 hips in Group A were healed at the time of follow-up. Twenty-six hips were closed primarily and 25 healed uneventfully. One patient required repeat debridement 19 months after excision arthroplasty to stop the drainage. Two patients were closed secondarily five months and 15 months after operation. One patient in Group A had a small amount of serous drainage daily. He, however, had an unlimited range of walking and an IHR of 84.

Fifteen of 17 hips in Group B were closed primarily and healed without difficulty. One hip was closed secondarily (interval unknown). One patient in Group B reported drainage one to two times per year and has required five debridements and numerous courses of antibiotics over the years. His wound was closed secondarily. His IHR is 73.

Strength

In Group A, 13 patients were tested and all could flex their hip against gravity and all but one could abduct their hip against gravity. However, only six patients could flex and seven patients could abduct their hip against minimal resistance. No patient had normal strength and all 29 hips had a positive Trendelenburg test.

In Group B of the 14 patients tested all could flex and abduct their hip against gravity. Ten patients could flex and seven patients could abduct their hips against resistance. Four patients had normal or close to normal strength about the hip. Only one patient, a 39 year old male, had a negative Trendelenburg test. Weakness or instability of the hip was a common complaint especially in Group A patients.

Ambulation

All 44 patients could ambulate after surgery. Of the 25 patients in Group A for which information was available, four patients are household ambulators and seven patients walk unlimited distances. The other 14 patients average 2.9 blocks. One patient with a bilateral excision arthroplasty is a household ambulator and the other is limited to one block. One patient uses no ambulation aides, two use one cane, three use two canes, five use two crutches, seven use walkers, and seven use a combination of crutches, canes, or walkers. Only the household ambulators owned wheelchairs. One patient was limited to household ambulation because of a stroke and left sided hemiparesis. One patient ambulated with a swing through gait, and all other patients ambulated with an abductor gait.

Of the 16 patients in Group B for which information is available, two patients are household ambulators, and four patients walk unlimited distances. The other ten patients average 2.5 blocks. One household ambulator is limited by severe spinal stenosis and contralateral hip osteoarthritis, and the other is limited by severe RA, having had a contralateral total hip replacement and bilateral total knee replacements. Two patients use no ambulation aides, three patients use one cane, one patient uses two canes, three patients use crutches, three patients use walkers, and four patients use a combination of aides. One patient uses a motorized cart regularly, and the patient with severe RA uses a wheelchair regularly. The two patients who ambulated without aides had mild short leg limps, and all other patients had abductor lurches.

Motion

All patients in Group A felt they had a satisfactory hip range of motion. This motion was measured in 18 patients. Four patients had flexion contractures averaging 9° with a range of 5-10°. Three patients had external rotation contractures averaging 20° with a range of 5-45°. Flexion averaged 82.5°, abduction 27.2°, adduction 14.2°, internal rotation 23°, and external rotation 37.8°.

All Group B patients felt they had a satisfactory range of motion. Five patients had flexion contractures averaging 12° with a range of 5-20°. Three patients had external rotation contractures averaging 15° with a range of 5-20°. Flexion averaged 86°, abduction 32°, adduction 18°, internal rotation 22° and external rotation 39°.

Hip telescoping was difficult to evaluate especially in the overweight patients. Four patients in Group A and three patients in Group B were definitely felt to telescope. This was not painful. IHR's for these patients were equal to the group's average.

Radiographic Findings

In Group A, 27 of 29 hips had AP pelvis and true lateral films available. Twenty patients had an oblique intertrochanteric level of resection (IHR-76), three patients had a transverse intertrochanteric level, one patient had an oblique base of femoral neck level (IHR-84), and three patients had a transverse resection at the level of the lesser trochanter (IHR-80).

The femoral resection surface was smooth in 15 hips (IHR-85) and irregular in 12 hips (IHR-76) suggesting that patients with a smooth femoral surface osteotomy may do better than those with an irregular surface. All femurs were out of the acetabulum and no acetabular modification was documented in the operative reports or present on radiograph. Two patients appeared to have formed a secondary acetabulum; the other 25 had no bone to bone contact. No evidence of active osteomyelitis existed.

Nine femurs had no cement present, seven had a small amount, five had a moderate amount, and six had a large amount. Fourteen acetabuli had no cement present, seven had a small amount, three had a moderate amount, and three had a large amount. In addition, nine hips had wire present, and two hips had screws present. The patient with active drainage had a large amount of femoral cement and a moderate amount of acetabular cement.

Thirteen hips had had trochanteric osteotomies with reattachment during the procedure (IHR-80) and 12 hips had not had trochanteric osteotomies (IHR-74). Trochanteric nonunions were present in two patients (IHR-76) and the greater trochanter was absent in five patients (IHR-80). This suggests a trend that patients may do better with a trochanteric osteotomy and reattachment.

The distance between the most proximal aspect of the femur and the base of the tear drop was used to determine the degree of proximal femoral migration. On the supine pelvis film the range was 4.3-13.3 cm with an average being 8.6 cm. The average distance was 6.6 cm in four patients treated with skeletal traction, 8.2 cm in 12 patients treated in balanced suspension and 9.0 cm in 12 patients treated with postoperative Buck's traction. The average IHR for ten patients treated in Buck's traction was 78, and for nine patients treated in balanced suspension the average IHR was 79 — an insignificant difference. For those patients treated in skeletal traction, insufficient data was available for comparison. The IHR for ten patients with a distance of 8.5 cm or less was 76.5 and for nine patients with a distance greater than 8.5 the IHR was 78. Six patients with a distance less than 7.5 cm had an IHR of 77. Seven patients with a difference of more than 9 cm also had an IHR of 77. These figures show that the distances between the proximal femur and tear drop have no predictive value.

Sixteen Group B patients had supine AP pelvis and lateral hip films. Twelve of these patients had an oblique intertrochanteric level of resection (IHR-76), two had a transverse through the lesser trochanter (IHR-74.5), one patient each had a subtrochanteric level resection and a base of the neck level resection. The difference between the groups is insignificant.

The femoral resection surface was smooth in seven patients (IHR-77) and was irregular in nine patients (IHR-76). There was no acetabular modification evident on x-ray or described in the operative notes on any patient. One femur was in the acetabulum and had a uniform cartilage shadow. His IHR was 68 with only fatigue pain but was limited in function by arthritis in his other hip. One hip had formed a secondary acetabulum and the other 15 femurs were out of the acetabulum without bony contact. The patients had no signs of osteomyelitis.

Eleven femurs and 13 acetabuli had no foreign material present, three femurs and one acetabulum had a large amount of cement, one femur and one acetabulum had a moderate amount of cement, and one femur and one acetabulum had a small amount of cement. The only patient with wound drainage had no foreign material.

One patient had a healed reattached trochanteric osteotomy, one patient had no greater trochanter present, and the other 14 patients had not had a trochanteric osteotomy.

On the supine pelvis film, the distance from proximal femur to tear drop ranged from 5.8-10.5 cm with an average of 8.7 cm. The IHR of five patients with the distance 8.5 cm or less was 75 and for seven patients with a distance greater than 8.5 cm the IHR was 77. The IHR of three patients with a distance of less than 7.5 cm was 78. The IHR of six patients with a distance of more than 9 cm was 77. These differences are not significant.

Patients' Assessment

During the interview, each patient was asked to compare their overall status prior to their initial procedure to their status at the time of interview. They were also asked if they felt their function improved over time after the exclusion arthroplasty, if they would have the excision arthroplasty done again, if they were satisfied with their current status, and if they would accept another surgical procedure with a 70 to 80 per cent chance of success.

In Group A, 16 patients (59 per cent) felt they were better now than before their total hip replacement. Eight patients were worse, and three were unchanged. The preoperative total hip replacement IHR was available for 11 patients with an average of 50. After excision arthroplasty, the average IHR for the same 11 patients was 79 which is similar to the whole group's average. This is a marked difference.

Nineteen patients (73 per cent) were satisfied with the result of the surgery. Eight of 19 did not like the ambulation aides. Seven patients were not satisfied. Of these seven patients, three stated they were better than their preoperative status, one patient was the same, and three patients were worse. The IHR of the satisfied patients was 81 and of the unsatisfied patients was 67.

Twenty-three patients (92 per cent) would have the excision arthroplasty again. Sixteen patients (64 per cent) desired no further surgery. Three patients had undergone total hip reconstruction, and six said they would accept total hip reconstructive surgery if offered.

Nine (56 per cent) patients in Group B felt they were better following the excision arthroplasty. Six patients were worse, but all six patients had suffered hip fractures and had previously been unlimited in their activity. One patient was unchanged. Five patients improved with time, six stayed the same, and five patients' function worsened over time.

Twelve patients (75 per cent) were satisfied with the result. Four patients were not satisfied. One of these patients, however, was still better than his preoperative status. The average IHR for eight of the satisfied patients was 77, and the average IHR for four unsatisfied patients was 74.

Fifteen patients would have the surgery again and none declined. Ten patients (63 per cent) declined further surgery, two had total hip surgery, and four patients would have total hip surgery if offered.

Most of the women in each group were homemakers before their excision arthroplasty and they all returned to this after surgery. Of the 12 men working prior to surgery, ten returned to the same job after the surgery.

DISCUSSION

This is a retrospective study and therefore has inherent faults. We do not have complete data base on all 44 patients, and some of the data had been collected by other physicians. We have followed 46 of the 63 hips (73 per cent) available but still may have a sampling error. We did not have controls. We did not statistically analyze the data because of the small numbers and the study's retrospective nature. However, the results do suggest trends and allow us to answer the questions we proposed.

The data from the two groups in the study was remarkably similar for all parameters. The average IHR for Groups A and B was 78 and 76.5, respectively. Both had good ratings for pain relief; 29 out of 35 points. Parr et al. reported an average IHR of 70 in his series[23], and Petty et al. reported an average IHR of 49[24]. Most of the studies have shown that excision arthroplasty provides good pain relief in 80 to 90 per cent of the patients[1,2,6,10,18,19,22,23,29]. Petty et al., however, reported that 16 of 21 patients had moderate to severe pain with sitting or weight bearing following excision arthroplasty for infected total hips[24]. We have no explanation for this apparent discrepancy.

Ahlgren et al., Haw et al., and Murray et al. also reported good functional results[1,20,22] consistent with our findings. McElwaine et al. and Petty reported poor functional results[19,24]. Our results indicate at least 50 per cent of the patients improved from their preoperative status. Of the eleven preoperative total hip replacement IHR's available (average IHR 50), all 11 improved (average IHR 79). This is a significant difference. Our data suggested that younger patients, both at the time of excision arthroplasty and at the time of the follow-up, function better than older patients. Haw and Kuesswetter[10,16] support this opinion.

The majority in each group required ambulation aides. Most patients could walk unlimited distances, a few were household ambulators only. Only two patients used wheelchairs frequently. This is in accordance with most other studies in the literature[1,6,7,10,22,23,29]. However, Petty reported that use of wheelchairs was common[24], and McElwaine reported that 12 of the 24 patients "were either bedridden or were restricted to walking a few yards indoors"[19].

The leg length discrepancy averaged 5.7 cm in both groups. Leg length discrepancy did not correlate with IHR. The type of postoperative traction did not seem to affect the leg length discrepancy though the number of patients treated in skeletal traction was small. Three authors stated similar views[7,10,23]. Several of the other authors recommended the use of skeletal traction for three to six weeks, but did not relate traction to leg length discrepancy nor did they relate leg length discrepancy to function[1,19,22,24]. Leg length discrepancies ranged from 3.5 to 7 cm in these studies.

In infected hips, excision arthroplasty proved to be effective in all but two patients. The presence of cement or other foreign material did not seem to affect healing. The two patients with drainage had fatigue pain only and IHR's of 73 and 84. Only Petty reported a significant number of patients with active drainage at time of follow-up (five of 21) with an average IHR of 29[24]. According to Clegg, complete cement removal was essential for healing,[6], but several authors have refuted this statement[1,3,19,24]; we also disagree. While we do believe that most of the cement should be removed, extraordinary measures (prolonged operating times, femoral windows, etc.) to remove all cement are unnecessary.

All patients had quite functional range of motion without significant contractures. Strength was fair in abduction and flexion with a positive trendelenburg test in all but one patient. As might be expected, the younger patients tended to be stronger. Almost all patients walked with some degree of abductor lurch. Most authors reported similar findings[1,16,18,22,23] though Clegg, Haw, and McElwaine reported a much higher proportion of fixed contractions and decreased range of motion[6,10,19].

The IHR did not vary depending upon the level of femoral resection. Our data suggest that patients with smooth femoral resection surfaces and united trochanteric osteotomies have better results. Petty agrees[24], but his statistics are not significant. The two other studies note no correlation between x-ray findings and function[10,18]. No acetabular modification was done in any of our patients. Several authors advocate acetabular modification[2,6,8,9,18,20,27,29], and other authors believe it is unnecessary[10,16,22,23], but no one has supported their opinions with statistical data. The IHR was not related to proximal femur to the base of the tear drop distance. Similar findings were noted by Eftekhar though he measured the relationship of the lesser trochanter to the tear drop.

Seventy-five per cent of the patients were satisfied with the overall results of their excision arthroplasty, though several stated they did not like using ambulation aides. Greater than 90 per cent of the patients stated they would have an excision arthroplasty done again if needed. Sixty-six per cent of the patients would not accept any further surgery on their hip. The bulk of the literature reports good patient satisfaction with excision arthroplasty—ranging between 75 and 100 per cent. McElwaine and Petty et al. report poor patient satisfaction in most of their patients[19,24].

