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INSTRUCTIONS FOR AUTHORS

Any article relevant to orthopaedic surgery, orthopaedic science and the teaching of either will be considered by *The Iowa Orthopaedic Journal* 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. The journal will be published annually in May or June. The deadline for receipt of articles for the 1987 journal is February 1, 1987.

Articles published and their illustrations become the property of *The Journal.*

When you send an article it is *essential* that the following items be submitted:

The **original manuscript complete with illustrations.** The corresponding author must be clearly identified with address and telephone number. Manuscripts of accepted articles will not be returned.

2. A **bibliography,** alphabetical and double-spaced, of references made in text only. Refer to bibliographies in this copy of *The Journal* and follow style exactly.
3. **Legends** for all illustrations submitted, listed in order and typed doubled-spaced.
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   a. *Black-and-white glossy prints* of photographs. Give *magnification* of photomicrographs.
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Preparation of manuscript: Manuscripts must be typewritten, double-spaced with wide margins. Write out figures under 100 except percentages, degrees, or figures expressed in decimals. A direct quotation should include the exact page number on which it appeared in the book or article. All measurements should be given in SI metric units. In reporting results of surgery, only in rare instances can cases with less than two years' follow-up be accepted.

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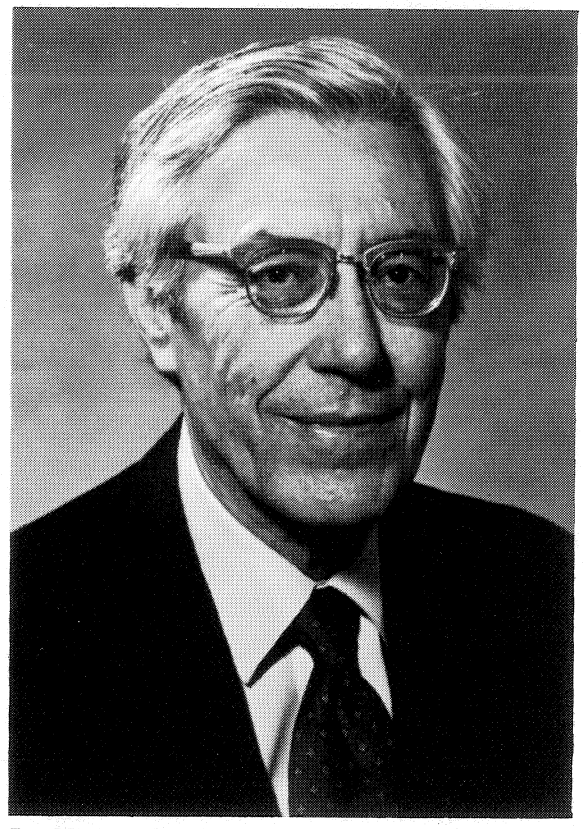

Dr. Michael Bonfiglio

The Iowa Orthopaedic Journal

Editor's Note

This journal has as its primary purpose education, and those who participate in its production undoubtedly learn the most. The journal also seeks to reflect the activity of the residents, faculty, alumni, and visitors to the department in a forum that allows the dissemination of scientific thought. As such we have included historical and philosophic articles as well as scientific and general review articles. The contents of this edition provide testament to its educational excellence. This reflects the authors' dedication to the highest standards in education, and we thank them for their contributions.

We would also like to thank Drs. Cooper, Clark and Weinstein for their guidance, Dale Clark for his administrative assistance, and Lois Riggan for her secretarial help in the production of this 6th edition. We extend a special thanks to Jeanette Marsh for her cooperation and superb secretarial help throughout the year.

We would like to dedicate the 6th edition of this Iowa Orthopaedic Journal to Dr. Michael Bonfiglio in honor of his upcoming transition to Emeritus Professor in June of 1987. The Michael Bonfiglio Lectureship in Orthopaedic Pathology was established this past year in honor of his many contributions to Iowa Orthopaedics and to Orthopaedics over the world. This edition notes a few of those contributions as a special thanks to Dr. Bonfiglio.

We hope that you, the reader, benefit from our efforts and welcome your response and constructive criticism.

JJH
RRW

A TRIBUTE TO DR. BONFIGLIO

Michael R. Mickelson, M.D.
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Pocatello, Idaho 83201

Dr. Bonfiglio, honored guests, and faculty, I am deeply honored to address you at such an occasion. Dr. Bonfiglio has meant so much to so many medical students and residents, and I feel privileged to represent them. For a few minutes I would like to reflect on that influence.

In his 35 year career in the Department of Orthopaedics and the College of Medicine, Dr. Bonfiglio has exemplified the true professor, one of those duties being a leader in education. He has organized one of the best, if not the premier student education resource centers available. In addition, he has single-handedly maintained a renowned clinically correlated pathology collection so that medical students, residents, fellows and faculty alike can continue to learn the basis for orthopaedic practice.

He has been continuously involved in medical student education, especially at the junior and senior level; and has formulated and implemented for many years an outstanding series of lectures for the junior orthopaedic clerkship. For many senior medical students, his senior electives have been the impetus to launch impressive orthopaedic careers. Thousands of physicians, graduates of the University, owe a debt of gratitude to you Dr. Bonfiglio for your commitment to education.

As residents under Dr. Bonfiglio's guidance, we managed to progress through roughly three stages. The first stage was termed by some healthy *Respect,* by others pure fear. We knew he was a physician demanding perfection and we were afraid to make a mistake, yet afraid not to try our best.

The second stage of our relationship with Dr. Bonfiglio is best summed up by the term *Admiration.* We all came to respect and appreciate his expertise and exactness. We realized there was no substitute for absolute thoroughness. The patient's life or limb may be at stake if our history was not thorough or directed appropriately. The physical exam must be completed with precision, and the x-rays (yes I mean *all* of the x-rays) interpreted appropriately. The pathology slides need to be reviewed, sometimes re-reviewed and sometimes recut. Yes, we needed all the data.

All of these lessons made us realize that we were learning the profession from a man who was using the scientific method to solve human problems.

The third stage of the residents' relationship with Dr. Bonfiglio is that of *Friendship* and *Comraderie* in a team approach. As senior residents, he gave us the confidence and guidance to analyze difficult problems, arrive at solutions, and perform difficult procedures as a team. More importantly, he taught us how to be compassionate physicians rather than medical technicians. We realized this by his example. An introductory touch of a handshake and square look in the eye confirmed to the patient that not only was the physician a human being too, but that we were sincerely interested in their problem. He taught us to sit down with our patients, conveying to them a willingness to listen. And when times got tough for the patients, we learned how to communicate the reality of their problem, yet to always maintain an optimistic attitude and give them hope.

We as former medical students and residents wish to thank you for never closing your door, for always being available to help us learn the scientific aspects of our profession. More importantly, thank you for teaching us to never close our heart to the patient and helping us realize that compassion and sincerity are virtues of incomparable merit.

M.R. Mickelson, M.D.

Presented at the Iowa Orthopaedic Alumni Association Meeting, September 19-21, 1985.

MEMORIES

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I've been asked to share with you a few memories of my life prior to coming to Iowa and some of those experiences which took place here. It might be subtitled "Serendipity".

Primarily, I'm glad to reminisce for my contemporaries so they will recall how things used to be. As for you YURPIES-Young Urban Rural Professional persons, what you need to know is that no matter how tough it is for you today, it was a lot tougher then!

As a product of Milwaukee's Third Ward, son of immigrant Sicilian parents, I was an integral part of the melting pot composed of many newly arrived families from diverse backgrounds who made their first homes there. As a result, I suffered from a language barrier as a youngster; that indigenous lingo known as "Milwaukee Talk". It's a combination of German, Polish, American English and twisted somewhat by a Sicilian accent and it sounds like this: "I lived by M'lwaukee awreddy and we go swimming down by the jumpin' board where the water is the tickest".

Fortunately the teachers had no problem with understanding us and it was from this kind of background that I learned the importance of education. It was those very teachers who helped to push kids like me into trying to do our best. I got an eraser in the face for failing to stop and think before giving an answer. Reasoning was administered with a ruler across the wrist or the calf of your leg which goes to show that simple methods of instruction were often the best — but they got our attention first. Miss Carrie Pashelles, a 7th grade teacher, demanded near perfection and served as my conscience ever since. She corresponded with me regularly until she died at the age of eighty-five. Surely there was a Miss Pashelles in your life too!

After high school and a couple of years of work in a Milwaukee drug company, (as a pill packager), I had enough tuition money for Columbia and went to New York to see what cosmopolitan life had to offer. It was far more exciting than I had thought as I studied with men in the forefront of their fields such as Nobel Laureates Harold Urey in Chemistry and Polykarp Kusch in Physics. Then there was Vladimir Kasekevich, a most colorful, wild eyed White Russian modern history teacher (who wore odd socks) — all of them made their classes most interesting. After finishing my third year at Columbia, I tried for medical school there and at Harvard, but it turned out they had a known reluctance to fill up classes with the children of so many immigrant kids from the neighborhood. My chance came at the University of Chicago where the system was more amenable and the school was closer to home.

It was my good fortune to go for an interview over the Christmas holidays when the only member of the Admissions Committee around over the Christmas holiday was Arno Luckhardt who was the first to use ethylene as an anesthetic gas. He projected the goals of the medical school and its image in most amiable manner. They seemed to match those I expressed to him. I was elated to be notified of acceptance a few weeks later.

At Chicago, I felt more at home than in New York, but equally in awe of the instructors and the system. Medical school was much less restrictive and carried with it a lot more responsibility than I had originally thought. We were pushed and given little opportunity to fail. If there was any slack in our performance we knew about it immediately and worked all the harder to avoid trouble. (Some of you may have felt that push while you were here to help bring out *your* best!)

I am indebted to the many instructors who gave unstintingly of their time and effort to instill principles in the medical students. An example of such a principle was brought home to students when one of Dr. Phemister's patients who would not let him start an operation until "her doctor", a third year medical student, was in the room. The student was promptly called from class and the operation delayed until he arrived.

My introduction to Dr. Hatcher and Orthopaedics came by way of a summer job, as an extern at the Country Home for Convalescent Children near West Chicago, IL. He conducted the interview, beginning with the question "How well do you get along with little old ladies?" The director was a Miss Dunwiddie, and only nurses and nurses aides worked under her supervision. Miss Dunwiddie required that the student come to her office for afternoon tea. So, I learned to like tea, while also reporting to Dr. Hatcher once a week on the health of children with TB,

Presented at the Iowa Orthopaedic Alumni Meeting on September 18, 1985.

osteomyelitis, polio, and rheumatic fever. The rides on the Crandic-like interurban trolley are indelibly stamped in my memory.

After graduation I started an internship at Chicago and met Fred Stamler from Iowa, my first "Iowa connection". We became, and remain, good friends and later he was an influence in our decision to come to Iowa. A rotation on Orthopaedics during a polio epidemic brought me to work for Dr. Hatcher again and with Dr. Mary Sherman, his senior resident, who was assigned to the service where the acute polio patients were housed. It was a most enlightening experience. Drs. Hatcher and Sherman employed simple routine hospital care while other hospitals went in for "special hot pack treatments". When we later compared our results of residual weakness to theirs, they were almost identical except that it was noted that our patients had less stiffness. I was offered a residency at the end of that rotation.

During that residency Gene Mindell, Tom Brower, Jim Miles, and later Crawford Campbell came along and made my life easy — depending on one's point of view! Dr. Enneking came later and shared the same interest. We got involved in teaching orthopaedic pathology to junior medical students and surgical anatomy to senior medical students — from which of course, we learned more than the students did.

Remember Yogi Berra's first law: "You can observe a lot by just watching."

So, after a year and a half of residency, I went into the Army for two years. During that time, I had excellent supervision of a number of commanding officers including Bob Denham from Indiana, and Carroll Adams, another Hatcher resident, from Mason City. I was fortunate to stay on the Orthopaedic service as there was enough work for all of us.