We concluded that resection arthroplasty following an infected total hip replacement, unreconstructable hips, and septic arthritis offers very good relief of pain. Most patients are satisfied and function adequately in activities of daily living. Younger patients with excision arthroplasties probably function better than do older patients. Though most patients need ambulation aides most of those working prior to excision arthroplasty returned to their previous occupation. We feel postoperative Buck's traction for comfort is sufficient as leg length discrepancy did not appear to be significantly affected by the type of postoperative traction nor did leg length discrepancy seem to be related to the result. A smooth femoral osteotomy should be made, and acetabular modification is probably unnecessary. A healed trochanteric osteotomy may improve function. Infected patients appear to heal their wounds and clear the infection regardless of the amount of cement or other foreign bodies.

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GUNSHOT WOUNDS-
HISTORICAL PERSPECTIVES

Nina Njus*

Billroth published a series of articles in the *Yale Journal of Biology and Medicine* in 1921-31 entitled "Historical Studies on the Nature and Treatment of Gunshot Wounds from the Fifteenth Century to the Present Time". In his introductory remarks he stated that ". . . notwithstanding the efficiency of modern medical teaching, an acquaintance with ancient authors will always maintain a place in the mind of the cultivated. It is so natural for the scientifically curious to inquire into the development of this or that newly observed fact that everyone should have some acquaintance with the history of his art or science, particularly in this age of education. Such an interest is seldom found, perhaps because it is too little encouraged, or possibly because modern medicine, by insisting on research by those who aspire to positions of leadership, lays too much weight on productive ability. It is possible that the younger generation is somewhat blinded by the concentrated beams of pathological anatomy as seen through the microscope, and may have difficulty in seeing the problems of practice clearly." With this in mind, I would like to address the nature and treatment of gunshot wounds from a historical perspective.

In 1242, Sir Roger Bacon first described an explosive mixture of saltpeter, charcoal and sulfur used to hurl a projectile from a gun. Previously described mixtures, such as those used in China in fireworks and rockets, were not explosive enough to use in firearms. These early powders were quite labile and dangerous to handle; the early literature contains several case reports of injury to the user. More than a century passed before artillery played a deciding role in the outcome of a battle during the War of Roses in 1400. Previously artillery had been employed during sieges only; it was not mobile enough to be useful in the open field.

Psolspeundt, a German war surgeon, first mentioned gunshot wounds in the literature. His picture of the "Wounded Man" (Fig. 1) illustrates the more common war injuries of his time; the gunshot wound is conspicuously absent. It is mentioned only briefly in the text where he recommends the use of a sound in extraction of bullets and bone splinters.

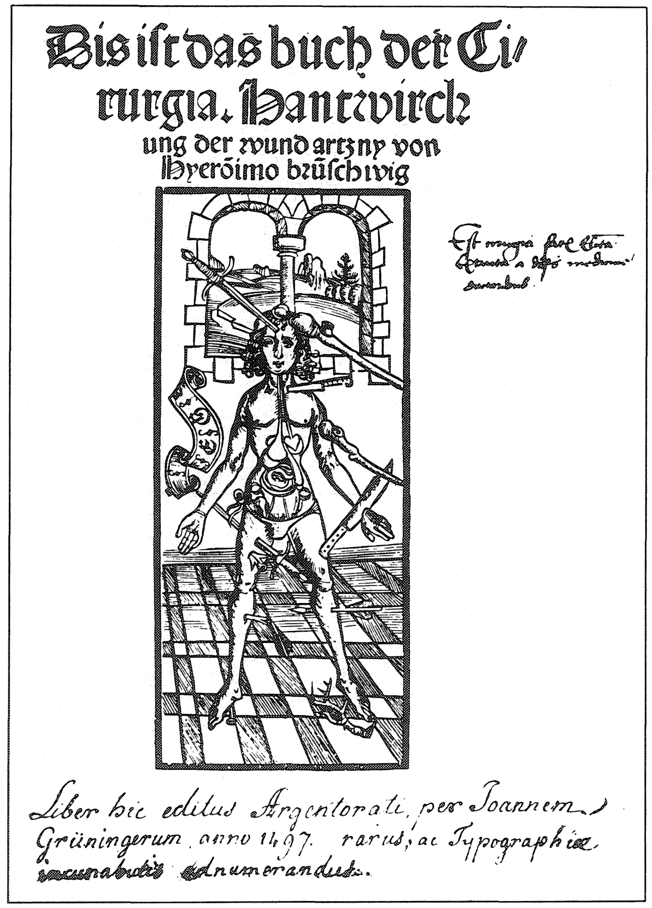

Fig. 1: Psolspeundt's "Wounded Man". No gunshot wounds are apparent.

As gunshot wounds became more prevalent they received more attention in the surgical literature. Brunschwig, a German surgeon from Strassburg, included the artillery wound in his version of the wounded man published in 1497. As he illustrated (Fig. 2), most weapons were of the cutting type and caused wounds which were either fatal or healed rapidly. Gunfire created lacerating, contusing, and penetrating wounds and carried infectious material into the wound, leading to suppuration in nearly all cases. This led to the belief by Brunschwig and others that wounds resulting from gunfire were poisoned. He described the treatment of gunshot wounds in the following manner: "Take a seton, push it through the wound,

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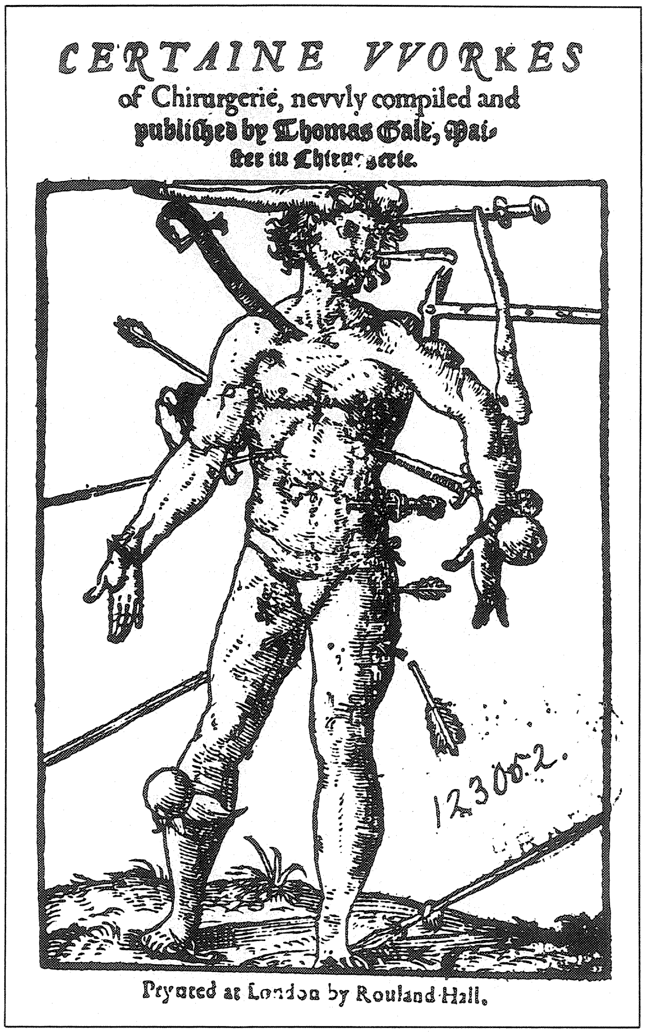

Fig. 2: Brunschwig's wounded man including two injuries caused by cannon.

and pull back and forth to force the powder out. The wound will then not suppurate. You may then insert a lint plug moistened with bacon or lubricated with ox grease . . . Next heal the wound with a good greased patched, or use equal parts of oil of rose and turpentine with a fifth part of powdered camphor . . . In case a man has been shot with a gun and the bullet remains in the body, widen the wound by packing or cut as described in the part on removing arrows. If possible, you should have bullet-forceps and should explore the wound with them neatly and cleverly. If it is possible, it (the bullet) may be drawn out . . ." This method of wound enlargement by compression packing, where a dry material was inserted into the wound and allowed to swell and enlarge in the wound, was employed to avoid hemorrhage. Vascular anatomy and the concept of blood flow to and from the heart was unknown at the time, hence tourniquets were not employed. Brunschwig designed several instruments for extracting bullets, including the stork bill and raven bill forceps. Additional surgical instruments such as the borer, the loosener and the twister were advocated for the removal of bullets (Fig. 3).

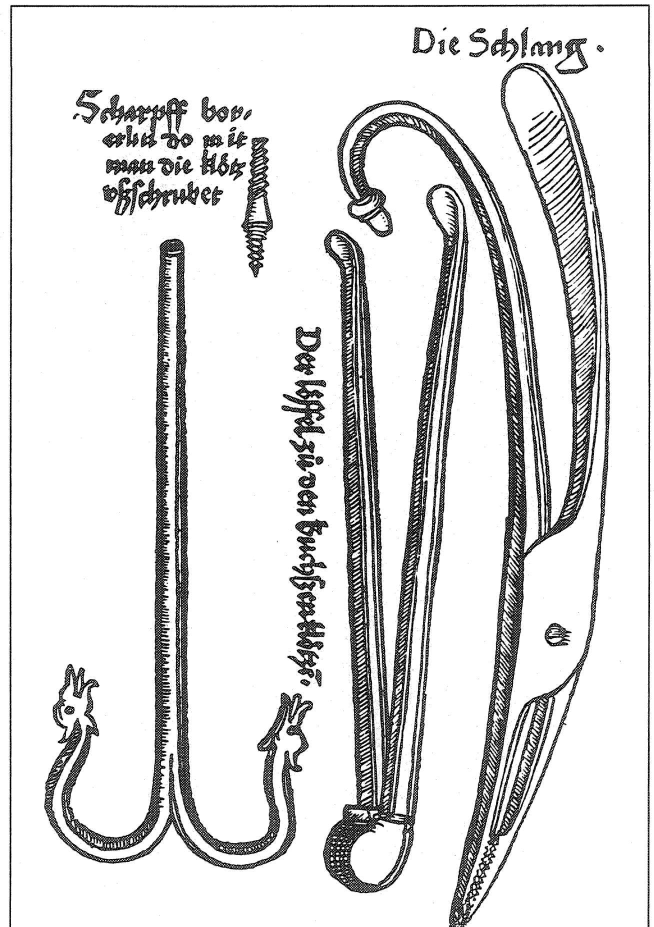

FIG. VI. FROM GERSSDORFF. THE "BORER", THE "LOOSENER" AND THE "TWISTER" (FROM LEFT TO RIGHT).

Fig. 3: From Brunschwig, the "borer", the "loosener" and the "twister".

Alfonso Ferrio wrote the first definitive Italian work on gunshot wounds in 1552. He designed the "Alphonsium" for the extraction of bullets, used ligature to control bleeding, advocated the use of the finger rather than the sound for probing wounds, and felt that not all bullets required removal. For treatment of open wounds near joints he recommended immobilization, warm oil and vinegar baths, massage and slow active range of motion exercises within the limits of pain tolerance (not so different from some modern regimens).

At the same time, Pare, the greatest surgeon of the 16th Century, was practicing in France. Pare learned most of what he knew from reading or personal observation, and generally followed the recommendations of his predecessors, cauterizing wounds with hot oil. In his journal he stated that ". . . at last my supply of oil ran out and I was obliged to use in its place a digestive made of yolk of eggs, oil of roses, and turpentine. That night I could not sleep well, thinking that I might find the wounded, who had been deprived of the oil, dead from poisoning through the lack of proper cauterization. It made me get up very early to go to see them. Beyond all my hopes, I found that those who had received the application of the digestive on their wounds, were feeling little pain, they were without inflammation or swelling, and they had rested quite well during the night. The others, to whom application of the oil had been made, I found having a fever, with great suffering, and with swelling and inflammation around the wounds." Pare took this as proof that gunshot wounds were neither poisoned nor burned, only crushed. He significantly advanced the treatment of these wounds by advocating the immediate debridement of foreign bodies, creation of an exit wound, where necessary, and closure of wounds after the operation. Routine use of ligatures, and loose packing of open wounds with non-caustic compressive dressings were other Pare innovations.

Clowes compiled a text on the treatment of gunshot wounds for the young surgeon, including detailed accounts of the nature of the injury as well as its treatment. He included illustrations of the essential surgical instruments to be carried into the field during war (Fig. 4).

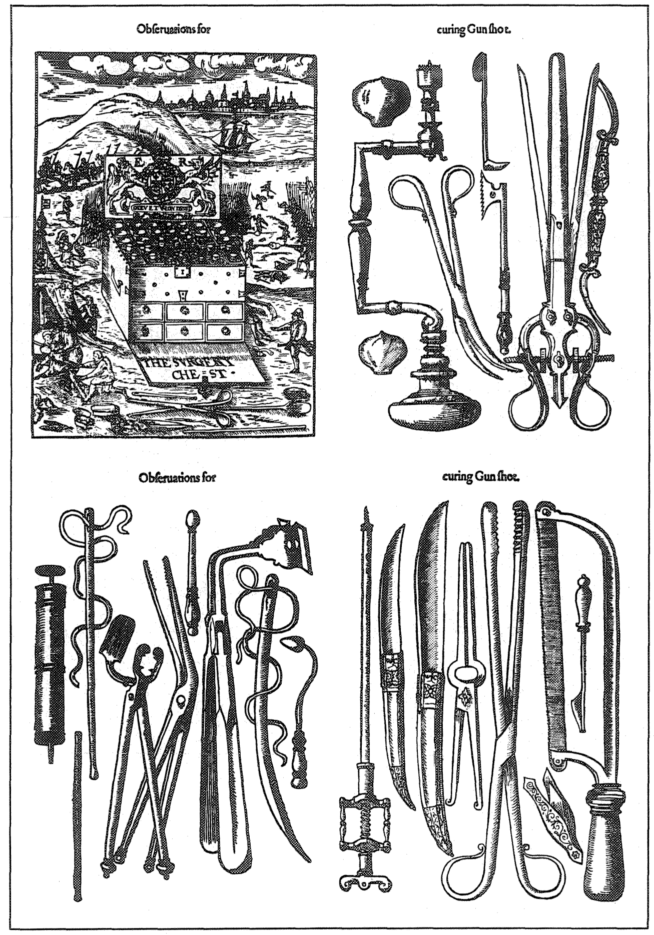

Fig. 4: Clowes' surgeons chest and medical instruments.