I returned to finish my residency at Chicago to spend a year as Phemister's resident. That was when, at his suggestion, two projects were started. The one on the immunology of bone and skin transplants was continued here with Wayburn Jeter and Irvin Snyder and the other on the repair of aseptic necrosis of the femoral head was continued as a clinical project. Another facet of that is under study with Drs. Brand and Brown.

An indication of Dr. Hatcher's teaching style came when he encouraged me to write up the cases of eosinophilic granuloma which were in the path files. I did, and presented the paper to the Chicago Orthopaedic Society in 1949. It was the one that Ponseti heard, since he was a member. The paper never was published, after thirteen revisions. However, twenty-five years later, Dr. Hatcher returned it with a cryptic note: "It has been under my blotter long enough".

Ponseti suggested that I might like the Iowa Department of Orthopaedics. After coming here for an interview, I thought it was a great idea. Of course, every resident was aware of the excellent work which was done here. It was a pleasure to join the staff.

We all lucked out when Carroll Larson took the department chairmanship. We found him very influential in guiding young staff and residents and medical students. His was more the indirect approach beginning with a phrase "Had you ever thought about . . .?". He was the kind of teacher who could encourage, and provide time and leadership for developing the potential in each of his staff. He was reassuring without being intrusive.

To reminisce, I saw him lose his cool only once — A group of well-intentioned residents asked if they could have Wednesday afternoons off, "to play golf like other doctors!" They were surprised at his lack of understanding of the problem. We owe him much.

We know that Larson's teaching style worked as evidenced by the many men who were Iowa residents under his direction, now examiners at the Boards . . . and we have Dave Murray as a past President of the Academy, we have Reg Cooper past Secretary and President-Elect and not to mention several Kappa Delta Awards in research . . . that's leadership at its best.

As you know, I have worked with Naci for thirty-five years. He has been my closest colleague during this long stretch. He has pointed the way for me, as well as for the residents, and I have enjoyed every minute of it. As you may know, our names are often confused by members at national meetings — they see one of us, think "Iowa" — and a name ending with a vowel. During an in depth discussion of this problem, he told me that he knew why this was happening. He told me it was because he had lost his accent! I *thought* it was because we looked so much alike! It's not an easy choice.

Looking for answers to tough tumor problems often took me to the Pathology Department to talk with real pathologists. Fred Stamler and Emory Warner and more recently Chuck Platz have been a source of strength and insight as they showed us possible approaches to the problems of patients with tumors. Their advice has been invaluable to the department, the referring orthopaedist, and to me in particular. They have always been helpful with my difficulties.

Carl Gillies came to the department as our expert radiologist in the 60's. He was a man who saved us from many a missed diagnosis. His keen eye for radiographic signs of child abuse was uncanny. Finding unusual fractures was his special contribution to my education. I hesitate to recall how many times he found answers for me, and was gracious about it.

Finally, you ought to understand, that each of these academicians were doctors first, they learned the basics, and they never took their eyes from the "patient's point of view", but over and above that they were teachers. That's what I wanted to do!!!

Some of you more recent residents may wonder about my favorite story about Reg Cooper—how he has been able to accomplish so much over ten years as a department head and all—Well, while one hesitates to oversimplify, it can easily be traced to his interest in music! After hearing him play the guitar and sing country-western, the senior staff all agreed, "We must put that man behind a super microscope". See what happened—he became an expert in electron microscopy. That's teaching!

The opportunity at Iowa, earlier with Naci, Carroll, and Adrian, and now with all of my younger colleagues, let me reap the greatest rewards of teaching.

I would be remiss not to say a word about my good friends and colleagues Jonathan Cohen and the late Crawford Campbell, men who have enhanced my professional life through association on The Journal Editorial Board, the Academy Path Committee and ABOS examinations

I am indebted to my wife and four children for strong and continued support who have added the balance and responsibility needed for a full life—and the grandchildren are an excuse to travel!

Over the years, there have been some allusions to my arbitrariness—these have been true but misunderstood . . . it was only a teaching technique, but worth it all just to see you here today—laughing.

I offer special thanks to former staff member, Mike Mickelson for his kind words, plus the many hours of service he gave. I am grateful to Charles Clark and Joseph Buckwalter for having put the program together. There are never enough thank-yous to pass out to all of the nurses, residents, students, and secretaries who have had to put up with me—but the gratitude is there.

REPAIR OF BONE DEFECTS WITH AUTOGENOUS GRAFTS AFTER TREATMENT OF BONE TUMORS BY LOCAL RESECTION

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Transplantation of organs, limbs, and bones is a very old concept. In the beginning Adam lost a rib: the first major orthopaedic transplant operation by the greatest orthopaedic surgeon of them all. This started the natural evolution of our subject and look at the marvelous end result! (Genesis 2:21-23)

The subject captured the imagination of man through artists of medieval times[17]. Pictures of the great painters often adorned the hospitals and especially recorded the miracles of the medical saints of the time. Saint Damien and Saint Cosmas performed miracles in the middle ages, one of which was the transplantation of a Moor's leg to a white man who had an amputation for a cancer of the leg (Fig. 1). It is obvious that no one then paid attention to the immunologic aspects of transplantation in the performance of what was an obvious composite allograft[12].

Figure 1
Transplantation of a Moor's leg to a white man after amputation for a cancer of the leg by Saint Cosmas and Saint Damien, from a triptych by Hugnet, a 15th century Catalan printer. Displayed in a church in Tarassa, Spain (Courtesy of Dr. Ponseti).

One could spend the entire time in the discussion of the fascinating history of human tissue and organ transplantation. My purpose, however, is to put in proper perspective the role of bone transplantation in the repair of defects created by the surgical treatment of bone tumors. In particular, I will concentrate on the repair of surgical defects with autogenous bone and show the functional result in several patients.

Bone transplants used in orthopaedic surgery have included autografts, allografts — fresh, frozen or freeze-dried, and xenograft. Autografts may be free or vascularized. Allografts are usually free. One must assume that in the painting just depicted, that a vascularized composite allograft was used. There has been considerable experimental effort directed toward the use of a vascularized allograft of bone but the problems, both experimental and clinical, have been so great as to make that method impractical for general use at this time. Fortunately, xenografts of bone are no longer used.

The repair of various kinds of grafts has been extensively studied, demonstrating the use of free autogenous grafts in the experimental animal, and need not be repeated here[2,3,7,17]. Autogenous bone still provides the best osteogenic potential for repair and incorporation into the recipient bed. The surface cells in the periosteum and endosteum of the fresh autografts actively proliferate to provide the osteoblasts for the new bone. Reconstitution of the graft by revascularization and replacement proceeds in an orderly manner. Graft fractures occur commonly in transplants healing readily in autografts but not in allografts[1,9]. This capacity for healing is essential when bridging large defects after resection or curettage of tumors.

The repair of bone autografts in humans confirms the experimental data. Cortical-cancellous grafts repair rapidly and become incorporated in the recipient bed (Figs. 2, 3).

Cortical bone undergoes repair in a somewhat slower but no less effective manner. A tibial bone graft recovered at fourteen months after bone grafting for nonunion and aseptic necrosis of the femoral head shows Haversian systems reforming throughout the tibial graft (Fig. 4).

A high power view showed that approximately 50 per cent of the graft was replaced at that time. Similar observations have been made from many other specimens indicating that over the course of time, replacement is as much as 90 percent over a ten year period. The graft, however,

Presented at the Iowa Orthopaedic Alumni Meeting on September 19, 1985

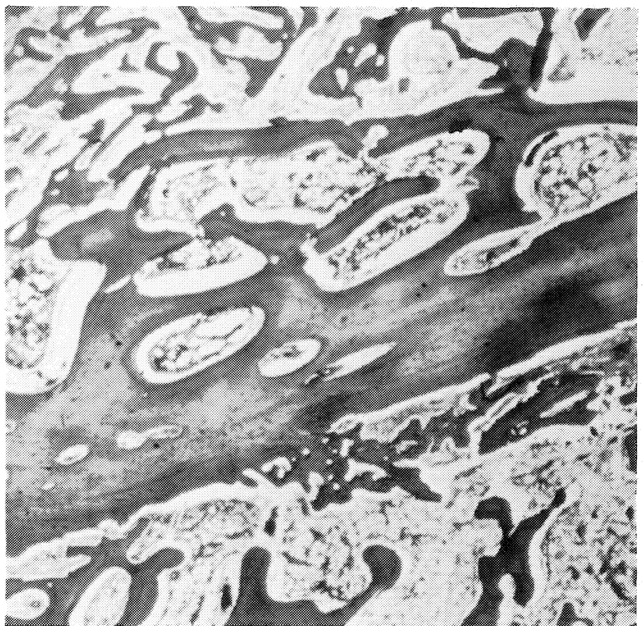

Figure 2
Cortical cancellous graft—seven weeks spinal fusion bed. X30

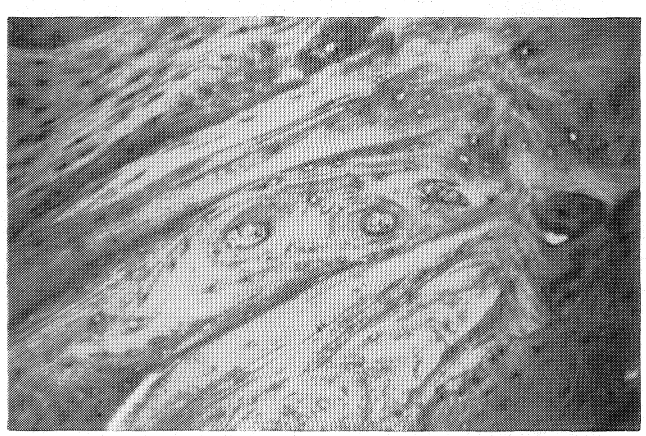

Figure 3
H-graft—one year spinal fusion bed. X100

Figure 4
Tibial cortical graft—fourteen months. Low X30

functions well long before that point is reached.

Clinical situations for use of free autogenous bone transplants include nonunion, defects, cavities, arthrodesis and support[9]. They are applied in an onlay, sliding, medullary, or combination method, with the tibia, ilium, rib, fibula or local bone serving as a source of bone. A vascularized graft can be obtained from the ilium, rib, or fibula[25].

Talking abut bone tumors to many of you in the audience (and particularly to Drs. Enneking and Mindell) is like "bringing coals to Newcastle", but I thought I would share with you a few of my experiences in the use of free autogenous transplants to repair defects created by treatment of bone tumors.

Reconstruction procedures following intralesional, marginal, or wide resection of malignant bone tumors utilize transplants of autograft and allografts with or without internal fixation[7,12,14]. Arthrodesis of the joint and replacement prostheses of various kinds are also utilized[7]. Other supportive procedures include internal fixation using screws, plates, or intramedullary rods, or external fixation.

With any method the goals of treatment should always be those of local control, survival, and whenever possible, preservation of function—a principle espoused in an editorial by Dr. Phemister in 1951, but practiced by him long before that[14,20,21,22,23].

Before undertaking any plan of treatment a careful evaluation of the tumor, including staging, histologic diagnosis, and consultation with pathologist, radiologist, and oncologist is essential[9,10,16,19].

There is much diversity of opinion regarding treatment of malignant bone tumors[6]. The surgical treatment of bone tumors depends on the type of malignant tumor, the extent and location of the lesion, and the particular philosophy of the surgeon regarding such tumors[14,22]. Sarcomas located in an extremity are usually treated by amputation or disarticulation with or without prior chemotherapy or radiation therapy[16]. In addition, reports of long-term survival after resection of bone sarcoma would suggest that factors other than the mode of surgery determine the survival of a patient[24].

The anatomical sites most amenable to repair of autogenous bone grafts after local excision of selected bone tumors are those in the diaphyseal-metaphyseal location. Defects created by resection of tumors about joints may require autografts to assist in arthrodesis of the joint[7,8].

Since it is worthwhile to save hand function, a tumor in the upper limb lends itself to resection provided there has not been extensive invasion of soft parts (particularly nerves and vessels). In such cases, amputation or disarticulation may be preferable unless tendon transfers are available to restore function. The scapula or clavicle may be removed with mimimal functional loss. Removal of the proximal end of the humerus will require suture of the shoulder muscles to the humerus, replacement with a prosthesis, or shoulder fusion. Reconstruction after resection of a humeral diaphyseal-metaphyseal segment requires tibial or fibular bone grafts with insertion of an intramedullary rod for stability. Replacement prosthesis or arthrodesis with a bridging bone transplant are methods of management for resection about the elbow. Resection of the distal two thirds of the ulna without replacement is compatible with good function. The proximal third of the fibula may be used to replace the distal end of the radius. The wrist can be fused with a posteromedial tibial bone graft as described by Campbell[4,5].

In the lower limb, the same principles apply. In my opinion, however, malignant tumors about the knee and ankle joints are usually best treated by amputation since modern prosthetic limbs afford the patient good function after surgery. If the patient refuses amputation, resection and fusion can be performed. Replacement prostheses are useful in the proximal femur but are not as functional over time in the lower femur. Massive resections of the lower femur and replacement with cadaver allografts have also been used. The results are unpredictable due to the allograft rejection reaction to these implants. In particular the massive amount of necrotic bone causes complications leading to loss of knee joint function, resorption of bone, and fractures. Tumors located anywhere in the fibula may be resected with impunity.

The cases that follow illustrate a few examples of the treatment of bone tumors by marginal or wide excision and reconstruction with autogenous free grafts and in one case, with a vascularized bone graft.

A forty-one year old farmer-politician complained of pain in his left knee for nine months. He had pain one day while pitching hay, then fell four months later followed by swelling of his knee. The swelling receded. He had mild swelling, pain and limp thereafter. Radiographs made eight months after the onset of his first symptom show a large lytic process in the proximal posteromedial aspect of his knee (Fig. 5A). This giant cell tumor was treated by an

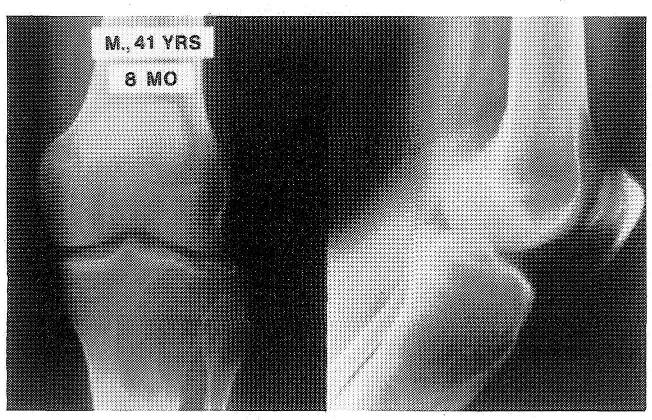

Figure 5a
Giant cell tumor, anterolateral proximal tibia, 41 year old male eight months post onset of symptoms.

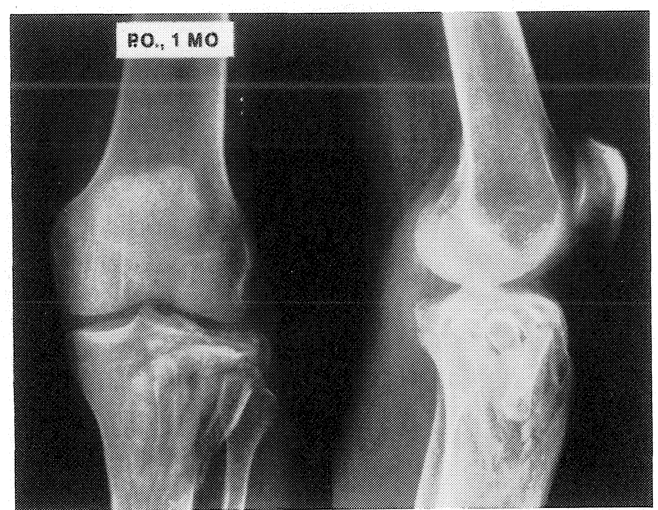

Figure 5b
One month post surgery—iliac grafts.

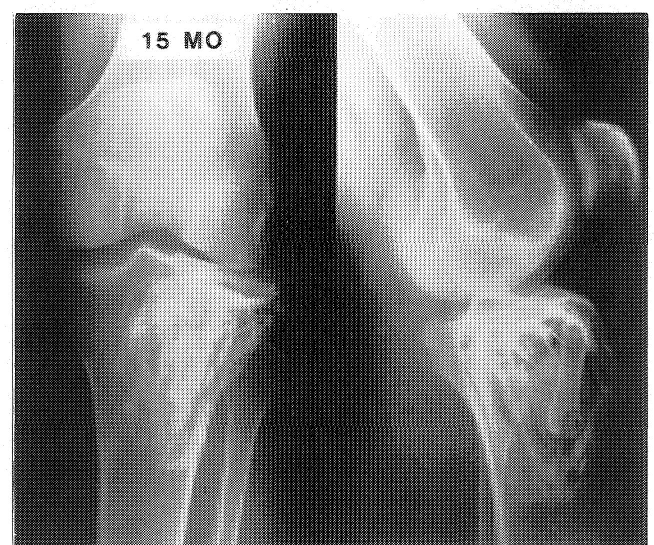

Figure 5c
Fifteen months post surgery—iliac grafts.

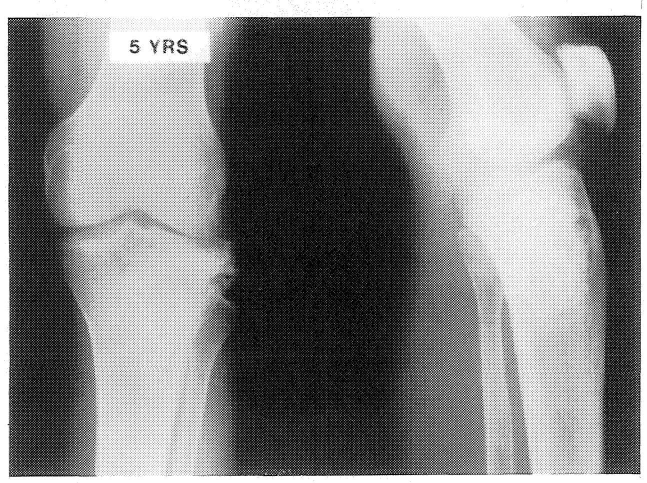

Figure 5d
Five years—no recurrence—full function.

intralesional resection and curettage including the subchondral cortex using a high speed burr. The defect was repaired with autogenous iliac bone. A concave cortical-cancellous piece was inserted to support the articular cartilage and struts of cortical-cancellous bone were placed perpendicularly to prevent collapse of the articular surface as shown, at one month post operation (Fig. 5B). He walked with a long leg cast for three months. At fifteen months, the grafts are incorporated (Fig. 5C). At five years radiographs show no recurrence and the defect is solidly healed (Fig. 5D). The patient is doing well at ten years.

The second patient, a twenty-one year old male, presented with a recurrence from an intralesional curettage for a giant cell tumor of the proximal tibia. The radiographs show that recurrence is laterally and posteriorly located (Fig. 6A). A gross specimen photograph shows the extent of the recurrence in the resected posterolateral aspect of the proximal tibia after a marginal excision of the tumor (Fig. 6B). The histological features are those of a classical giant cell tumor. One reason for recurrence was the invasion of the subchondral cortex and the articular cartilage by the giant cell tumor as shown in this photomicrograph (Fig. 6C). This underscores the difficulty with curettage alone as a surgical procedure. Part of the femur was turned down as a free local autogenous graft and the upper end of the fibula was used to fill the defect in the femur. A radiograph shows solid fusion of his knee twelve years after a marginal resection and reconstruction (Fig. 6D).

Figure 6a
Giant cell tumor, 21 year old male, AP and lateral knee.

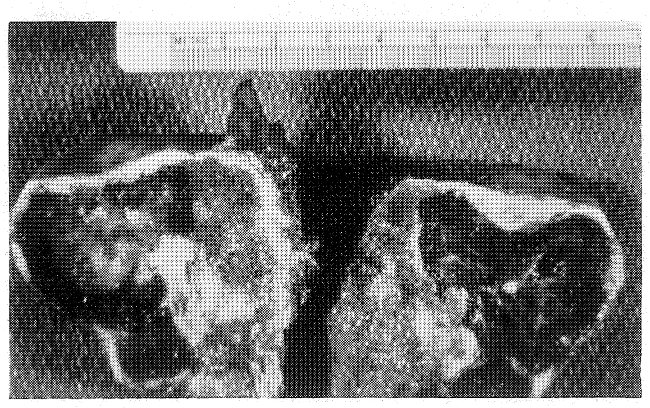

Figure 6b
Gross specimen, giant cell tumor extends to subchondral cortex.

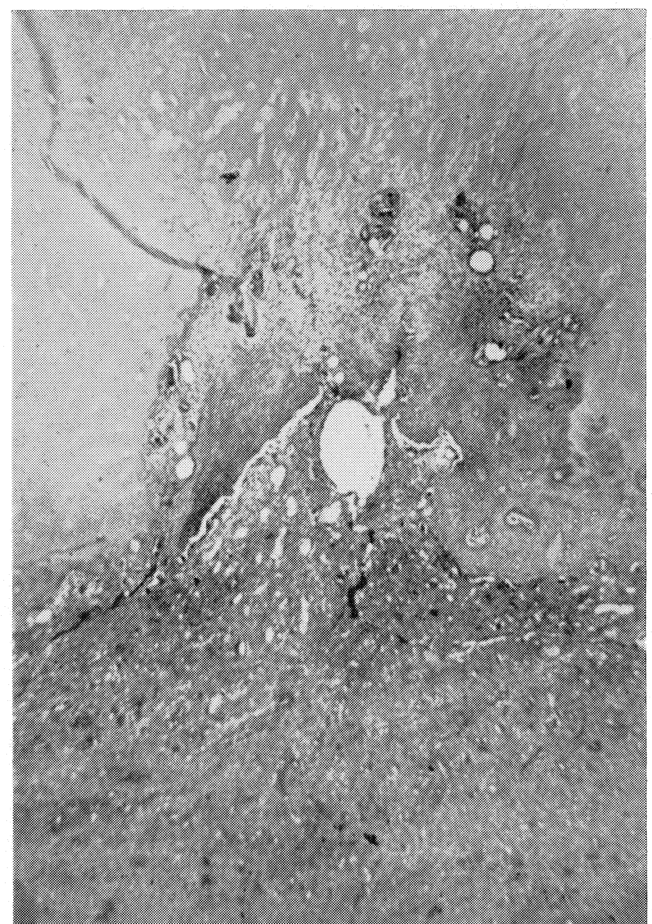

Figure 6c
Shows giant cell tumor invading subchondral cortex. Micro X150

Figure 6d
Arthrodesis of knee with local bone—distal femur and proximal fibula.

Parosteal osteosarcomas are known to have a better prognosis than classic osteosarcoma and therefore lend themselves to a limb sparing resection whenever feasible. The following case demonstrates the repair after a resection of a parosteal osteosarcoma of the right humerus.

A twenty-eight year old woman presented with a painless mass in the right humerus of eight months duration. The roentgenograms of her humerus show a lytic lesion involving the distal third with a mass extending laterally and anteriorly to the humerus on palpation (Fig. 7A). On biopsy, the histologic diagnosis was that of a low grade parosteal osteosarcoma. A gross photo of the specimen illustrates the extent of the tumor and the excised biopsy tract (Fig. 7B). It also included the radial nerve. Reconstruction was accomplished by the use of an intramedullary rod and a large autogenous tibial inlay graft. The graft was held in place with sutures and the remaining muscle envelope. At one year the humerus had sufficiently repaired to remove external support, and tendon transfers for the wrist drop and loss of finger extensors were performed at that time. At two years after resection the Kuntschner rod was replaced with a shorter one to relieve restricted shoulder motion. At seventeen years the bony reconstruction is excellent (Fig. 7C). The patient has excellent function of her right upper limb.