Heister, the father of Scientific Surgery in Germany, published the first descriptions of the tourniquet for the control of bleeding in 1718. This device allowed surgeons to control life-threatening bleeding both on and off the battlefield for the first time.

During the 1700's surgeons became concerned with the mechanism of injury and resulting wounds created by gunfire. Henry Le Dran noted that exit wounds were often larger than those of entry. To explain severe crushing injuries seen with gunshot wounds, the air theory (trauma caused by an air concussion with or without a break in the skin) developed and gained popularity. John Hunter, the father of English surgery, noted the effects of missile velocity on the severity of the resultant wound and established guidelines for the surgical enlargement of wounds associated with uncontrollable hemorrhage, head injuries, bone fragments or foreign bodies, punctured viscera, or pressure on vital organs.

Notable improvements in the care of casualties occurred in 1780 when Percy, the Inspector General of Medical Services for the French army during the Napoleonic Wars, instituted a corps of stretcher-bearers who removed the wounded from the battlefield during, rather than after the battle. In 1812, this was taken a step farther by Larrey, one of the greatest military surgeons of all times. He, while serving in the French Revolutionary and Napoleonic Wars, organized the medical services so that the surgeon followed the advance guard and attended to wounded in the field. Casualties were then taken to temporary hospitals via Larrey's "flying ambulances" and later evacuated to permanent hospitals (Fig. 5).

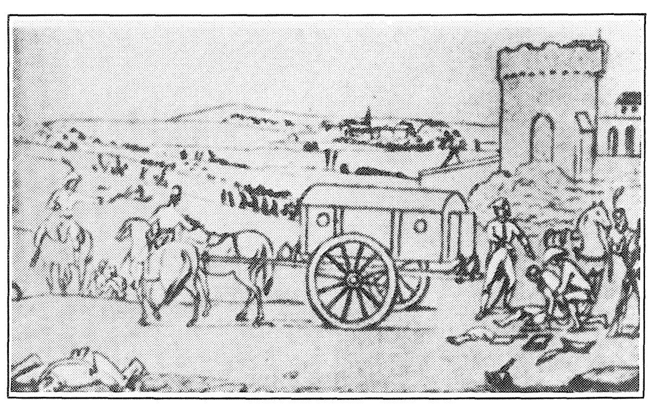

Fig. 5: Larrey's "Flying Ambulance".

The question of early versus delayed amputation for gunshot wounds was approached in a systematic fashion for the first time by John Thompson in 1816. He outlined those cases in which amputation should always be performed as follows: 1) if a limb had been shot away; 2) if cannon-balls had caused considerable degree of damage to bones or joints; 3) if large amounts of soft tissue had been avulsed, with consequent injury to nerves and vessels; 4) if a bone had been broken by a flattened bullet without breaking the skin, but with soft tissue destruction; 5) if a musket bullet had penetrated a main artery and broken the bone at the same time; 6) if a musket bullet had passed through a joint, destroyed the articular surface and severed tendons.

Perhaps the most important advancement in the treatment of gunshot wounds occurred in 1867 when Lister, guided by the work of Louis Pasteur, published two papers in Lancet: "On a New Method of Treating Compound Fracture, Abscesses, etc., with Observations on the Condition of Suppuration" and "On the Antiseptic Principle in the Practice of Surgery". Lister, by practicing antisepsis, lowered the mortality rate following elective amputation from 43 per cent, considered excellent at the time, to 15 per cent.

The next fifty years brought the advent of steam sterilization, rubber gloves, masks, X-rays, and reliable anesthetics. These advances allowed the surgeon to perform painless controlled operations rather than the slight of hand art and led to the first attempts to prevent infection of open fractures and gunshot wounds during World War I. Military surgeons in World War I initially practiced the Carrell-Dakin method of wound care (a spin-off of the Listerian school). This consisted of daily wound irrigation with antiseptic chlorinated solutions. This method was superseded by the Orr technique during the later half of the war.

Winnett Orr, after his experience with the Medical Corps of the American Expeditionary Forces in France, arrived at the conclusion that many of the infections in open fractures were due to repeated redressing of wounds communicating with bone. He later documented this in his civilian practice in Nebraska. He also objected to the introduction of irritating chlorinated solutions and the inadequate immobilization of the parts in the Carrell-Dakin method. He developed what became known as the "Orr technique" of wound treatment — consisting of thorough surgical debridement, subsequent packing of the wound with vaseline gauze and encasement of the injured limb in a plaster of Paris bandage. The bandage remained in place for long periods and was changed only when the offensive odor made change imperative. Wounds healed with granulation formed from the bottom up. Trueta, during the Spanish Civil War (1935-38) added topical and oral sulfonamides to the Orr closed plaster technique. Orr's technique remained the method of choice in the treatment of open wounds through World War I until the outbreak of World War II.

During World War II the U.S. military, through the office of the Surgeon General, initiated basic research into the mechanism of wounding and wound ballistics; this was made possible by the development of high speed cinematography and roentgenographic techniques. The major investigation included determination of the factors involved in wound formation and missile characteristics such as its mass, velocity, shape, momentum, energy, and power. They also studied the nature of the trauma damage, whether it results from stretching and displacement or from pressure changes accompanying the shot. While these studies acknowledged that such information would greatly aid the surgeon in his treatment of wounds, their primary purpose was to predict the offensive effectiveness of various weapons. The authors attempted to predict the degree of incapacitation resulting from a hit by a missile of mass (M), moving at a velocity (V). The phenomenon observed in soft tissue wounding was fundamentally like the phenomenon which occur when a high-velocity missile enters a liquid; thus the subject was treated as a branch of underwater ballistics.

Kinetic energy is computed through the formula $\frac{1}{2} MV^2$. Because kinetic energy varies with the square of the velocity, velocity has a much greater effect than mass on the kinetic energy. Velocity is subdivided into the initial or muzzle velocity, the impact velocity, and the remaining velocity, or velocity of the missile on exit from the target. Traditionally, wounds are classified according to their initial velocity into low (velocity $<$1200 fps.), medium (velocity 1200 to 2500 fps.), and high (velocity $>$2500 fps.) velocity injuries. The resultant wounds were studied as physical entities. When a bullet enters tissues there are two immediate effects, the cutting of a permanent cavity along its tract and the initiation of severe shock waves. These emanate from the missile at the velocity of sound in tissues. As the bullet passes through the tissue, considerable radial motion is imparted to the tissue elements and a large temporary cavity is formed. Microsecond x-rays and high speed motion picture studies showed the formation of a temporary cavity with a volume nearly twenty-seven times larger than the permanent cavity. Histological studies demonstrated an area of extravasation of blood around the permanent cavity about twelve times that of the permanent cavity (Fig. 6). Thus by noting the size of the hemorrhagic zone around an entry wound the approximate area of the temporary cavity can be estimated. Having demonstrated through survival studies that the hemorrhagic tissue would regenerate if kept clean, military surgeons recommended early adequate debridement of this tissue on the battlefield. Wounded were initially attended to by aidmen, then transferred to clearing stations where

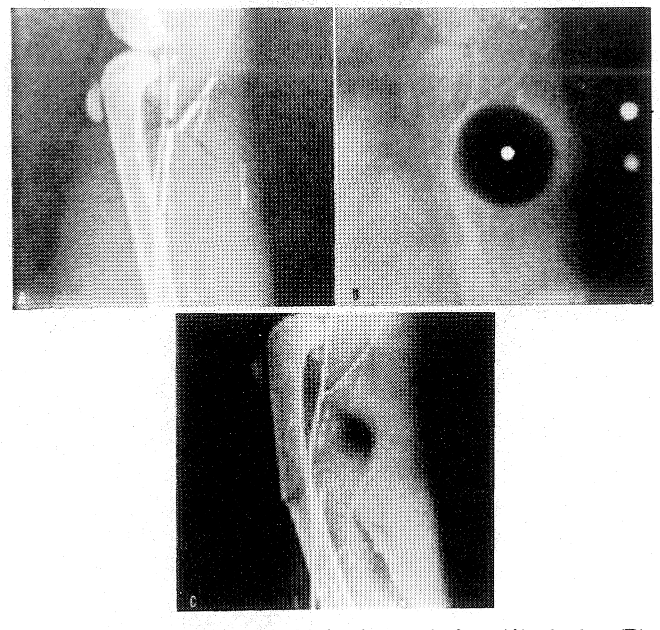

Fig. 6: Radiograph of the thigh of a cat before (A), during (B), and after (C) a high velocity missile has passed through. The femoral artery has been injected with barium.

superficial wounds were treated and patients with more serious wounds were stabilized for transport to Evacuation Hospitals. To save time patients with life-threatening injuries were often transported directly to Evacuation Hospitals where major surgery was performed by qualified specialists. Plasma and blood were administered in large quantities to control shock. The total mortality rate among treated wounded was about 4 per cent. Death was due primarily to uncontrollable hemorrhage. The discovery of penicillin during World War II reduced the rate of chronic osteomyelitis from 80 per cent in World War I to 25 per cent. Open fractures were treated with primary debridement and closure, skin grafting, or further surgical debridement in an attempt to convert open to closed fractures as rapidly as possible. Also at this time, the first platings of open fractures were performed to obtain early stabilization and facilitate wound care.

During the Vietnam War the primary advance in the treatment of gunshot wounds was in the area of vascular reconstruction, allowing limb salvage where it had previously been impossible. Recent literature on the subject has concentrated on the treatment of the more common low velocity wounds seen in civilian practice, as opposed to the high velocity military injuries.

Finally, to quote Billroth once more, "Only the man who is familiar with the past of his art is competent to aid in its progress in the future."

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PATELLAR STRAIN IN THREE MODELS OF TOTAL KNEE PROTHESES

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William L. Bargar, M.D.**

ABSTRACT

Five normal adult cadaveric knees were prepared and mounted in a loading frame permitting a full range of motion under a constant quadriceps force. Strain over the anterior patella was plotted versus flexion angle, before and after capsulotomy, and after each of a series of arthroplasties. Three component systems, the Robert Brigham Total Condylar, the Total Condylar 1, and the Insall Burstein Posterior Stabilized Total Condylar Knee Prosthesis were serially implanted in each knee. Strains in the Robert Brigham were recorded both before and after sectioning of the posterior cruciate ligament. All components produced a significantly higher strain than in the intact knee, and peak strains were seen at the extremes of flexion in all components. Total Condylar 1 system yielded the highest strain throughout the range of motion. Over the functional range of motion the Robert Brigham component produced the lowest strains. Sectioning the PCL made no difference in anterior patellar strain in the Robert Brigham knee.

INTRODUCTION

The advent of patellar resurfacing as an integral part of total knee arthroplasty has improved functional results with a decrease in patellofemoral pain[2,4,25,26]. Patellar stress fractures, symptomatic and asymptomatic, with rates up to 21 per cent after resurfacing[4,6,9,12,20] raise questions about patellar strain. Mechanical considerations of patellar component design have been addressed, but no study has addressed the effect of femoral component design on patellar strain. This study analyzes such effect of three different components.

MATERIALS AND METHODS

Five adult cadaveric knees, free of deformity were prepared for study by removal of unnecessary muscle and soft tissue. The vastus lateralis, vastus medialis, and hamstrings were removed proximally, and the gastroc-soleus complex distal to its origin was dissected free. The extensor aponeurosis, joint capsule, distal two thirds of the femoral shaft, and proximal two thirds of the tibia were retained. The bone ends were potted in methylmethacrylate cement, and the specimens were mounted in a loading frame which allowed a free range of joint motion from full extension to 130 degrees of flexion under a constant quadriceps load (Fig. 1). As the principal strains in the patella during extension are essentially vertical[7], linear gauges were felt to be adequate for this study. A 1.5 cm square area of the anterior patella was cleared of all soft tissue, and an 8.0 mm Micromeasurements linear strain gauge was applied in the vertical midpatellar line.

The quadriceps tendon was dissected, releasing the vastus medialis and lateralis muscles and retaining the rectus femoris and vastus intermedius as the common extensor tendon. Approximately 15-20 cm of tendon were retained

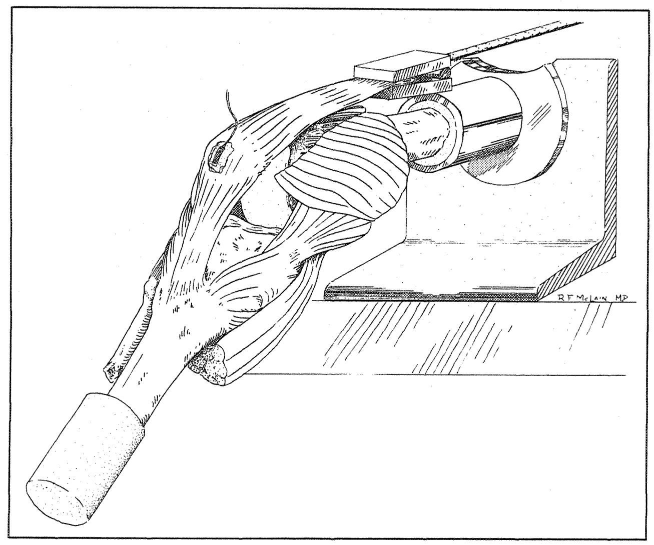

Fig. 1: ***The Loading Frame.*** **The proximal femur is potted in PMMA and mounted in the loading frame. Load is applied to the extensor mechanism through a pulley system. A strain gauge is applied to the anterior patellar surface. The bilateral capsulotomy allows the patella to be reflected forward during arthroplasty.**

for insertion into a soft tissue clamp. A pulley and cable mechanism applied a force to the extensor tendon in the direction of the central quadriceps tendon.

A constant load of twenty-five pounds was applied to the quadriceps tendon, and the knee was manipulated through a full range of motion. Using a standard two

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dimensional plotter, all strain measurements were plotted as a function of the flexion angle as determined by a rotary potential goniometer. Measurements were obtained in each knee both before and after bilateral capsulotomies. The postcapsulotomy measurements served as the control for all subsequent measurements in each knee, and all data obtained was later normalized to the peak strain of the precapsulotomy control. In each knee serial arthroplasties were performed with three total condylar knee prosthesis: 1) Robert Brigham, 2) Total Condylar 1, and 3) Insall Burstein Posterior Stabilized Knee Prosthesis. A standard operative technique was used [11,18] except that the component surfaces were coated with vacuum grease to allow interchange of components without disruption of the bone/cement interface. The measured flexion gap was 17.0 mm in the Total Condylar 1 knee, and 21.5 mm in the Robert Brigham and Insall Burstein prosthesis. The extension gap measured 20.5 mm in the Robert Brigham knee and 21.0 mm in the other two components. The anterior cut surface of the femur was used as the reference point for each of the prostheses. Only enough cement was removed between component placements to allow tight contact of the anterior flange and the anterior cut surface of the femur.

The anterior posterior diameter of the patella following resurfacing was within 1.5 mm of the diameter of the intact patella in every case. A 38 mm domed polyethylene patellar component with a central post was used in all knees.

A comparison of strain in the Robert Brigham system before and after sectioning of the posterior cruciate ligament was performed in three knees.

At the end of each experiment the last prosthesis was removed, and the bone cement was removed. One of the previously analyzed components was then reimplanted and data was collected as before. The strain characteristics of this reimplanted prosthesis were then compared to its previous results in order to determine the reproducibility of the measured strain curves.

RESULTS

Comparison of strain measurements in intact knees to the postcapsultomy measurements showed no significant difference. Separation of the rectus femoris and vastus intermedius tendons from the rest of the extensor aponeurosis consistently produced an increase in measured strain, but this was not statistically signifcant.

Total knee arthroplasty with patellar resurfacing increased the strain over the anterior patella up to three times that in postcapsulotomy controls. This increase in strain was observable at flexion angles greater than 30 degrees in all of the three components, and was independent of minor surgical variations and capsulotomy. Comparison of the three appliances demonstrated significant differences in strain characteristics at flexion angles greater than 30 degrees (Fig. 2). The Total Condylar 1 knee prosthesis produced significantly higher patellar strains throughout the range of motion than did the other prostheses, particularly throughout the functional range of motion — 30

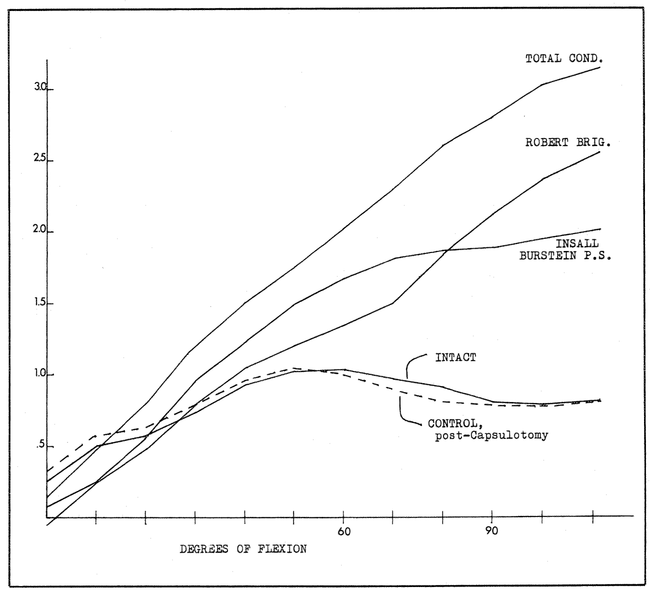


Fig. 2: Mean strains in five knees, normalized to the peak strain of the post-capsulotomy control.

degrees to 90 degrees. Typical strain measurements are those of knee II (Figure 3). At 60 degrees of flexion, with twenty-five pounds of quadriceps force, strains were obtained of 274.6 microstrain in the Total Condylar 1, 205.4 microstrain in the Insall Burstein PS prosthesis, and 171.2 microstrain in the Robert Brigham. At 110 degrees of flexion the measured strains were 370.8 microstrain in the Total Condylar 1, 311.9 microstrain in the Robert Brigham, and 238.8 microstrain in the Insall Burstein PS.

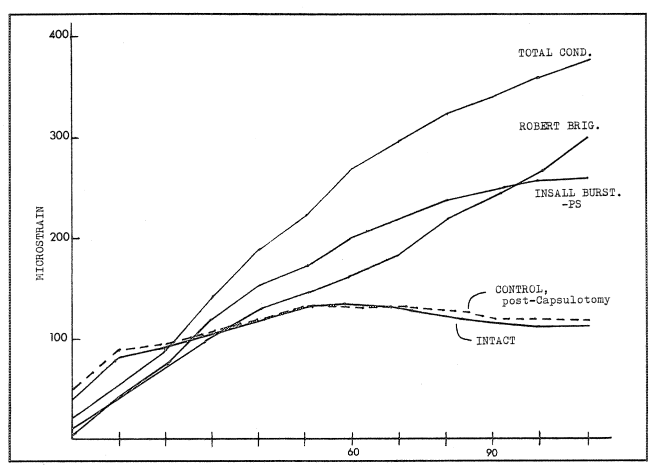


Fig. 3A: Anterior patellar strain in Knee 2, observed during flexion from 0 to 110 degrees, in microstrain.

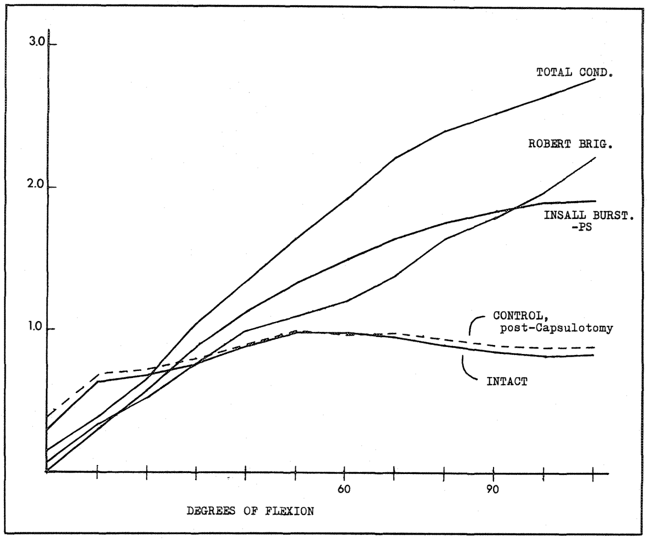


Fig. 3B: Anterior patellar strain in Knee 2, observed during flexion from 0 to 110 degrees, normalized to control peak value.

Total Condylar 1:

The Total Condylar 1 prosthesis produced the highest mean strains at all flexion angles greater than 30 degrees. At 60 degrees of flexion, the Total Condylar 1 produced strains 28 per cent higher than the Insall Burstein PS and 64 per cent higher than the Robert Brigham knee ($p < .05$) (Fig. 4A). At 90 degrees, the Total Condylar 1 produced mean strains 52 per cent higher than the Insall Burstein and 39 per cent higher than the Robert Brigham. At 100 degrees of flexion the Total Condylar 1 produced an anterior patellar strain 279 per cent higher than the postcapsulotomy control (Fig. 4B). The strain produced in the Total Condylar 1 prosthesis continued to increase throughout the tested range of motion.

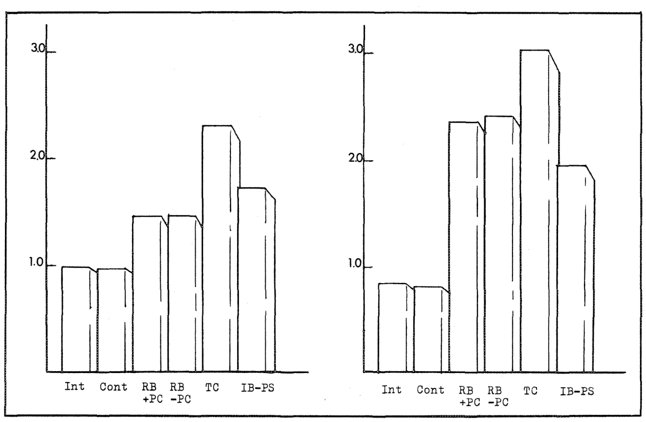


Fig. 4: Mean strain in five knees, normalized to control peak values. Int – Intact; Cont – Control, postcapsulotomy; RB + PC – Robert Brigham with intact posterior cruciate; RB – PC – Robert Brigham after sectioning of the posterior cruciate; TC – Total Condylar 1; and IB-PS – Insall Burstein Posterior Stabilized Knee. A. Relative normalized strains observed at 60 degrees of flexion. B. Relative strains observed at 100 degrees of flexion.

Insall Burstein PS:

Due to their differing strain characteristics, both the Insall Burstein PS and the Robert Brigham prosthesis demonstrated specific advantages at different ranges of flexion. The Insall Burstein PS prosthesis's strain curve is distinguished by a relatively steep slope initially, with a tendency to plateau at the extremes of flexion. At 60 degrees of flexion the Insall Burstein PS produced a mean strain 22 per cent higher than the Robert Brigham knee ($p > .10$). Throughout the functional range of motion (30 degrees–90 degrees) the Insall Burstein consistently produced higher strains. From 90 degrees to 120 degrees there was no increase in measured strain; however, at 120 degrees, the Robert Brigham prosthesis produced strain measurements 22 per cent greater than the Insall Burstein PS ($p < .10$).

Robert Brigham:

As noted above, the Robert Brigham total knee prosthesis produced strain measurements significantly lower than those seen in the Total Condylar 1, and lower than those produced by the Insall Burstein PS knee when compared over the range or functional motion. Sectioning of the posterior cruciate ligament produced no change in the strain characteristics observed in the Robert Brigham knee.

DISCUSSION

In 1980 Roffman et al. reported two cases of patellar stress fracture following total knee arthroplasty and patellar resurfacing[20]. Both patients presented with minimal pain or swelling, mild to moderate loss of knee function, and an extensor lag notable on physical examination. One patient with a transverse fracture of the proximal third went ununited despite open reduction and fixation, while the other obtained a solid union following immobilization of her distal third transverse fracture.

The reported incidence of patellar fractures has varied because these fractures are frequently asymptomatic and will not be recognized unless specifically sought. Consequently, reviews utilizing routine radiographic follow up report a higher incidence of patellar stress fractures. Insall, in his initial review of the total condylar knee experience at the Hospital for Special Surgery noted only one patellar fracture in 461 arthroplasties followed for variable intervals[10]. However, in a two to four year follow-up of patients with the posterior stabilized total condylar knee, routine radiography demonstrated ten patellar fractures in 118 patients[9]. Despite the fact that these fractures were commonly comminuted and displaced, eight of the ten patients were asymptomatic, with good overall range of motion and function.

Certain prostheses have been associated with higher incidences of fracture. Cameron[4] reported on seventy-seven patients undergoing total knee arthroplasty utilizing the ICLH (Imperial College and London Hospital) prosthesis. Fourteen had patellar resurfacing. Three of the fourteen patients (21 per cent) with a resurfaced patella later developed fractures. The authors postulated generous patellar resection and breach of the anterior cortex while drilling the centering hole as causative factors. Reviewing the London Hospital experience with the ICLH knee, Levai[12] reported three asymptomatic patellar fractures in seventy-one patients; thirty-nine with patellar resurfacing and thirty-two with patelloplasty. The incidence of fractures was stated as equal, when two fractures, one patelloplasty and one resurfacing, originally excluded from the study were included.

Though the data is inconsistent, there appears to be an association between patellar resurfacing and the incidence of stress fractures in total knee arthroplasty. Aside from surgical technique, a wide number of factors may play a role in determining the incidence of fractures associated with a particular component system.

Morrison noted three peaks in joint force generated during ambulation, all occurring between heel strike and toe off and corresponding to the activity of the hamstring, quadriceps, and gastrocnemius muscle groups[17]. Our system does not take into account effects of hamstring or gastrocnemius forces on the knee. Our model also examines knee motion in a non-weight bearing mode. Stresses generated in vivo in non-weight bearing activity are due only to muscular forces acting across the joint, and differ from those generated during weight bearing activity. With weight bearing, the quadriceps force must increase dramatically with increasing flexion to counterbalance the increasing flexion moment (Fig. 5A). As the knee approaches full extension and the flexion moment decreases, the requisite quadriceps force diminishes accordingly[1,8,19]. In non-weight bearing extension against gravitational resistance, the flexion moment increases as the knee approaches full extension (Fig. 5B); this requires a proportional increase in quadriceps force. In our model the quadriceps force and flexion moment are maintained constant (Fig. 5C).