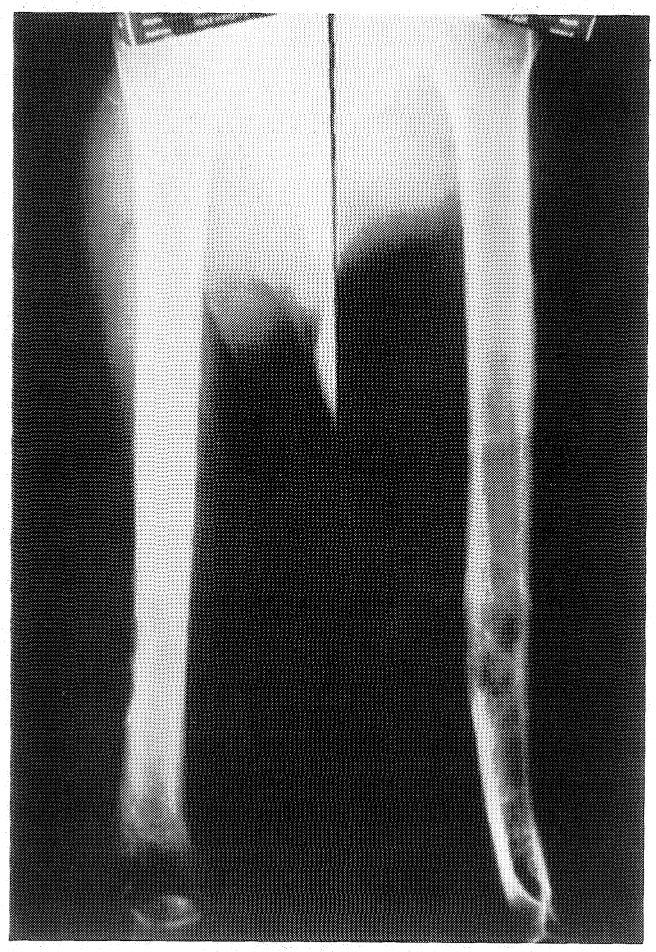

Figure 7a
Twenty-eight year old female, AP and lateral right humerus — parosteal osteosarcoma.

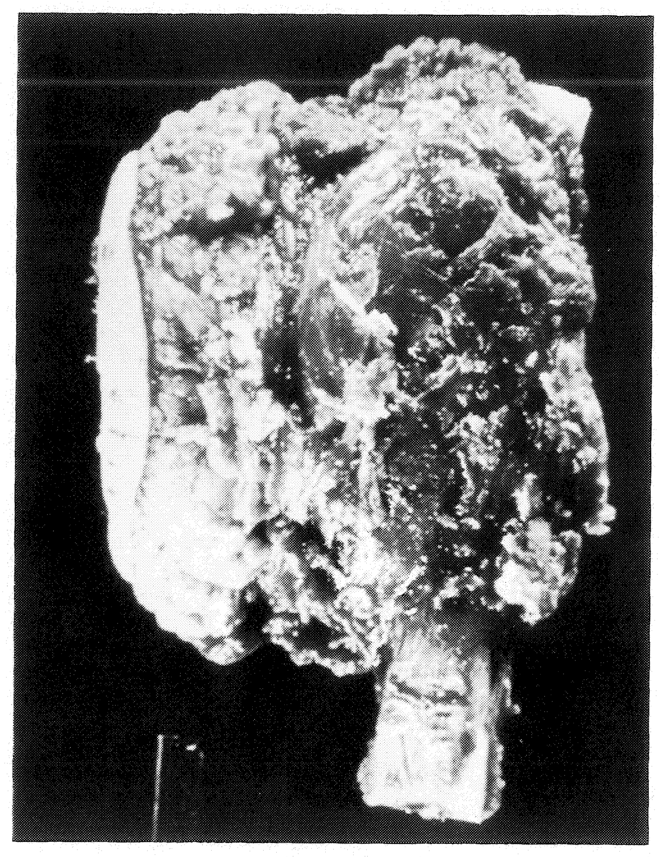

Figure 7b
Gross photograph of resected specimen.

The next example is that of a low grade chondrosarcoma arising from an enchondroma of the proximal femur in a twenty-nine year old man (Fig. 8A). The patient presented with an aching of the right thigh for ten months. The gross photograph and x-ray of the split specimen are shown (Fig. 8B). The resection of 17 centimeters of the proximal diaphysis of the femur was performed with reconstruction by tibia as well as iliac grafts after stabilization with a Kuntschner intramedullary nail. (We would probably now use a Zickel rod for this same problem.) The postoperative treatment was a single hip spica for nine months. One year after resection, the transplants were well incorporated and function of the limb is good (Fig. 8C). At two years supplemental bone from the ilium was added (Fig. 8D). There is no evidence of recurrence or metastases at twenty-five years after surgery and the femur (Fig. 8E) and tibial donor site (Fig. 8F) are reconstituted. Except for 3 cm of shortening of the right lower limb, the patient has excellent function of his hip and knee.

For lesions involving the distal end of the radius a resec-

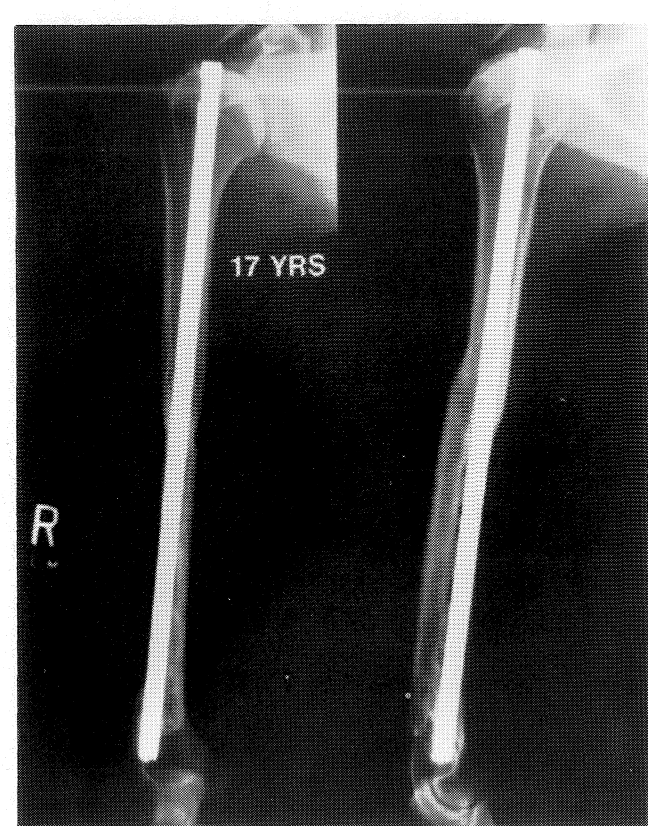

Figure 7c
AP and lateral reconstructed humerous at seventeen years after resection.

Figure 8a
AP and lateral radiograph shows lytic lesion in proximal third of femoral shaft. Biopsy proven low grade chondrosarcoma.

tion followed by fusion to the lunate and scaphoid with a posteromedial tibial graft provides excellent function of the forearm[5].

A fifty-five year old woman had a lytic lesion of her radius curetted elsewhere for mild pain in her wrist (Fig. 9A). The histological diagnosis was low grade chondrosar-

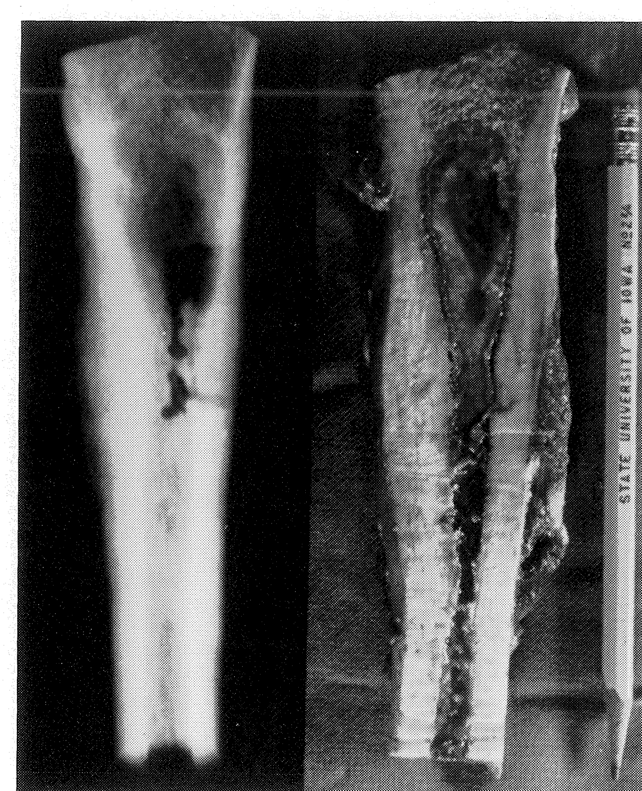

Figure 8b
Gross photograph and radiograph of split specimen—17 cm.

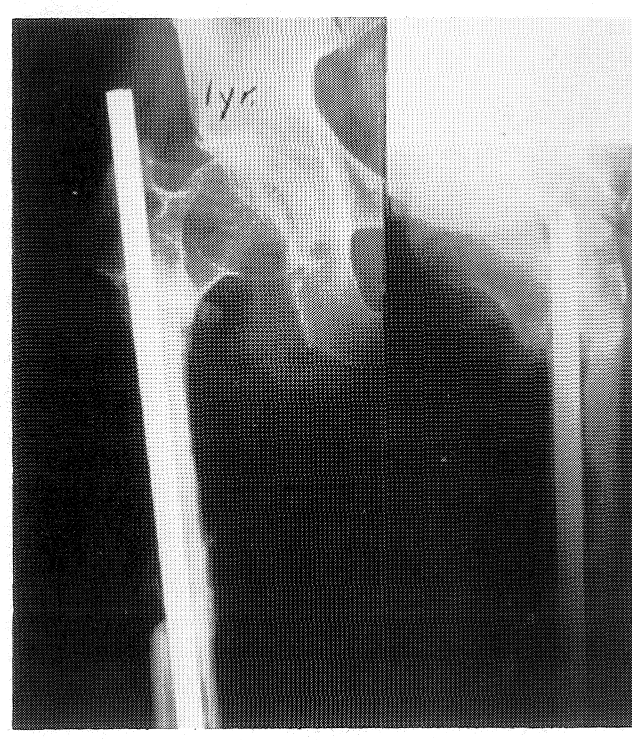

Figure 8c
Radiograph one year.

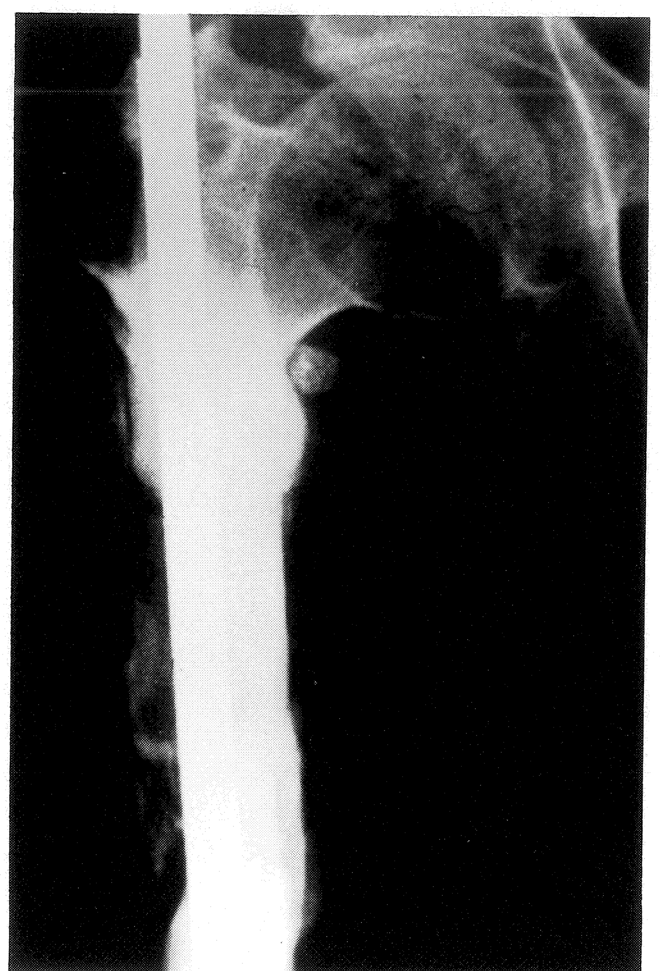

Figure 8d
At two years supplement iliac crest bone graft was added.

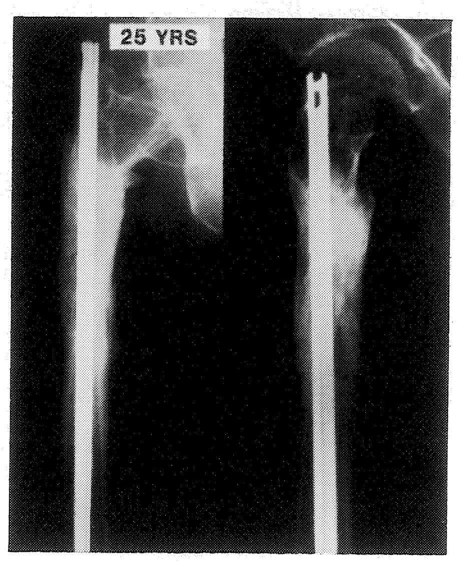

Figure 8e
At twenty-five years the femur defect is reconstituted.

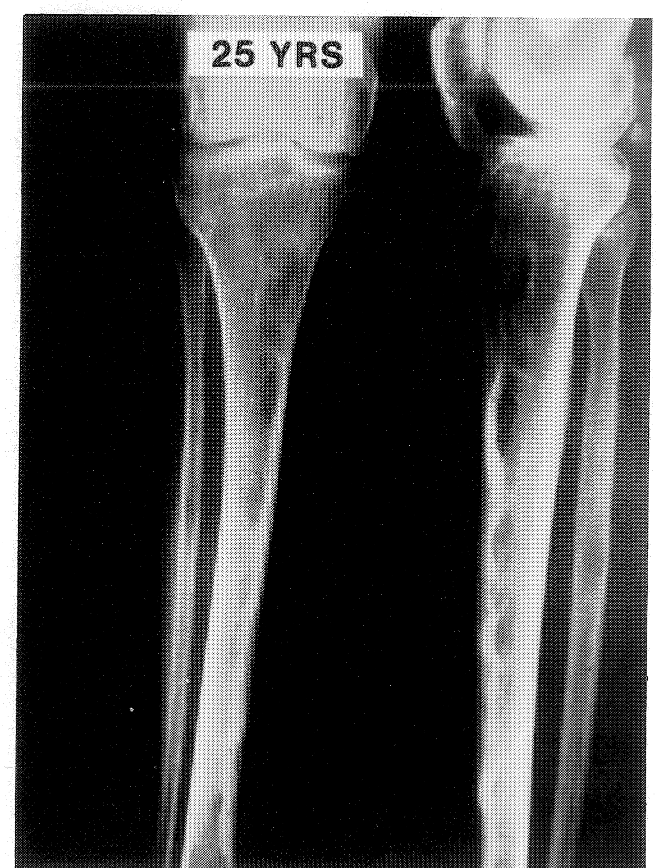

Figure 8f
At twenty-five years the tibial graft donor site is reconstituted.

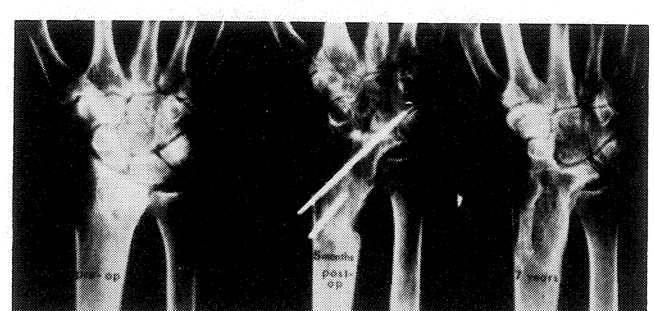

Figure 9a,b,c
Preop, five months postop, and seven years after resection and fusion of distal radius for a low grade chondrosarcoma.

coma. A marginal resection and fusion by the Campbell method[5] was performed (Fig. 9B). At seven years, there is no recurrence of the tumor, and solid fusion was achieved (Fig. 9C).

The last example of repair with an autogenous bone graft is that of a vascularized fibular graft used to replace a desmoplastic fibroma resected from the femur of a sixteen year old girl. The end result at four years shows a reconstituted femoral shaft in spite of numerous problems

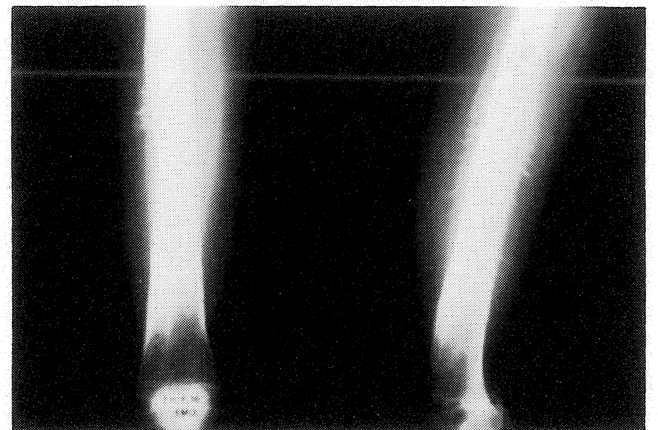

Fig. 10a-f Sixteen year old female, desmoplastic fibroma of the femur replaced with a vascularized fibular graft. Complications included loosening of the external fixation, fracture of the fibula with healing but gradual reconstitution of the femur at four years. AP and lateral radiographs of desmoplastic fibroma right femur.

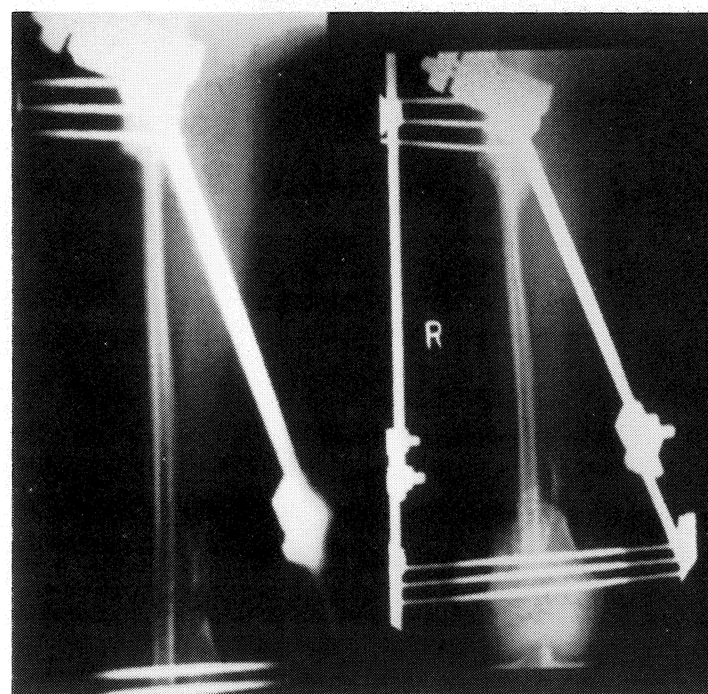

Figure 10b
Radiographs AP right femur, fibular graft, and external fixation device.

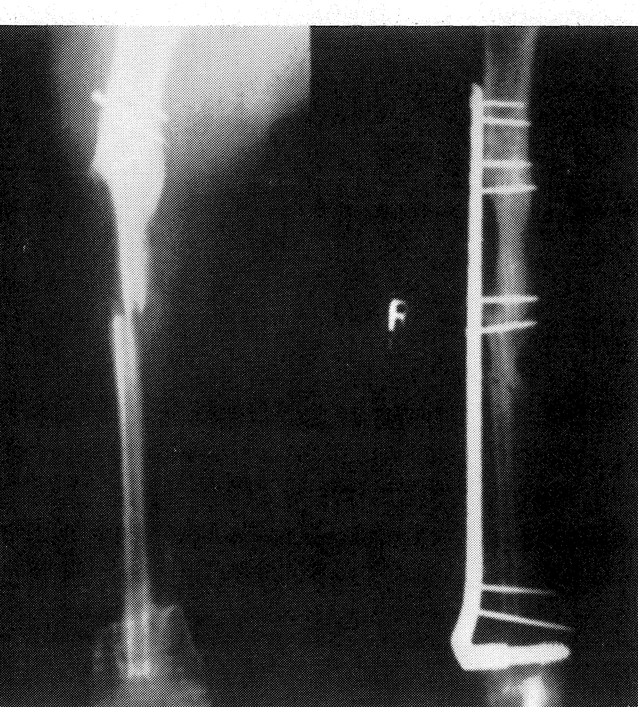

Figure 10c,d
Radiograph AP fibular graft with fracture. Treatment with supracondylar compression screw and side plate.

with the external fixation, a fracture of the fibular graft and the internal fixation with a Zickel nail plate. The patient now has excellent function of her limb (Figs. 10A-F).

These are examples of only a few resection defects amenable to repair with autogenous bone grafts.

SUMMARY

The goals of treatment of tumors by bone resection and reconstruction are first, local control consistent with survival of the patient and second, preservation of function. With the use of adjunctive therapy to control micrometastases, we should not lose sight of those goals in our efforts to spare limbs in the treatment of bone tumors.

Improvement in the results of treatment of malignant primary tumors of bone will occur with accurate diagnosis based on a planned biopsy, accurate histologic grading of the tumor, and proper staging of the tumor. This should be performed at a center where appropriate surgical procedures with adequate surgical margins can assure local control of the disease and the best opportunity for survival.

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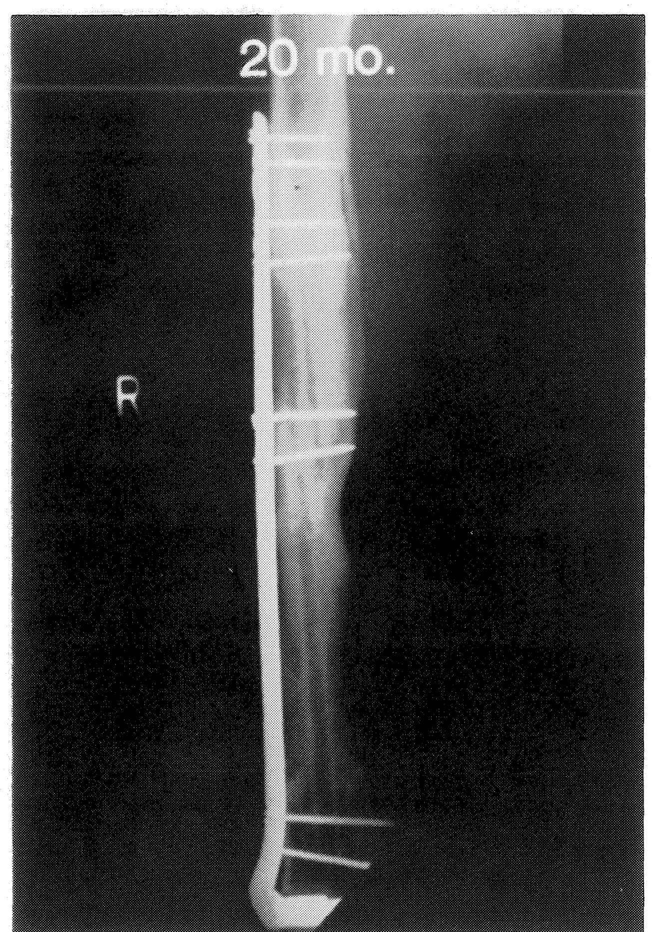

Figure 10e
Radiograph AP femur at 20 months.