During extension of the knee, the patella functions as a frictionless pulley over the trochlea of the femur and increases the effective lever arm of the quadriceps mechanism with improvement in the mechanical efficiency of the joint. The articular cartilage of the patella provides an insensate, deformable surface ideal for distributing high compressive loads. Loss of articular cartilage disturbs the smooth function of the patella and leads to significant patellofemoral pain. Patellofemoral contact force in the intact knee varies directly with the flexion angle, and can exceed body weight several times. Reilly and Martens[19] estimated compressive forces of over 1500 N for descending stairs with a knee flexion angle of 30 degrees and noted an

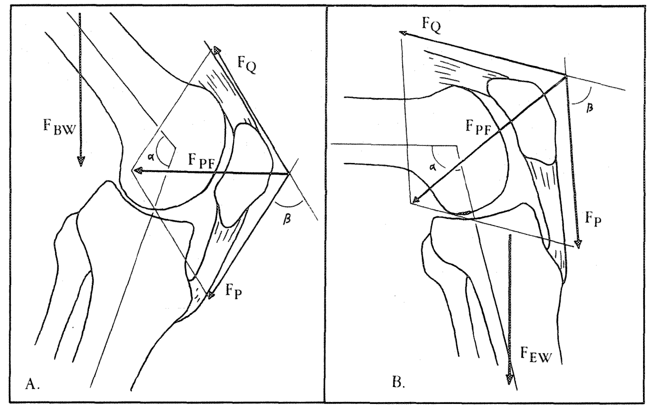
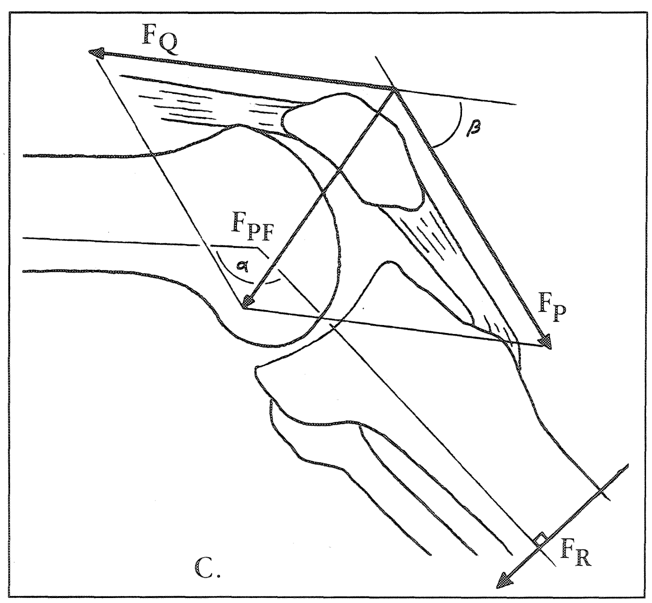


Fig. 5: ***Summary of Forces Acting at the Knee.*** **FBW = flexion force secondary to body weight; F_Q = force of quadriceps contraction; F_P = force acting through the patellar tendon; F_{PF} = patellofemoral joint reaction. F_Q is equal to F_P in the static state. F_{PF} is the resultant of F_Q and F_P.**

5A: Forces acting on the knee in weight bearing extension —the major flexion force is secondary to the weight of the upper body, acting through a moment arm perpendicular to F_{BW} originating at the instant center of joint rotation. As the angle of flexion increases the moment arm increases and F_Q must increase to compensate for the greater flexion force. As F_Q increases the resultant F_{PF} also increases.

5B: Forces acting in non-weight bearing extension against gravity — in extension a gravitational force such as an ankle weight, the major flexion force is secondary to the weight of the lower leg combined with the added weight, acting through the center of the mass. This force, F_{EW}, acts through a moment arm originating at the instant center which increases as the knee approaches full extension. As the flexion angle decreases F_Q increases, but the resultant F_{PF} decreases.



5C: Forces acting on the knee in the experimental model —in this situation the major flexion force is applied to the tibia, perpendicular to the tibial axis. This force, F_R, is sufficient to resist the extension force produced by the constant load applied to the quadriceps tendon, and acts on a moment arm which is constant throughout the range of motion. F_Q is constant, and F_{PF} varies with the angle β.

increase in compressive forces to over 4000 N during deep knee bends to 110 degrees flexion. These findings have been supported by a number of subsequent studies[8,14,22]. Because the patellar anatomy provides increased contact area with increasing flexion angles, and because the deformable cartilage surface provides increased contact area under compression, compressive articular stresses rise more slowly relative to flexion angle than might otherwise be expected[13].

When the patellar articular surface is replaced during total knee arthroplasty, the polyethylene prosthesis is subjected to these same forces. Because the contact area of the prosthesis is significantly smaller than that of the intact patella, contact stresses are proportionally higher. Anatomic patellar buttons have been shown to increase contact area and decrease peak contact stresses relative to domed patellar prostheses. Because peak compressive forces at large flexion exceed the yield strength of polyethylene, these prostheses do exhibit an element of deformability.

Patellar prosthesis fixation may alter the mechanics of the system. The use of a prosthesis utilizing a single centrally located mounting post produces a greater increase in anterior patellar strain than does an implant with smaller proximal and distal pegs[7]. Removal of bone stock for placement of the central post creates a large mechanical defect, and this associated with the parapatellar incision may interrupt the vascular supply to the anterior patella. The use of bone cement may produce heat necrosis of the subchondral bone. Each of these, or all three in concert, may be responsible for creating a predisposition to stress fracture, and vascular compromise may predispose those patients who do develop fractures to nonunions[20] or ischemic necrosis[21]. Improper placement with disruption of the anterior cortex, has also been suggested as a possible cause of fracture.

According to recent reviews, the design of the total condylar prosthetic components may have a significant influence on patellar strain, either directly, through biochemical considerations, or indirectly, through functional considerations. Some prosthetic designs may be associated with a higher incidence of fracture than are others[4,5,9,10,12]. While variations in femoral component geometry might logically be expected to alter patello femoral mechanics, even like components from different manufacturers can produce differences in anterior patellar strains[3]. Functional capacity may play a role in a particular component's association with stress fractures. Insall noted an increased incidence of fractures in patients with posterior stabilized components. The cam mechanism to replace the posterior cruciate should have reduced patellar strain by forcing the tibia anteriorly and reducing the β angle of the extensor mechanism. However, patients with the PS knee were capable of a much greater range of motion and may have been exposing the knee to higher patellofemoral joint forces than had previous groups[9].

In light of the above, one might expect the function of the posterior cruciate ligament to be more important in in vivo activities than in the constant load mechanism used in this study. Indeed, though the lowest mean strains were obtained in the cruciate retaining Robert Brigham knee and the highest in the cruciate sacrificing Total Condylar 1, there was no observable change seen in the function of the Robert Brigham after sectioning of the PCL. Retention of the PCL must have some protective function in daily activities, but is probably not the major determinant of patellar strain.

It is more likely that the conformation of the femoral anterior flange, by altering the patellofemoral load distribution, will be the determining factor in the magnitude of strain developed in each system. Although a complete analysis of these complex three dimensional surfaces has not been made, it is noteworthy that the Total Condylar 1 prosthesis with its more acutely convex anterior flange did produce the highest strains.

CONCLUSIONS

Total knee arthroplasty with patellar resurfacing produces an increase in anterior patellar strain up to three times that seen in controls. This increase is independent of surgical capsulotomy and is prominent at flexion angles greater than 30 degrees. Minor alterations in surgical technique do not affect the observed strain. Peak strains were seen at the extremes of flexion in all prostheses.

The highest strains were recorded for the Total Condylar 1 prosthesis, throughout the range of motion. Although not statistically significant, the Insall Burstein knee consistently produced higher strains than did the Robert Brigham knee throughout the functional range of motion. For the Robert Brigham knee sectioning of the posterior cruciate ligament resulted in no significant change in the measured strains.

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ELECTOMYOGRAPHIC CHANGES AFTER CARPAL TUNNEL RELEASE

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Electromyography is a valuable adjunct in the diagnosis of the carpal tunnel syndrome. These techniques can assess multiple electrophysiologic phenomena, including needle electrode potentials for thenar muscles, sensory and motor latencies, incremental sensory and motor latencies, and sensory and motor conduction velocities. The data derived from these studies can confirm the clinical diagnosis of median nerve compression in the wrist, quantitate the severity of the disease, and indicate associated diseases such as polyneuropathy, simultaneous ipsilateral compression neuropathy, brachial plexopathy, and cervical radiculopathy.

Surgical decompression for carpal tunnel syndrome is generally efficacious[9,12]. However, a small but significant number of patients have persistent or recurrent symptoms, suggestive of continuing median nerve compression. The patient's physician may use repetitive electroymographic studies to re-evaluate median neurophysiology. These studies are undertaken with the assumption that electrophysiologic abnormalities improve or return to normal after surgical decompression. The literature both supports and refutes this assumption. Support is best supplied by Kemble, who found that distal electrophysiologic measurements, especially the distal latencies, showed changes which accurately reflect the progress of clinical improvement[5]. This concept is also supported by the work of other authors[2,4,10], but sometimes with limited quantitation of electrophysiologic improvements. A few anecdotal reports support the concept that electrophysiologic recovery occurs after carpal tunnel release[1,11]. However, limited electrophysiologic improvement is suggested by other research [3,7]. Goodwill, reporting on fifty-five cases, noted that 11 percent did not recover[3]. A thorough statistical analysis of the problem was described by Melvin, et al., who studied thirty cases postoperatively[7]. Their patients demonstrated a prolonged afferent latency (75 per cent), an abnormal insertional activity in the thenar muscles (40 per cent), and an efferent conduction defect (27 per cent) in the postoperative period. In summary, existing postoperative electromyographic studies are somewhat contradictory.

Clinicians also use clinical measurements (grip and pinch strengths, two-point discrimination) to re-evaluate median neurophysiology in the patient who has not responded to treatment. Again, the values of these variables are assumed to improve after surgical decompression. A literature review fails to uncover specific data dealing with these clinical variables. This prospective clinical study intends to quantitate the postoperative electromyographic changes in the median nerve at the wrist and to evaluate grip strength, pinch strength, and static two-point discrimination after carpal tunnel decompression.

METHODS AND MATERIALS

Thirty-six patients were sequentially indicated for carpal tunnel release in fifty-four of their hands. Mean duration of symptoms prior to surgery was 21.9 months. Median duration was 12 months. All participants gave informed consent. A sensibility and strength exam and an electromyographic study were obtained on each hand a few weeks prior to surgery. Similar repeat studies were attempted for each hand, postoperatively, at two weeks and then at three, six, nine, twelve, eighteen, and twenty-four month intevals.

All electrophysiologic studies were done under supervision of the same physician. The median nerve was stimulated percutaneously, by the technique of Kimura[6]. The anode is 2 cm proximal to the cathode with the ground electrode affixed to the forearm. This method permits a measurement of distal palmar latency from distal to the transverse carpal ligament to the thenar muscles. Besides an accurate determination of median nerve latencies and conduction velocities, the method specifically localizes the physiologic impairment to a region of the palm and considers the post-carpal tunnel recurrent median motor endplate physiologies. Measurements included motor and sensor latencies, and motor and sensory conduction velocities. One value for each of these parameters was statistically analyzed for each patient.

Sensibility testing, using the Weber two-point discrimination method, as described by Omer[8], was completed by the same examiner (DS). Testing began distally in the radial or ulnar autogenous zones of each digit's pulp. The test began with a large distance between points (7-10 mm) and was reduced by 1 mm distances until the patients could not distinguish between the points or gave less than four out of five correct answers. In this case, the two point value would be considered that distance which was last reliably reported. One value was derived for each region. The regional values were averaged for each digit and were subjected to statistical analysis by digit.

The same examiner (DS) performed grip and pinch measurements. With the shoulder abducted and neutrally rotated, the seated subject's elbow was flexed to 90 degrees, and the forearm and wrist were in the neutral position. A JAYMAR dynamometer (Asimow Engineering Company, Los Angeles, California) and a pinch gauge (B & L Engineering, Pinsco, Inc., Santa Fe Springs, California) were used. Consistent verbal commands were given to each patient during three attempts at each strength test. The results were averaged, and this mean value was used for statistical analysis. Strength testing was not performed at the two week postoperative follow-up visit, as the surgical incisions were in an early healing phase.

The statistical analysis used the SAS package. The group mean for each variable was compared to the preoperative values using a one sample t-test. These analyses were completed for each postoperative time interval. Each of the physical examination and electromyographic variables were analyzed.

RESULTS

The data from electromyography and physical examination indicate an improvement toward normal values for all study variables.

In the electromyographic studies, the motor and sensory latencies decreased through the twenty-four months of postoperative evaluation. Correspondingly, the calculated motor and sensory conduction velocities increased. Table 1 presents the group mean data and denotes the statistically significant data. The number of patients participating in each of the postoperative groups ranged from thirteen to thirty-four but is accounted for in the method of statistical analysis. The calculated motor and sensory conduction velocities were significantly increased by two weeks postoperatively and generally remained increased during the two years of study. The sensory latency, although

Table 1

Latencies and Conduction Velocities

	Pre-op	2 wk	3 mo	6 mo	9 mo	12 mo	18 mo	24 mo
Latency, Motor (m/sec)	2.60	2.71	2.47	2.17*	2.15	2.18	2.09*	1.83*
Latency, Sensory (m/sec)	1.87	1.63	1.44*	1.46*	1.39	1.45*	1.42*	1.40
Velocity, Motor (m/sec)	29.98	33.05*	37.37*	34.59*	41.88*	38.60*	33.54	37.29
Velocity, Sensory (m/sec)	37.91	42.60*	42.38*	42.84*	43.18*	44.17*	41.38*	45.79*

Asterisks denote significant differences from preoperative values, at $p<.05$.

decreased at the two week interval, was not significantly decreased until the three month interval. The motor latency increased at the two week interval but decreased significantly by the six month interval.