Figure 10f
Radiograph AP and lateral reconstructed femur at 4 years.

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THE PHILOSOPHY AND NATURE OF MEDICAL RESEARCH*

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I am directing this article to those of you who are orthopaedic research fellows or residents because you have the potential to become medical scientists or clinician-scientists — either part-time or full-time — and also because of my own personal conviction that research is essential to the continuing progress of all medical and surgical specialties.

My purpose is three-fold; first, to help you to appreciate the importance and philosophy of medical research; second, to stimulate you to contemplate the possibility of your own personal improvement; and third, to share with you some thoughts concerning the nature of such research as well as some guidelines that I have found especially helpful during a thirty year period of consistent, part-time involvement in this fascinating and exciting facet of academic medicine.

For these purposes the terms "medical" and "medicine" are used in their broadest context in that they are meant to include all medical and surgical specialties within the profession even though I write from my perspective as an orthopaedic surgeon-scientist.

A DEFINITION OF RESEARCH

The English noun, research, is derived from the French verb "rechercher" which means simply to look again or to take a second look — in contradistinction to being satisfied with one superficial look. Thus, research involves taking a fresh and concentrated look at a given problem in an attempt to find a solution.

From a distillation of definitions in various dictionaries, research could be defined as "an investigation or experimental study of some phenomenon directed to the discovery and interpretation of new data through the critical approach of the scientific method".

THE IMAGE OF MEDICAL RESEARCH

As postgraduate students of orthopaedic surgery today, you may have been negatively influenced by the current trend among some of the young to harbor feelings of antiestablishment and anti-science. Added to this you will have heard much about the budgetary constraints on research funding through governments and also that there may be few opportunities for either full-time or part-time positions in medical research. Although such negative attitudes have often been exaggerated they may explain — at least in part — why only approximately 5 per cent of undergraduate medical students in North America are currently attracted to a career in medical research.

This negative image of research, although unjustified, is not new. The 19th Century philosopher and critic John Ruskin wrote, "Science lives only in quiet places, and with odd people, mostly poor". But all of this has changed! Visit the medical or surgical research laboratories in your own university and you will find them not to be "quiet places" but rather hives of intellectual and physical activity. You may find the medical or surgical scientists unusual or uncommon individuals perhaps, but not "odd", and you will find that they are no longer "mostly poor".

THE GOALS AND IMPORTANCE OF RESEARCH

In the broad fields of medicine and surgery and their related basic sciences, the primary goal of the various types of research is to achieve a more complete understanding of biological processes — both normal and abnormal — in order to make significant advances in the treatment of disorders and injuries in man through the development of more effective methods for their prevention, detection or treatment. In this sense, all medical research has a bearing on health, either directly or indirectly, either immediately or eventually.

In an academic setting, however, research has an additional goal, namely the enrichment of the education — as opposed to the mere training — of a clinician. In this context the term "education" implies the intelligent understanding of clinical teaching while the term "training" implies uncritical acceptance of such teaching.

Research enhances the quality of medical education — both undergraduate and postgraduate — because the scientific atmosphere has a beneficial impact on all aspects of the educational program. In addition, such an atmosphere is testimony to the fact that medicine as a science is dynamic, growing and constantly changing for the better. Furthermore, a lively and exciting program of medical research in a given University attracts the brightest young people as postgraduate students and new faculty members to that University.

Through your personal involvement in either clinical or

*A modified version of the author's article entitled "The Philosophy and Nature of Surgical Research" published in the Canadian Journal of Surgery 23(4):349-354, 1980.

experimental investigation as an undergraduate or postgraduate student, you should acquire qualities such as intellectual curiosity, critical thinking, logic, and discrimination that can be applied not only to your work, but also to the work of your colleagues as expressed through both the spoken and written word. Indeed, in any postgraduate surgical training program that does not include a significant amount of research activity, the potential clinician will receive more of a technical or trade school training than a true medical education in both the art and science of Medicine.

In any given university the importance of medical research varies directly with the degree to which these two major goals are being achieved. Although much more emphasis on medical research is required throughout the world, such research has already gained a position of great importance in many major universities not only because of its intrinsic contributions to new knowledge but also for its contributions to medical education.

First-rate medical research within the University Medical School invariably improves the quality of patient care in the affiliated teaching hospitals of that University. Indeed the quality of patient care in hospitals throughout the world is improved as new scientific knowledge is soon shared with fellow clinicians and scientists internationally through the media of scientific meetings and publications.

THE MOTIVATION FOR SEARCH AND RESEARCH

Search for knowledge that is both true and new has always challenged and motivated intelligent humans. In his famous 12th Century Prayer the physician-philosopher Maimonides expressed such motivation thusly, "Let the thought never arise that I have attained to enough knowledge".

One of the world's leaders in the philosophy of science, Karl Popper, has stated that "It is not the possession of knowledge, or inrefutable truths, that constitute the man of science, but the incessant search for truth".

The underlying motivation of the scientist to become engaged in research — and indeed wedded to it — is a combination of intellectual curiosity and dissatisfaction with the current state of knowledge and understanding. As Voltaire has said "Without the spirit of constructive discontent we would still be eating acorns and sleeping under the stars".

THE PHILOSOPHY OF MEDICAL RESEARCH

Inherent in the philosophy of research is the aforementioned "constructive discontent" with the existing state of knowledge and traditionally accepted — but unproven — concepts. And yet as an undergraduate medical student you will have acquired an incredible amount of cognitive information, at least some of which needs to be challenged. George Perkins, a distinguished British orthopaedic surgeon who dared to differ with his more traditionally-minded contemporaries once stated that "The training of a medical doctor is such that it is difficult for him to break with tradition" — a sad commentary relevant to the difference between "training" and "education".

Although the success of research depends upon many factors, the pivotal and initiating factor is the scientific curiosity of the investigator, a curiosity that compels him or her to discover — or uncover — new data and new concepts through the application of the scientific method.

Understandably, the life of the clinician-scientist is not easy, but it can be very rewarding in terms of the quiet satisfaction that comes from achieving a scientific goal. In a sense the clinician-scientist is a bridge-builder who constantly strives to bridge the gap between the practical art and theoretical science of medicine. To be effective in this role, the medical scientist must merit the respect of both fellow clinicians and fellow scientists, and this calls for exemplary performance in both fields.

THE NATURE OF MEDICAL RESEARCH— A CYCLE

Even the most inspired and idealistic of potential scientists must accept and work within the rigorous discipline of the scientific method, the essence of all research. Seemingly complex and formidable at first to the uninitiated or inexperienced, the scientific method is best understood if presented as a series of well planned phases or steps.

During many years of teaching and supervising both undergraduate and postgraduate research fellows, I have found the concept of what one might call the "cycle of medical research" to be most helpful in outlining and explaining the multiple phases of the time-honored scientific method (Fig. 1). The cycle consists of a series of guidelines that start with patients and come back to patients. Medical research of the mission oriented or targeted type is designed to find the solution to an unsolved clinical problem in patients, and in due course, whenever appropriate to apply the new found knowledge to that problem.

CYCLE OF MEDICAL RESEARCH

In this cycle of medical research there are sixteen phases each of which merits individual attention.

1. Recognize an Unsolved Clinical Problem.

In order to find a solution to a given unsolved clinical problem it is essential that as a clinician-scientist you first recognize that problem, or a component of it, and this involves being a keen and alert observer; a human biology watcher. Unfortunately a poor clinician may "have eyes but see not" and may miss the critical observation that would lead to recognizing an unsolved clinical problem and

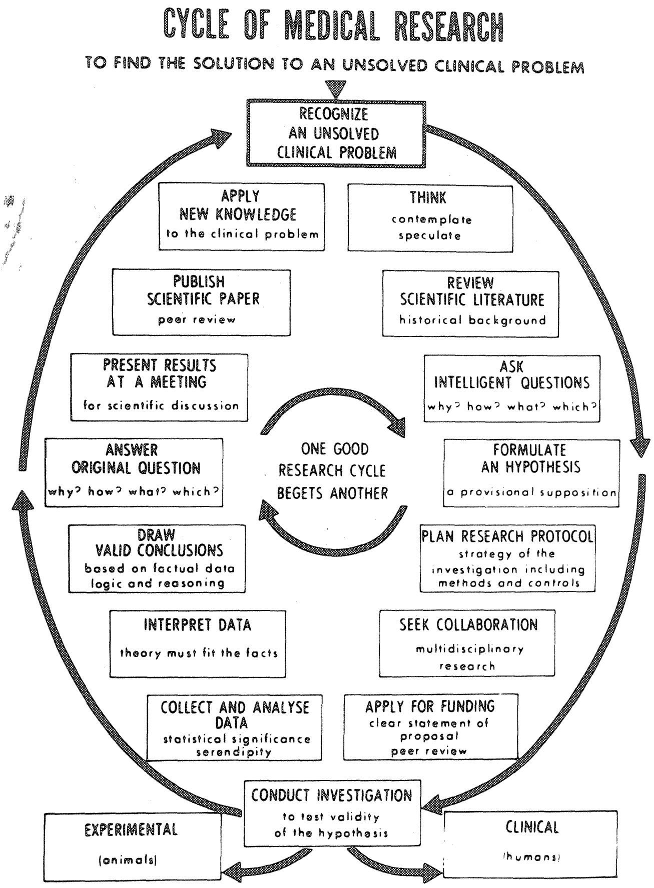

Figure 1

to its investigation. "In the field of observation", wrote Louis Pasteur, "chance favors the prepared mind".

2. Think

To think deeply, contemplatively, and speculatively about an unsolved problem requires determination and self-discipline on your part since there are so many interruptions in the daily — and even nightly — life of a physician or surgeon. Furthermore, such thinking is more difficult and more taxing than, say, making a fairly obvious diagnosis, prescribing a routine medical regimen or performing a routine surgical operation. It may, however, bring its own rewards such as the intellectual exhilaration that results from successful problem-solving.

3. Review the Scientific Literature

Before embarking on any research project you will need to review the scientific background against which your work will stand. In medical research, as in other forms of research, there have been many examples of "rediscovering the round wheel" which could have been avoided had the investigator been aware of the historical background of the subject. Churchill and others have expressed the thought that those who did not read history are doomed to repeat the errors (and one might add, the experiments) of the past. Fortunately literature surveys have been tremendously facilitated by modern computerized library science. As you review the scientific literature relevant to the problem you have recognized, you will not only be able to benefit from the labors of fellow scientists, but you will also be stimulated to build upon such labors through your own original thinking and questioning.

4. Ask an Intelligent Question

Having read the historical background of the problem you then need to ask an intelligent question, and furthermore, a question that can be feasibly answered through research. In relation to a specific phenomenon under investigation the question frequently begins with why? how? what? or which? Much time, effort and money will be wasted if an inappropriate question forms the underlying basis for a research project for as the scientist Sir Henry Tizard has emphasized "The secret of success in science is to ask the right question".

5. Formulate an Hypothesis

As the first step toward answering your own question you should formulate an hypothesis (literally a subordinate thesis or a theoretical and provisional supposition which serves as a starting point for further investigation by which it may be proved or disproved). The working hypothesis is a carefully reasoned but as yet unproven answer to the question, and should lend itself to the testing of its validity through the research project that is being planned.

6. Plan the Research Protocol

The next step in the cycle of surgical research is to plan in detail the protocol, or strategy, of the investigation. That is, to plan the experimental design, including the subjects of the investigation (either animals or human patients), the investigational methods, the equipment, the "controls" to deal with all possible variables, and finally the proposed methods of analysis of the data including the determination of statistical significance. The protocol should be planned with the primary purpose of the investigation in mind, namely the testing of the validity of your hypothesis.

7. Seek Collaboration

As biomedical research becomes increasingly complex and sophisticated, you must be prepared to collaborate with scientists of other disciplines — such as physiology, biochemistry, microbiology, immunology, biophysics and biomedical engineering — in multidisciplinary research. Through such collaborative research one mind fertilizes another, and the scientific investigation grows in both depth and breadth. It was the importance of collaboration in research that Claude Bernard was extolling when he wrote: "Art is I; Science is We".

8. Apply for Funding

In this enlightened era of science which is intermittently darkened by the clouds of anti-science and the resultant constraints of research budgets from governments and other agencies, it should be encouraging for you, as a potential clinician-scientist, to realize that there is still money available to support well-planned, clearly stated, exciting, significant, and original research. The peer review system would still seem to be the most appropriate mechanism whereby your grant application may receive the fairest consideration; at the same time the highest possible standards of research may be maintained.

Two of the criteria by which your fellow scientists in the peer review system judge a given proposal are the scientific significance of the project in terms of new knowledge or understanding and also the likelihood of its success.

9. Conduct the Investigation

Through the scientific investigation you set out neither to prove nor to disprove your hypothesis but rather to test its validity with complete objectivity.

As a clinical physician or surgeon your inherent reverence for human life and human comfort will compel you to confine experimental investigations to animals, and also to accept the principle that any proposed clinical investigation in humans must be morally and ethically acceptable to the review mechanism of a university-based "Human Clinical Investigation (or 'Experimentation' Committee") which includes clinician-scientists as well as members of other professions. Experimental investigations in animals must also be acceptable in that they must meet established government regulations to protect the comfort of the animals.

10. Collect and Analyze the Data

As you make observations and collect data during the progress of your investigation you should be alert to the possibility that an unexpected finding may have much significance—the phenomenon of serendipity (a word coined by Horace Walpole and based on the story of the Three Princes of Serendip who, during a long journey never did reach their planned goal but who, unexpectedly and by chance, found many things of even greater interest and significance along the way). Indeed, many important discoveries have been made through serendipity—penicillin, polio vaccine, and cryoprecipitate to mention only three.

A serendipitous observation, of course, should stimulate another cycle of research. But the scientist may fail to appreciate the significance of the unexpected as Churchill pointed out when he wrote "Man occasionally stumbles over the truth but he usually manages to pick himself up and continue on".

Provided that the protocol of your investigation has been well planned, it should be possible for you to analyze your data accurately and to determine its statistical significance.

11. Interpret the Data

This phase of the cycle of medical research is one of the most important because you may have collected important data, but unless your interpretation of these data is correct, you may find yourself off your cycle and into the ditch of delusion.

In the interpretation of the data you must consider all of the data and not just those parts that seem "to fit" your hypothesis because through the latter process you would, in fact, be deluding yourself—and others; you would be making the facts fit the theory rather than, as you should be, making the theory fit the facts. It may have been this type of intellectual dishonesty that George Bernard Shaw was contemplating when he wrote "Beware of false knowledge—it is more dangerous than ignorance".

12. Draw Valid Conclusions

Through the application of sound logic and scientific reasoning you should draw valid conclusions—insofar as that is possible—on the basis of the factual data. This is another difficult phase of the cycle of medical research since the clinician-scientist may be tempted, subconsciously and unwittingly, to draw conclusions that are not justified by the factual data. When more than one interpretation of the data seem reasonable, it may be necessary to initiate another cycle of research to clarify the matter.

13. Answer the Original Question

By the time you have reached this phase of the cycle you may well be able to answer the original question. You should not be disturbed if the answer is not that which you expected because, of course, you are seeking the truth rather than proof of a preconceived theoretical answer to the original question. The search for truth, however, is never-ending because the more questions you answer the more questions you will raise to take their place. Each of these questions, in turn, will serve as the catalyst for the creation of another research cycle.

14. Present Results at a Meeting

Having completed the investigation it is important for you to present the results at a scientific meeting in order that you may benefit from the resultant discussion—both positive and negative. Indeed, constructive criticism of a given scientific investigation can only help you to improve upon its final presentation. It would be considered unprofessional for you as a medical scientist to share the results of your research with the general public through the lay media—press, radio or television—before these results have been either presented at a major scientific meeting or published in the scientific literature.

15. Publish a Scientific Paper

If your investigation has been worth doing it is worth publishing and you should seek publication in a reputable scientific journal which is critically refereed. Indeed, you have a moral obligation to publish a significant scientific investigation for as Richard Bach has written in his book entitled Jonathan Livingston Seagull, "It is good to be a seeker but sooner or later you have to be a finder, and then it is well to give what you have found, a gift unto the world for whoever will accept it".

16. Apply the New Knowledge

As implied in the adjective "applied", this type of mission-oriented or targeted research frequently leads to new knowledge that can be applied to the unsolved clinical problem that initiated the cycle of medical research. The application may be relevant to an improved understanding of the etiology, pathology, pathogenesis, detection, treatment, or even prevention of the clinical problem under investigation.

Thus, the cycle of medical research is complete and you will have progressed from realistic research to clinical reality. It is hoped that you will have come to appreciate that it is better to move in the best circles of research than to walk the straight and narrow path of empiricism.

No matter how successful a scientist may be in solving problems, his or her "spirit of constructive discontent", of which Voltaire wrote, is self-perpetuating since one good idea begets another and one discovery leads to another.

In the final analysis, the success of any given medical research project will depend upon the intelligence and inquisitiveness of the individual scientist whose goal should be not to follow the established path of clinical empiricism but rather, through research, to explore where there is no path and leave a trail that leads into the future!

SPONDYLOLYSIS AND SPONDYLOLISTHESIS IN THE ADOLESCENT: WHEN TO DO WHAT

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Spondylolysis and spondylolisthesis are "ancient" orthopaedic topics, but a lively interest persists about them. The etiology remains obscure. The natural history is diverse, and the treatment highly varied. It is therefore no wonder that the student, trying to get a "handle" on the problem, is left in a state of confusion. The remarks contained herein are the opinions of the author, based sometimes on statistical evidence and sometimes merely on twenty-two years of experience as a spinal surgeon.

CLASSIFICATION

The modern classification of spondylolisthesis is a division into five major categories[11]: I. Dysplastic (in essence a congenital failure of the lumbosacral articulation without a pars defect or pars elongation); II. Isthmic (with a defect or elongation of the pars interarticularis); III. Traumatic (an acute injury of such significance as to cause an acute fracture of the vertebra); IV. Degenerative (due to degenerative disease of the facets and intervertebral disc complex); and V. Pathologic (due to tumor, infection, or metabolic bone disease).

This paper will discuss only the first two types, dysplastic and isthmic, since they account for 95 per cent of the problems seen in adolescents. Dysplastic spondylolisthesis is actually quite rare, but is often confused with isthmic spondylolisthesis associated with spina bifida occulta of S1.

CLINICAL EVALUATION

The adolescent with spondylolysis or spondylolisthesis may present in several ways. The most common is low back pain, but may include leg pain, an abnormal gait, scoliosis, or excessive lumbar lordosis. Others may have the problem detected on radiographs taken for other reasons.

The physical examination of the spine evaluates scoliosis, lordosis, lumbosacral kyphosis, decompensation, muscle spasm, and localized tenderness. Straight leg raising is tested supine, and the ability to bend forward at the waist with the knees straight is tested standing. The lower extremities are carefully tested for atrophy, weakness (motor loss), sensory loss, and reflex changes.

RADIOLOGIC EVALUATION

Full length spine radiographs in the standing position are useful for evaluating scoliosis, decompensation, lumbar lordosis, and the special relationship of the thorax to the pelvis. A standing spot lateral of the lumbosacral area is important for determination of the magnitude and angle of the slip under gravity-loaded conditions.

A supine anteroposterior view of the spine can be helpful for evaluating "spasm" curvatures, since the curve often disappears when supine. A supine spot lateral of the lumbosacral area gives the best detail of the slip and the local anatomy. Supine oblique views of the lumbosacral area (not lumbar) give the best detail of the pars interarticularis area. An anteroposterior view of the lumbosacral area (again not lumbar) is best for determining the presence or absence of spina bifida occulta of L5 or S1.

It is obvious that not all patients require all of these films for an adequate evaluation. The views required depend upon the clinical situation. There is considerable gonadal exposure involved in most of these views (in the female) and the minimum number necessary should be obtained. In the male, the gonads can always be shielded.

Special studies may at times be useful. Radioactive bone scans are used to determine if a pars defect is "active" or "quiet". If "quiet", it is presumed that the lesion is of long standing and will not heal if immobilized in a cast or brace.

CT scans are of relatively little value, since the plane of the cut is in the plane of deformity. Occasionally they are helpful, especially in the sagittal reconstructions, to determine the presence or absence of a pars defect not well seen on oblique views. They may also pinpoint more precisely (when combined with myelography) the point at which a nerve root is compressed.

Conventional tomography in the oblique projection can be helpful to determine the presence or absence of a pars defect not well seen on standard oblique views. Lateral

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tomography may be useful for more precise anatomical information at the slip level: to determine the presence or absence of spontaneous ankylosis of L5 and S1, and to determine the position or quality of healing of an anterior bone graft.

Myelography is reserved only for those patients with neurologic signs and symptoms. The chief purpose of the myelography is to rule out other causes of sciatica, e.g., spinal cord or cauda equina tumors. In the typical slip of Grade II, III, or IV, the dural sac is "pinched off" at L5-S1, but this occurs with or without neurologic signs or symptoms. The customary site of the L5 root compression (at the foramen) is *not* seen on the myelogram.

RADIOLOGIC MEASUREMENTS

In the past, the amount of slipping was classified according to the Meyerding scale of I, II, III, or IV with I being a slip of 0 to 25 per cent, II a slip between 25 and 50 per cent, III a slip between 50 and 75 per cent, and IV a slip between 75 to 100 per cent. A total dislocation with the body of L5 anterior to S1 was called a "spondyloptosis". These groups lacked precision and were often used casually without actual measurements. Furthermore, this system failed to recognize the kyphotic pathology of L5-S1.

As shown by Wiltse and Winter[13] in a recent publication, a far greater precision is now available. Multiple components of the deformity can now be measured. This permits a more accurate assessment of the patients' problem and thus hopefully leads to a better decision about the treatment needed. These measurements are also of value in monitoring the course of treatment, either surgical or nonsurgical.

Of the several measurements available, the two most important are the measurement of the forward displacement, and the measurement of the angular relationship between the lower lumbar vertebrae and the sacrum. The displacement is measured as a percentage, comparing the millimeters of displacement against the sagittal diameter of S1. If S1 is deformed excessively, the sagittal diameter of L5 is used instead (Fig. 1).

Measurement of the kyphotic relationship of L5 to S1 ("sagittal rotation" or "slip angle") utilizes the same principles as measurement of kyphosis elsewhere. The posterior border of S1 is used and is measured against the anterior border of L5, or a perpendicular to the posterior border of S1 is measured against the superior endplate of L5. Other authors[1] have suggested using the inferior endplate of L5, but this often leads to erroneous measurements due to the growth inhibition of the posterior-inferior portion of the body of L5 ("false slip angle").

It has recently become obvious that we must not only look at the slip angle of L5-S1, but also the slip angle of L4-S1. There are often situations in which there is a significant slip angle of L5-S1, but due to marked compensatory and opposite angulation between L4 and L5, the spatial relationship between L4 and S1 approaches normal. As will be seen later, the understanding of these spatial relationships may be of the utmost importance in deciding treatment (Fig. 2).