Data for static two-point discrimination testing was grouped by digit. In other words, radial and ulnar values were averaged for each digit and then analyzed. Table 2 presents the group mean data and denotes statistically significant changes. In all digits a significant decrease in two point discrimination was present at the two week postoperative interval. The group mean values remained significant through the twenty-four months of study, while the general tendency was a continued improvement with time. Notably, fingers with partial or total ulnar innervation showed changes similar to fingers with median innervation. The number of patients participating in these postoperative groups range from twelve to forty-five.

Pinch strength and grip strength testing yielded increased mean values for the group at each time interval. Exceptions were the mean values for palmar pinch and grip at the three month interval, when these actually decreased. Table 3 presents group mean data, noting the statistically significant changes. The number of patients participating in the postoperative groups ranged from twelve to forty-one. Significant changes did not occur for palmar and lateral pinch strength until six months and, for tip pinch and grip strength until nine months.

DISCUSSION

The results indicate that motor and sensory conduction velocities and sensibility undergo statistically significant changes within two weeks of carpal tunnel surgery. Sensory latencies are significantly changed at three months. Motor latency and strength took longer (6 months – 9 months) to become significantly improved. However, the results of this study, must be cautiously applied to any individual case because a range of values exists for each study variable and time interval. Furthermore, carpal tunnel syndrome can exist in the presence of normal electromyographic studies[3,6,12] and, presumably, so can recurrent carpal tunnel syndrome.

Our electromyographic results generally agree with the impression of previous authors: electromyographic variables improve postoperatively[2,4,5,10]. Our results most closely agree with Kimble, who found that sensory latency, motor latency, and sensory nerve action potential (amplitude and duration) demonstrated statistically significant changes over preoperative values[5]. Kimble's analysis did not sequence these electromyographic variables. Although we did not measure sensory nerve action potential amplitudes and duration, our temporal analysis indicated that motor and sensory conduction velocities preceded statistically significant latency changes. Importantly, we agree with Kimble that the rate of latency recovery is curvilinear

Table 2

Static Two-Point Discrimination

	Pre-op	2 wk	3 mo	6 mo	9 mo	12 mo	18 mo	24 mo
Thumb	6.2	4.8*	4.6*	4.7*	4.2*	4.3*	4.0*	4.0*
Index	6.0	4.7*	4.5*	4.6*	4.1*	4.2*	4.0*	3.9*
Long	5.8	4.9*	4.4*	4.8*	4.1*	4.2*	3.9*	4.0*
Ring	5.7	4.7*	4.5*	4.7*	4.1*	4.3*	4.2*	4.0*
Small	5.5	4.6*	4.6*	4.7*	4.1*	4.3	4.1*	4.0*

All data in millimeters. Asterisks denote significant differences from preoperative values, at $p<.05$.

Table 3

Pinch and Grip Strengths

	Pre-op	2 wk	3 mo	6 mo	9 mo	12 mo	18 mo	24 mo
Tip pinch	21.8		22.4	27.8	31.4*	37.6*	30.8*	31.9*
Palmar pinch	33.1		32.5	41.0*	46.1*	46.3*	40.7	42.6
Lateral pinch	56.6		59.6	73.0*	67.0	75.0*	69.0*	64.9
Grip	196.8		167.4	238.4	226.9*	235.4	234.5	248.0*

All data in Newtons. Asterisks denote significant differences from preoperative values, at $p<.05$.

with the rate of recovery slowing with time. We further concur that distal measurements of median nerve conduction, especially the distal latencies, showed changes in the carpal tunnel syndrome which accurately coincided with the progess of clinical improvement.

Our results are also similar to those of Hongell[4], Goodman[2] and Schlagenhauff[10]. Hongell and Mattson electromyographically studied fifty hands between one and eighteen months after surgical treatment for carpal tunnel syndrome[4]. Their method of statistical analysis was not stated, but they found a "significant" (0.5 per cent confidence level) postoperative reduction of sensory and motor conduction times. Schlagenhauff and Glasauer studied twenty-five hands with motor latencies only, preoperatively and at prescribed postoperative intervals up to thirty-six months[10]. Twenty-four of twenty-five hands improved with most improvement occurring within the initial three months. Goodman and Gilliatt, with similar results, expanded the interpretation of their observations to say that electromyographic "investigation is seen to particular advantage in the assessment of the difficult patient"[2].

In contrast, Melvin, et al., who reported that twenty-three of thirty wrists (77 per cent) showed persistent electromyographic abnormalities[7]. Twenty per cent of their patients had persistent increased polyphasicity, 70 per cent had prolongation of sensory latency, and 27 per cent had motor conduction defects. They suggested that sensory latency is not a function of the postoperative time interval, based upon a scattergram comparing postoperative months and sensory latency values. We have found the opposite, that the improvement in sensory and motor latencies and sensory and motor conduction velocities are a function of time. Although they recognized that a comparison of electromyographic variables by time interval is desirable, their insufficient data and inappropriate method couldn't accomplish this task.

The comparison of our electromyographic data with other studies is difficult, because most other studies have reported few patients, have evaluated each hand only once during the postoperative period, and have had highly variable follow up intervals. The beginning of the time intervals in other studies has been variably defined as the day of surgery or the onset of clinical improvement. A comparison among studies of the absolute values is also difficult, as we have utilized the method of Kimura[6], which measures segmental palmar latencies. Advantages of this technique include its specificity and the localization of the motor and sensory conduction defects within the carpal tunnel.

The comparison of our clinical data with other studies is possible only in the most general terms. Previous studies, within the limits of our literature review, have not quantitated the clinical variables which we consider consistent with a thorough examination of the hand—strength testing and two-point discrimination. Phalen examined his patients for thenar muscle atrophy and found that 81 per cent showed improvement or a return to normal after surgery[9]. Relative to sensation, 97 per cent of hands showed improvement or a return to normal after surgery. Most other studies report clinical response in subjective terms, such as the patient's estimate of recovery. For example, Thomas reported that 91 per cent of his patients reported good or fair results after surgery. However, interpretation of our clinical variables in the evaluation of the patient preoperatively or the patient who has not responded to surgery must be done with caution, because the measurements require patient cooperation.

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SQUAMOUS CELL CARCINOMA SECONDARY TO CHRONIC OSTEOMYELITIS

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ABSTRACT

Squamous cell carcinoma (SCC) is an uncommon complication of chronic osteoymyelitis with an associated sinus tract. We conducted a retrospective analysis of seventeen patients treated at the Memorial Sloan-Kettering Cancer Center over twenty-five years in an attempt to identify the relationship between survival and the type of surgical therapy.

Based on Enneking's concept of compartmentalization, we divided our patients into two groups. In group I, nine patients were initially treated by above bone amputation which we termed radical. Seven of these patients remained disease free at an average follow up of four years. Three patients have had a local recurrence, and two of them died from their disease. Regional lymph node metastases were present in all three patients with recurrence. Group 2 consisted of eight patients whose initial treatment was either a marginal excision or a wide amputation. Four patients have had a recurrence, one died from a myocardial infarction two years following a wide amputation, and the remaining three are free of disease at an average of 5.5 years since surgery. Three of the four patients with recurrent disease had proximal stump involvement, and all four had regional lymph node metastasis. Metastatic involvement of regional lymph nodes occurred in 100 per cent of our patients with recurrent disease.

We strongly recommend a radical surgical approach to the treatment of squamous cell carcinoma arising within a sinus tract of chronic osteomyelitis.

INTRODUCTION

Majolin, in 1828, allegedly recognized malignant degeneration in burn scars; however, it remained for Hawkins, in 1835, to establish the association between chronic osteomyelitis and squamous cell carcinoma[1,2]. During the next 100 years, sporadic case reports paralleled major military confrontations. As a result, trauma was implicated as a cause of epidermoid carcinoma, as SCC was formerly known. Devars was the first to emphasize the difference between the more common superficial lesion and the rarer occult variety[1,2,4].

In a review of 2,400 cases of osteomyelitis treated at the Massachusetts General Hospital, Benedict collected twelve cases of carcinoma, an incidence of 0.5 per cent. He stressed the prophylactic treatment of osteomyelitis[1]. In the same year, Milgram traced the migration of squamous epithelium from the skin surface into the depths of cavities and sinuses of chronic osteomyelitis[29], thus shedding a ray of light on the etiology of this process[18]. Henderson and Swart reported on five patients who developed SCC following chronic osteomyelitis[9]. In 1941, Bereston and Ney reported on the demise of two patients secondary to metastatic disease. They referred to the rarity of reports of this complication and offered an explanation for this discrepancy by stating: "the possibility that some of the reported cases may have been instances of pseudoepitheliomatous hyperplasia"[2]. Surgery, either excision or amputation, represented the standard of treatment at the time. Taylor, Nathanson, and Shaw noted that in their experience radiotherapy never cured metastatic disease. They stressed the relationship between nodal size and metastases and adovacted regional lymph node dissection in cases of persistent enlargement[23].

Following their experience of biopsy proven nodal spread in two of three patients who initially presented with nonpalpable lymph nodes[17], McAnally and Dockerty proposed prophylactic dissection of regional lymph nodes. Marks and Turner made reference to radical amputation as the treatment of choice; however, this proposal was based upon experience with only three patients[16]. Sedlin and Fleming advocated simultaneous biopsies of enlarged nodes and the primary lesion. They emphasized the potential early metastasis rate of twenty to 30 percent[21]. Horn and Templeton reported the case of a thiry-five year old black man with only a five year history of osteomyelitis developing a carcinoma. They postulated race as a modifying factor. Although previously reported, Johnston and Miles make note of two unusual and aggressive sarcomas arising from chronic osteomyelitic sinuses[12]. Manale and Brower recognized a relationship between bacterial flora and malignant degeneration; they state that the disappearance of staphylococcus aureus as a pathogen may herald the onset of malignant change[15]. In 1976, Fitzgerald, Brewer, and

Dahlin reported their findings on twenty-three patients[2]. They noted: the potential of these tumors to metastasize, the need for regional lymph node dissection where lymphadenopathy persists for three months following amputation, and the necessity of early aggressive surgical treatment[6].

The purpose of our study is to define adequate surgical treatment by identifying the relationship between the type of surgery and survival rates.

MATERIALS AND METHODS

Seventeen patients (thirteen males and four females) were treated at the Memorial Sloan Kettering Cancer Center for SCC secondary to chronic osteomyelitis, between 1957 and 1982.

The mean age was sixty years with a range of thirty-eight to eighty-one years. The duration of disease ranged from one year to sixty years with a mean of twenty-five years.

The tibia was the most frequently involved site, accounting for seven cases, with the femur involved in four patients. Other sites of involvement were: two metacarpals, one phalanx, one tarsus, one sacrum, and one humerus. Twelve patients gave a history of trauma and five other cases were attributable to hematogenous osteomyelitis.

The presenting complaint was pain in six patients, an enlarging mass in six patients, and an increase in the quantity of drainage in five patients. On the average, seven months transpired before a patient reported the changes. Eight patients were recorded as having enlarged regional lymph nodes. Some admission laboratory results were significant. The leukocyte counts were normal in eight patients and elevated in four patients; the highest was $28,500/mm^3$. The erythrocyte sedimentation rate was greater than 46 mm/hr in all patients. Sinus tract cultures revealed no growth in six patients, staphylococcus coagulase negative in one patient, and mixed organisms in the remaining patients. Plain radiographs most commonly revealed a soft tissue mass overlying an area of permeative bone destruction. A radionuclide bone scan was reported as positive in the three patients tested. The early flow phase of the scan demonstrated increased soft tissue uptake in the only patient studied.

TREATMENT

A total of twenty-three operative procedures were conducted in seventeen patients. These included seven above-knee amputations, three below-knee amputations, five hemipelvectomies, two hip disarticulations, two forequarter amputations, three ray resections and one local excision. Six patients required a second procedure for local recurrence. Two of these patients were treated with adjunctive radiation and both died from their disease within a year of recurrence. One patient died within two years of surgery from a myocardial infarction; another died ten years postoperatively from causes unrelated to SCC. The remaining two patients are clinically free of disease more than six years after their second operation.

Radiation therapy was utilized in three patients. All succumbed to their disease within a year of treatment.

Lymph node dissection was conducted in five patients. Four patients underwent a groin dissection, three died. A neck dissection accompanied a forequarter amputation in a patient who presented with recurrent squamous cell carcinoma of the metacarpal two years following a ray resection. This patient is presently disease free eleven years after the recurrence.

Based upon Enneking's concept of compartmentalization, we further analyzed our initial surgical results and divided our patients into two groups.

In group one a total of nine patients were initially treated for squamous cell carcinoma with an above bone amputation. Five patients underwent above-knee amputation for tibial involvement. Hip disarticulation was done in one patient with femoral disease. One patient had a forequarter amputation for humeral squamous cell carcinoma, one below-knee amputation was performed for tarsal involvement, and one ray amputation was done for distal phalangeal involvement.

Seven of these patients were disease free at an average follow up of four years. Three patients have had a local recurrence, two of them died as a result of their disease. Regional lymph node metastasis was present in all three patients with recurrence. One patient underwent a second radical amputation for recurrence and is now disease free six years since surgery. Analysis of this data reveals a 78 per cent cure rate utilizing a radical surgical approach.

Group two consisted of eight patients whose initial treatment consisted of a marginal excision or wide amputation. Above-knee amputation was the treatment in two patients with femoral involvement. Below knee amputation was performed on two patients with tibial disease. The remaining procedures included two ray resections, one hip disarticulation, and one local excision. Four patients have had a recurrence, one patient died from a myocardial infarction two years postoperatively, and three others are free of disease an average 5.5 years since their surgery. All four of the patients with recurrence had regional lymph node spread, three of the four had stump involvement. When less than a radical approach was employed, as in group two, a cure rate of 43 per cent was obtained.

Metastatic involvement of regional lymph nodes occurred in 100 per cent of our patients with recurrent disease. Two patients from group two with recurrent disease were subsequently managed by a radical approach. Both of these patients had regional lymph node spread at the time of their second procedure. One patient died seven months later, the other is disease free eleven years after a forequarter amputation.

DISCUSSION

Despite the attempts of previous investigators to clearly define a successful approach to the patient with squamous cell carcinoma, several problems remain unanswered[6,16,17,21,23]. We intended to clarify the role of surgery in the treatment of squamous cell carcinoma. While the percentages favor a radical surgical approach, our series was not large enough to yield statistically significant differences. The knowledge we acquired by a review of the literature together with an analysis of the data in our patients has generated, what we believe to be, a rational approach to the patient.

The incidence of chronic osteomyelitis has decreased over the past fifty years and with it a decline in secondary squamous cell carcinoma[14,17]. This change may be attributed to antibiotics and early aggressive surgical eradication of osteomyelitic foci. However, in spite of our best surgical attempts and recent technological advancements, there still remains a sizeable number of patients with chronic osteomyelitis. From this group, approximately 0.2 – 1.7 per cent will develop squamous cell carcinoma[9,17,21].

We must be aware of this uncommon but potentially fatal complication. We suggest that all patients with chronic draining osteomyelitis be observed closely for evidence of malignant degeneration. The typical patient at risk is a sixty year old white male with a twenty-five year history of a chronic draining osteomyelitis of the tibia, who has noted an increase in local signs or symptoms over a six month period. When this occurs we advocate a prompt diagnostic evaluation, including multiple biopsies of the lesion.

Since histopathologic changes of squamous cell carcinoma tend to be intermingled with more peripheral areas of pseudoepitheliomatous hyperplasia the biopsies should be concentrated centrally[24].

Having established a diagnosis of squamous cell carcinoma we suggest an early radical surgical approach.

Of the remaining unanswered problems one appears most crucial—the treatment of lymph node enlargement. The common factor in recurrences is lymph node metastasis. Previous reports have been conflicting with regard to the proposed management of lymph node enlargement, since biopsy usually reveals histologic evidence of inflammatory hyperplasia in the majority of cases[21,23,24]. Some authors have advocated that lymph node enlargement be observed for six to twelve weeks following surgical ablation of the primary lesion[6,23]. Others have encouraged simultaneous biopsy of enlarged nodes and the primary lesion[21,24]. Overall, of eight patients presenting with enlarged regional lymph nodes, six had metastatic involvement. Three patients died with local recurrence and positive nodes, and three patients with positive nodes are alive an average of eight years following radical amputation. Although statistical evidence is lacking, our data suggest a trend toward increased survival rates in patients managed by a radical surgical amputation. Therefore, our present approach to the patient with enlarged regional lymph nodes, is a simultaneous biospy of the nodes and the lesion, the result determining the need for and the extent of a racial procedure.

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KIENBOCK'S DISEASE
CASE REPORT OF FAMILIAL OCCURRENCE

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SUMMARY

The etiology of Kienbock's disease, avascular necrosis of the carpal lunate, is unknown. Causal factors are implied by their prevalence in the literature. The role of heredity in Kienbock's disease has not been addressed. This report documents the familial occurrence of Kienbock's disease in a mother and daughter and raises the possibility of a genetic contribution.

Kienbock's disease is the eponym designating avascular necrosis of the carpal lunate[2,4]. The events initiating and propagating avascular necrosis in this carpal bone remain unknown. Compression fractures, negative ulnar variance, embolism, and either isolated or repetitive trauma have all been implicated by their prevalence in clinical series[2,3,5,6,8,10].

The definitive diagnosis of Kienbock's disease is made roentgenographically, as the clinical findings are nonspecific[4,7]. Lichtman[9] outlined four stages of Kienbock's disease: Stage I — normal lunate architecture with or without possible linear or compression fractures; Stage II — density changes within the lunate but no change in the shape or anatomical relationship to the remainder of the carpus; Stage III — lunate collapse with associated proximal capitate migration with or without intercarpal instability patterns; Stage IV — Stage III changes with generalized degenerative changes throughout the carpus.

The incidence of Kienbock's disease is not reported. Also lacking is any statistical analysis of sexual predilection or familial occurrence. Lichtman[9] presented two sisters with stage II disease and Simmons[11] described two brothers who "reportedly developed the disease secondary to mycotic emboli". Our report documents the occurrence of Kienbock's disease in a mother and daughter.

CASE REPORT

A twenty-two year old woman was seen for treatment of Kienbock's disease involving her nondominant left wrist. Her chief complaint was dorsal wrist discomfort for six months. There was no history of a specific traumatic episode. Examination revealed dorsal swelling and tenderness with restricted active motion: flexion 0-55°; extension 0-35°; compared to the normal wrist where flexion was 0-75° and extension 0-55°. Radiographs revealed early Stage III disease, complete sclerosis and minimal collapse, with an ulnar negative variant of 1 mm (Fig. 1).

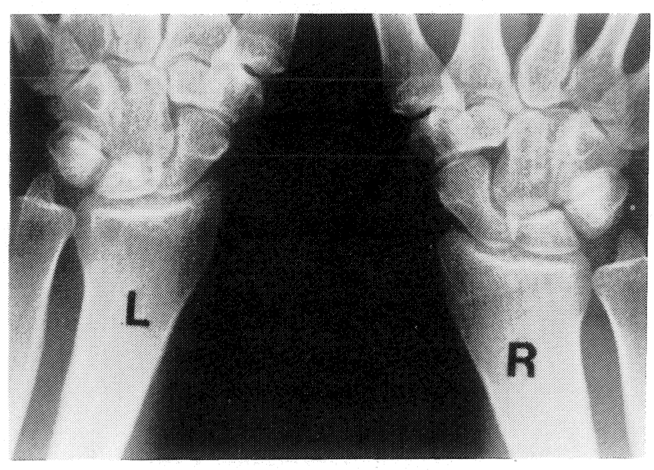

Fig. 1: Stage III progression (daughter).

The mother, a right hand dominant fifty-three year old, had experienced left wrist pain following a dorsiflexion injury thirty-four years earlier. Radiographs taken within weeks of the injury were reported as normal. Her wrist discomfort, although not severe, never completely resolved. Additional radiographs taken twenty-eight years later, supported a diagnosis of Kienbock's disease. Our exam, thirty-four years following the onset of pain, revealed slight dorsal swelling and tenderness. Active range of motion was limited by pain with flexion 0-50° and extension 0-55° (the normal wrist being 0-80° and 0-65°, respectively). The roentgenograms revealed early Stage IV disease, lunate collapse, and a negative ulnar variance of 2 mm (Fig. 2). Neither the mother nor daughter were aware of relatives with wrist problems.

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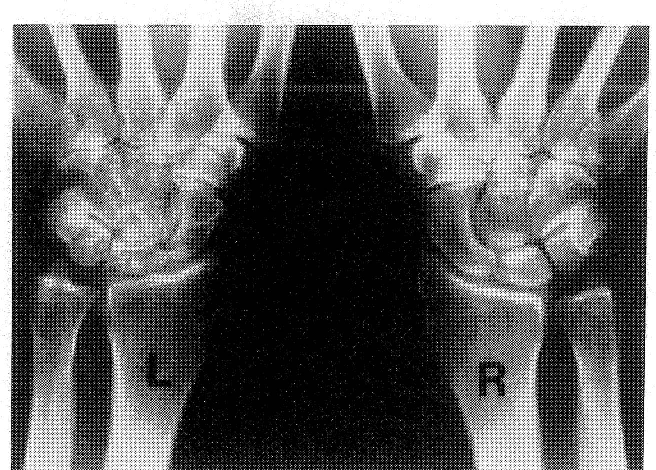


Fig. 2: Stage IV progression (mother).

DISCUSSION

The etiology of Kienbock's disease is unknown. Current hypotheses favor trauma, negative ulnar variance, and vascular patterns[4-6,8]. The clinical history of little or no trauma is consistent with the observations of larger series[3,10].

Hulten reported the incidence of negative ulnar variance in the general population as approximately 26 per cent[1]. The prevalence of negative ulnar variance in patients with Kienbock's disease is reported as 50-87 per cent, a statistically significant association[6]. Gelberman[6] noted a greater magnitude of negative ulnar variance of the affected wrist in unilateral cases. Negative ulnar variance was present in both mother and daughter. We are unaware of studies projecting familial trends of ulnar variance.

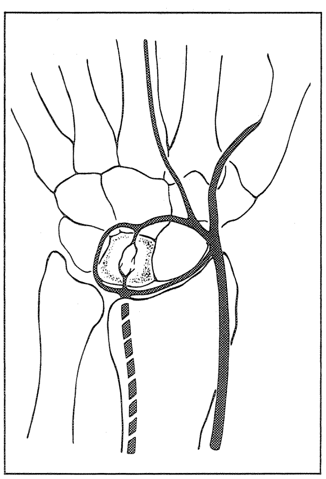
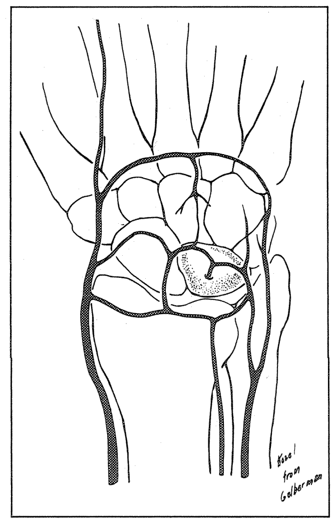


Fig. 3: Dorsal extraosseous vascularity of the lunate. Consistent contributions from the radial and anterior interosseous arteries, with inconsistent branches from the ulnar artery[5].

The extraosseous and intraosseous vascularity of the lunate has been elucidated[5,8]. Extraosseous vascular plexuses provide both dorsal and volar blood supply to the carpal lunate[5] (Fig. 3 and 4). The intraosseous vascularity seems to occur in three differing patterns (Fig. 5). The consistent feature of each is the orientation of the major vascular trunk in a dorsal-volar axis just distal to the center of the bone. Horizontal compression fractures separating the proximal pole from its vascular supply could initiate avascular necrosis[5,8]. Which of these intraosseous vascular patterns is most susceptible to Kienbock's disease, or if these vascular patterns occur in familial trends remains to be established.

Although unsubstantiated, it seems logical that vascular patterns, ulnar variance, and other etiological factors may occur in familial trends. Thus there may be genetic contribution to the development of avascular necrosis of the carpal lunate.

Fig. 4: Volar extraosseous vascularity of the lunate. A volar plexus composed of branches from the radial, ulnar, and anterior interosseous arteries, with a major supply via the recurrent branch of the deep palmar arch[5].



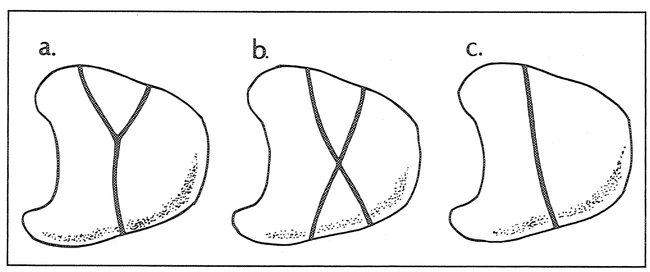


Fig. 5: Intraosseous vascularity of the lunate[5].
a) The Y pattern, with a volar or dorsal stem, 59 per cent of specimens.
b) X patterns 10 per cent.
c) I pattern 31 per cent.

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TALONAVICULAR INSTABILITY IN DIABETIC FEET

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Various patterns of bone and joint disease of the foot have been reported in patients with diabetic neuropathy. Although osteomyelitis has been the most common entity seen in these feet, neuropathic joints, as first reported by Charcot, have become increasingly well recognized. Included in this spectrum are isolated tarsal dislocations. Not much has been written, however, concerning the prevention, etiology, or treatment of these tarsal dislocations.

In this report we review eight cases with talonavicular dislocation in diabetic neuropathic joints. Both acute and chronic presentations with a period of follow up are included. A review of the literature is then presented. Treatment modalities are suggested based on the chronicity of the involvement as well as on the potential prophylaxis of this problem.

Case. 1. A fifty-nine year old Mexican male insulin dependent diabetic presented with pain and swelling of his left foot, localized to the medial aspect of the foot near the talonavicular joint. X-rays were within normal limits. He returned three weeks later at which time an x-ray showed a dislocated navicular. This was manually reducible, but unstable. The patient subsequently underwent talonavicular and navicular to first cuneiform arthrodeses with casting for three months. At eight months post surgery, the fixation screws had been removed and there was radiographic evidence of fusion of the talonavicular and navicular first cuneiform joints. He was weight bearing without any problems.

Case 2. A fifty-six year old American Indian male with a fifteen year history of insulin dependent diabetes presented with severe deformities of his ankles and feet bilaterally secondary to Charcot changes. A year later he underwent a right BKA for gangrene. His left foot, although deformed, demonstrated no ulcers or skin changes. Roentgenograms of the left foot showed a fragmented navicular with dislocation medially, as well as multiple Charcot changes throughout the tarus. He was functioning satisfactorily with no subjective complaints. Treatment consisted of attention to diabetic foot care, with well fitted foot wear; in this instance space shoes.

Case 3. A fifty-four year old American Indian male, an adult onset diabetic, not on insulin, initially injured his right foot twenty-nine years prior to presentation with pain and swelling as a result of blunt trauma. The foot was taped and the symptoms improved. When he was seen for the first time at the VA hospital in San Francisco, complaints consisted of medial foot pain after prolonged weight bearing. Physical exam revealed a protuberance on the medial aspect of his foot which was not reducible. Roentgenograms revealed an old medial and dorsal dislocation of the navicular on the talus. He refused surgery and was treated conservatively with a double upright brace with a medial T-strap, and has subsequently been lost to follow up.

Case 4. A fifty-five year old black male, insulin dependent diabetic of twenty years, had radiographs of his feet that showed Charcot changes including framentation in the cuneiform and other tarsal bones. Medial dislocation of the navicular was noted. Treatment was symptomatic only, consisting of vigilant skin care and proper fitting shoes.

Case 5. A thirty-three year old male diabetic referred to the University of Iowa with a complaint of medial right foot pain and swelling. Physical exam showed tenderness over the medial protrusion of the navicular as well as pain with motion and weight bearing. No skin changes were noted on the involved extremity. Roentgenograms revealed a navicular dislocation and early Charcot changes (Fig. 1). Although the dislocation was felt to be recent, Charcot changes were present, and he was treated with a short leg nonweight bearing cast, with progression to partial weight bearing after four weeks. After eight weeks of total immobilization he had improved markedly with minimal residual tenderness and was progressed to full weight bearing. His subsequent course has been asymptomatic.

DISCUSSION

There is no reason to suggest that bones in diabetic patients differ from bones in normal patients. Studies have shown normal ash composition of these neuropathic bones[5]. The problem rather lies with the insensate foot sustaining repetitive trauma. The initial injury appears to originate in the soft tissues rather than the bone.

Johnson has described a normal two phase reparative process of bone and soft tissue: atrophic (destructive or

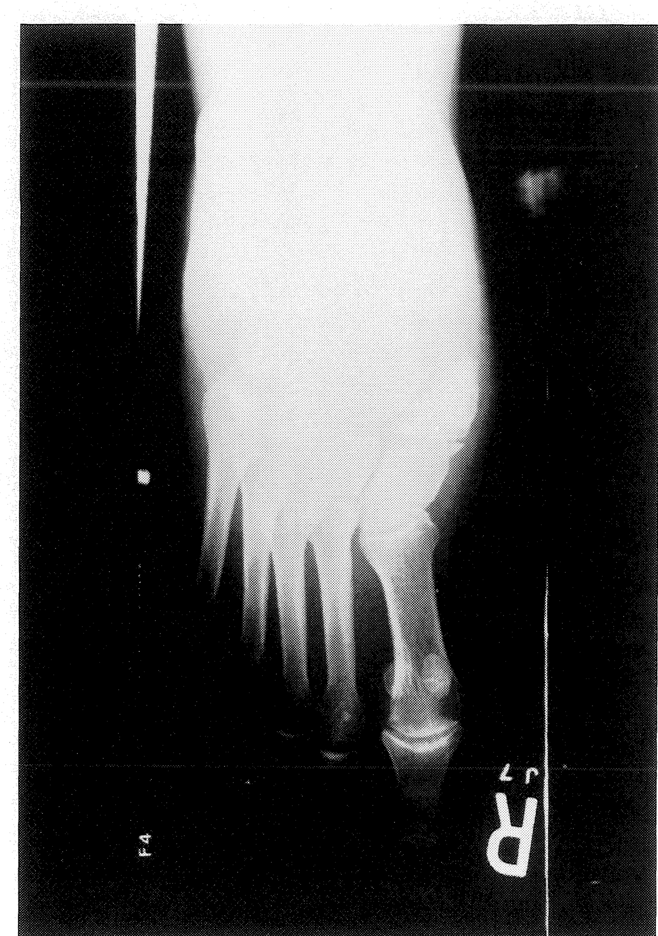

Figure 1-A

Figure 1-B

Fig. 1: (A, B, & C) A-P, lateral, and oblique right foot of Case 5. Navicular dislocation and Charcot changes are present.

Figure 1-C

hyperemic) phase and hypertrophic (reparative or sclerotic) phase. In the early destructive or atrophic phase, there is local hyperemia in which histiocytes and osteoclasts remove the irritant blood clot, dead bone, and cartilage. Bone resorption and softening can result from the initial phase of hyperemia, and the resultant atrophic bone can be easily traumatized. In the extremity with intact sensation, pain limits further trauma and the hypertrophic phase, or callous formation, can commence. However, the injured insensate extremity isn't rested and further trauma leads to more hyperemia and more resorption of damaged bone. In the neuropathic joint, this vicious cycle continues until the joint is destroyed.

A severe sprain by hyperemia resorption can cause stretching and weakening of the ligaments and capsule, especially at their osseous insertion. In the unprotected foot the undue stresses and abnormal positions are not prevented by pain and normal proprioception, and subsequent gradual stretching of the ligamentous structures continues until subluxation or complete dislocation occurs. Even a relatively minor fracture or sprain may signal the onset of disaster if it causes the joint to become unstable and subjected to abnormal stresses[5].

Similar ligament or bone and joint changes may be seen in joints without a sensory abnormality. These joints are referred to as "stoic joint injuries"[5]. These individuals are so rugged and determined, that even when sustaining a significant injury with traumatic synovitis and ligamentous laxity, they continue to weight bear and traumatize the joint. If this repeated stress destroys the joint more rapidly than it can be repaired, instability can develop with resultant Charcot-like changes.

Newman has described six different noninfectious conditions of the diabetic foot including spontaneous dislocation. The most striking finding of the spontaneous dislocations was the roentgenographically normal bony architecture. The abnormality was confined to the soft tissues. All six cases of spontaneous tarsal dislocations had had diabetes for a relatively short period, and none required insulin. This was in contrast to diabetic patients who subsequently developed the more common Charcot joint. Implicit is the primary role of ligamentous injury and laxity in this patient population as suggested by Johnson. A continuum may encompass these spontaneous tarsal dislocations and the Charcot joint, with the first major derangement being a spontaneous subluxation secondary to ligamentous laxity. If this remains unrecognized, the subsequent changes of dislocation, fracture, and hypertrophic bone formation are allowed to occur in an architecturally abnormal foot[3].

Generally, the amount of damage sustained is determined by the amount of sensory loss, the stress on the joint, and the patient's willingness to continue activity despite pain, swelling or deformity. Recognition of the problem is the first and most important step in treating these patients.

After recognition, the aim of treatment would be to provide a stable foot of satisfactory shape. This is accomplished by prolonged immobilization during the active phase of the disease so that the reparative phase can commence and proceed to final healing. If a deformity has developed, however, the chronicity of the problem has to be determined.

Patients seen acutely with reducible subluxations and without radiographic bony abnormalities would be candidates for a reduction and arthrodesis[7]. If Charcot changes exist or the subluxation is irreducible, then these injuries should be considered chronic and treated with immobilization, support, and reduced weight bearing until the destructive or initial phase has passed[5,7,10].

In treating the chronic patient who has Charcot changes, the goals are twofold: maintain stability and prevent pressure ulcers over prominent areas. When these patients present with red, swollen feet, they are best treated with immobilization and elevation until the atrophic phase has completed its course. Any surgical intervention at this time would only accelerate the destructive phase. Any subsequent foot deformities can then be dealt with in the second reparative phase. If trophic skin changes develop over areas of prominence, the bones should be surgically reduced before skin ulceration occurs[5,10]. Prophylaxis is the key in the treatment of these people.

A good supportive shoe wear is imperative[9]. Shoe wear should consist of a molded shoe insert or a shoe molded to the deformed foot with a rigid shank and rocker bottom sole so that during gait, weight bearing can pass from heel to toe without a "breaking" moment to the midfoot.

In the destructive phase, weight bearing should be restricted[4,10]. This can be accomplished by adding a patellar tendon bearing short leg brace to the above described shoe. This same brace may be used in the later reparative phase if the foot is severely deformed and in danger of skin breakdown in weight bearing areas.

Surgical correction for these neuropathic feet is reserved for either "the acute dislocations" or for correction of such severe deformity that soft tissue breakdown can not be prevented by footwear and bracing alone. Various midtarsal arthrodeses are successful when done after acute dislocation. Arthrodeses done in the late chronic phases have a higher incidence of nonunion[5,6], but union can be achieved if adjacent sclerotic bone is resected to expose healthy bleeding surfaces and nonweight bearing immobilization continues for three to four months.

People with neuropathic feet or diabetes should be watched carefully for any complaints of pain or signs of inflammation in their feet. Even in the absence of radiographic changes, if these patients present with pain, erythema, or swelling, they should be immobilized so that stability is maintained[6,10]. If this is not done they run the risk of subluxation or frank dislocation of their tarsal bones and possible progression to Charcot joints, ulceration, infection, and subsequent amputation.

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FOCAL MYOSITIS PRESENTING AS A SOFT TISSUE MASS

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Focal myositis, a benign inflammatory pseudotumor of skeletal muscle, may closely resemble a malignant, rapidly growing soft tissue sarcoma[1-4]. Typically, patients notice a mildly painful, poorly circumscribed, and steadily enlarging mass in an extremity. Microscopic examination of the lesion shows lymphocytic infiltrates, muscle fiber necrosis, fibrosis, and muscle fiber regeneration resembling polymyositis, but the process remains localized.

This paper presents an example of focal myositis presenting as a thigh mass initially considered to be a possible sarcoma and reviews the clinical and histologic features of this deceptive lesion.

CASE REPORT

A sixty-five year old white female presented with a fifteen month history of progressive enlargement of a painless right hip mass. She denied a history of trauma to the area, prior masses, muscle weakness or dysfunction, similar masses elsewhere, collagen vascular diseases, or skin diseases. A discrete 12 × 9 cm nontender, soft tissue mass was present 10 cm inferior to the right iliac crest. Radiographs showed a soft tissue mass with no bony involvement. A blood pool scan with 99M-Tc MDP showed slight uptake in the mass implying increased blood pooling. Biopsy was done under general anesthesia and a pale fibrofatty tissue was found infiltrating the gluteus medius.

The specimen was fixed in formalin and processed in a muscle clamp (per the protocol of Dubowitz and Brooke[5]). Hemotoxylin and eosin sections showed atrophic muscle fibers, interstitial fibrosis, central nuclei, a diffuse inflammatory cell infiltrate and regenerating and necrotic muscle cells (Fig. 1). This inflammatory myopathy was consistent with the pathologic diagnosis of focal myositis.

DISCUSSION

Focal myositis is one of a group of inflammatory pseudotumors of skeletal muscle which includes myositis ossificans, proliferative myositis, and nodular pseudosarcomatous fasciitis. It was initially described as a clinical entity in 1977[1]. In the reported examples of focal myositis the lesion has appeared as a steadily enlarging mass within

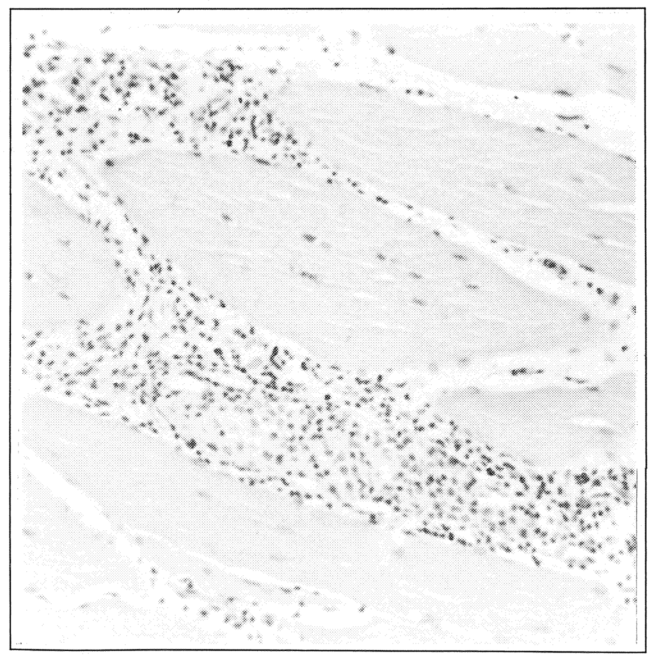

Fig. 1: Light micrograph of the biopsy specimen showing infiltration of inflammatory cells among the skeletal muscle cells. (16×)

skeletal muscle most commonly in the lower extremity, but additional sites have included the thorax, abdomen, forearm, perioral musculature, and sternocleidomastoid[1-4]. The mass is typically painful and unattached to the overlying skin. It may be present from two weeks to three years prior to surgery and often undergoes a rapid growth phase during a two to eight week period. Excised specimens have measured 10 cm in diameter, but more commonly range from 2-5 cm. Radiographs may show a soft tissue density. Arteriography and computerized tomography appear to contribute little to the diagnosis[10]. Blood pool scans show enhanced uptake, but do not add significant information.

Characteristic histologic findings distinguish this lesion from the other focal inflammatory myopathies. In proliferative myositis, there is prominent fibroblastic proliferation within the connective tissue and large basophilic giant cells[6] which are absent in focal myositis. Fascial involvement, a zonal phenomenon of varying maturity in ossification, and complete replacement of muscle fibers in a circumscribed area such as occurs in nodular fasciitis and myositis ossificans[7,8] are also absent in focal myositis. While polymyositis has been reported as a focal lesion[9], progression to systemic disease eventually occurs.

Searches for the etiologic agent have thus far been unsuccessful. Heffner, in the original series, reported no identifiable organisms using special histochemical stains and electron microscopy[1]. Although, localized trauma may have a role, no clear examples of focal myositis following injury have been reported. Changes consistent with denervation atrophy, reinervation, and fiber hypertrophy have been found[2]; these suggest a denervating process might play an important role in the pathogenesis. Vascular thrombi have also been reported[4], but the thrombi probably represent a normal response to severe focal inflammation.

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