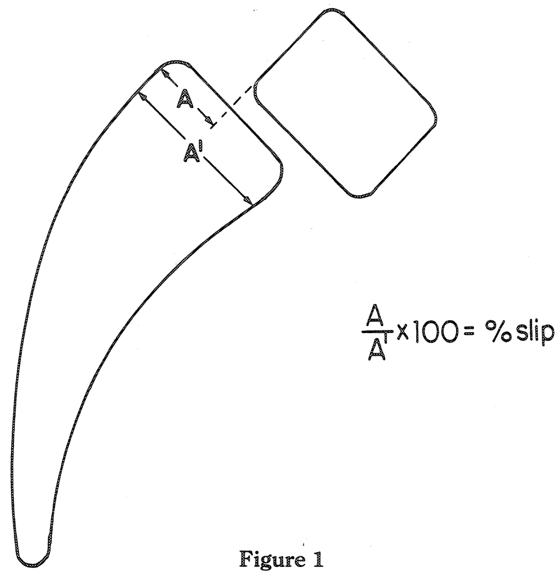

Figure 1
The amount of forward displacement of L5 on S1 is measured (A), as well as the total sagittal diameter of S1 (A'). From these two measurements the percent slip is calculated. (Reproduced with permission from Wiltse, L.L., and Winter, R.B., Terminology and Measurement in Spondylolisthesis, J. Bone and Joint Surg., 65A:768-772, 1983.)

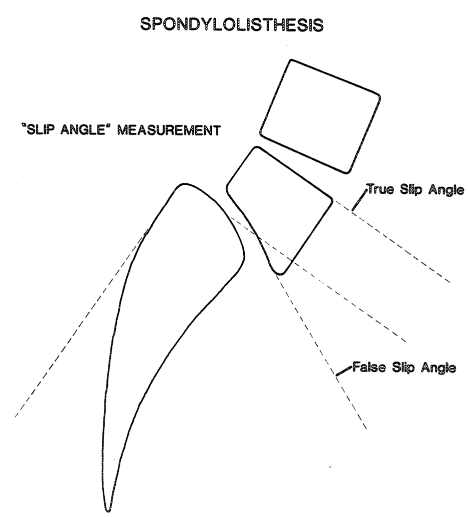

Figure 2
Measurement of the angular relationship of L5 to S1 is accomplished by first drawing a straight line along the posterior cortex of S1, then erecting a perpendicular to that. Secondarily, a line is drawn along the superior endplate of L5 extending it forward to intersect the perpendicular from S1. This creates an angle, the true slip angle. A line drawn along the inferior endplate of L5 will create a larger angle (the "false slip angle") due to the hypoplasia of the posterior-inferior portion of the vertebral body of L5.

TREATMENT

Introduction

There are a large number of treatments available for spondylolysis and spondylolisthesis. The fundamental problem is the making of a decision: what treatment is best for the patient being seen?

Treatments include: 1) doing nothing, 2) serial observation, 3) limitation of activities, 4) exercises, 5) bracing, 6) casting, 7) repair of the pars defect, 8) one-level fusion, 9) two-level fusion, 10) laminectomy and fusion, and 11) partial reduction and fusion.

The factors which must be considered are a) the chief complaints, b) age, c) sex, d) physical findings, e) degree of displacement (percent slip), and f) the slip angle. It should be emphasized that the degree of displacement by itself is not the sole factor in deciding treatment.

Spondylolysis

An asymptomatic patient with pars defects discovered on incidental films requires no treatment. If growth is complete, no follow up is necessary. Children with growth remaining should be followed with periodic radiographs to make sure a slip does not occur. Activities should *not* be limited.

The patient with a painful defect should be placed on abdominal and spinal muscle strengthening exercises and have excessive activities limited until the symptoms subside. An orthosis can be used if exercises aggravate or fail to solve the pain problem.

A patient who has become symptomatic only following an acute injury should have a radionuclide bone scan. If the pars area is active on the scan, the lesion should be considered an acute failure and treated by immobilization, either in a cast or preferably a well-fitted plastic orthosis (Fig. 3)[12].

The patient with chronic pain, unresponsive to non-operative treatment, should be surgically stabilized. If the defect is at L5, a one level transverse process fusion by the Wiltse technique[12] is preferred. A lumbosacral orthosis is worn for three months following surgery.

If the lesion is in L3 or L4, it is preferable to repair the defect directly. The preferred technique is that of Scott[9] in which the defect is grafted with cancellous bone and immobilized with wire passed around the transverse process and the spinous process (Fig. 4).

Spondylolisthesis (No Symptoms)

Patients who had no symptoms but with a lesion discovered on incidental films need no treatment if their slip is less than 50 per cent. These should be carefully monitored by periodic lateral standing lumbosacral roentgenograms. Further slipping can occur, especially in growing children, and can occur completely without symptoms. Catastrophic slipping is more likely to occur in females, in younger patients, and in patients who already demonstrate rounding of the top (superior end plate) of S1 and wedging of L5. Slips of greater than 50 per cent should be fused[4]. The reason for this is the high likelihood of further slip and major symptoms if left untreated.

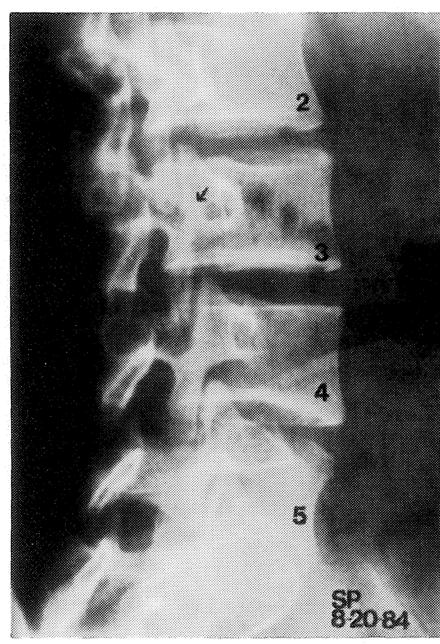

Figure 3a
An oblique radiograph showing no pars defect. The film was taken because of generalized low back pain.

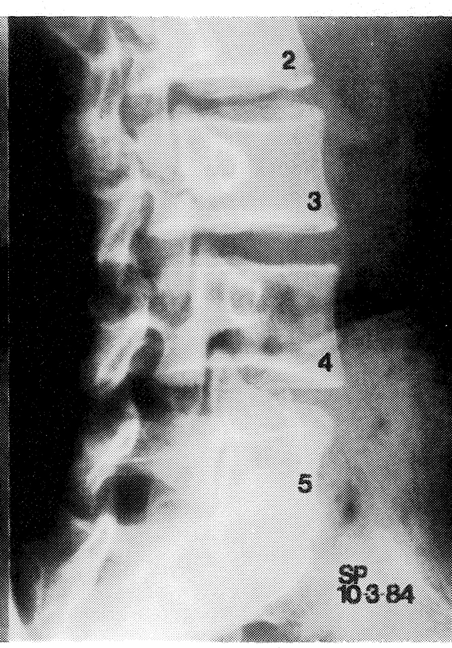

Figure 3b
Two months later, and ten days following an acute back injury during athletics, a pars defect at L3 is clearly visible.

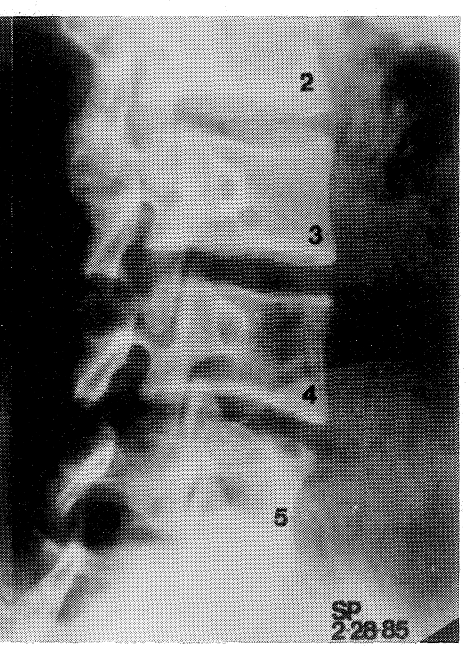

Figure 3c
Four months later, after three months of orthotic treatment, the lesion has healed.

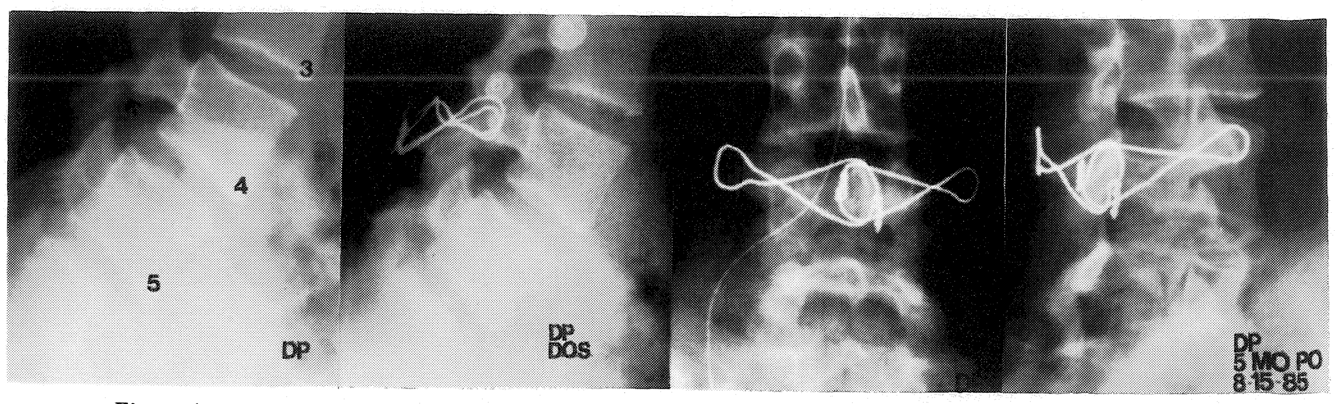

Figure 4a
A fourteen year old girl with a chronically painful low back and bilateral pars defect of L4.

Figure 4b
After bone grafting and wiring (day of surgery); lateral view.

Figure 4c
After bone grafting and wiring (day of surgery); AP view.

Figure 4d
Five months after surgery—now solid.

Spondylolisthesis (Low Back Pain)

Patients with low back pain, but no spinal deformity (e.g. scoliosis) and no neurologic signs or symptoms should have fusion if the slip is 50 per cent or more, but if less than 50 per cent, can be tried on activity limitation and exercise treatment. If these fail to relieve symptoms, an orthosis should be prescribed. If this fails to relieve symptoms or pain recurs on brace removal, then fusion should be done regardless of the severity of the slip. There is no reason to deny a child a comfortable back when a safe and highly successful operative procedure is available. Once solid, the patient can return to full activities including all forms of competitive athletics except gymnastics. A one-level L5-S1 transverse process fusion is recommended for slips of less than 50 per cent, and a two-level L4-S1 fusion for slips of greater than 50 per cent. A plastic orthosis is used for one-level fusions in children and two-level fusions in those whose growth is complete. A body cast with a single leg extension to the knee is used in those children still growing who undergo a two-level fusion.

Spondylolisthesis (With Sciatica)

Patients presenting with leg pain, an abnormal gait, and/or positive neurologic findings require surgical treatment. Non-operative treatment is contraindicated. Quite often a patient will have marked limitation of straight leg raising, but no objective evidence of a neurologic deficit. Such a patient needs surgical stabilization, but nerve root decompression is *not* necessary[5].

If there is an objective neurologic deficit, the nerve root (L5) should be decompressed and a fusion done. There is no place in children or adolescents for decompression alone. For decompression and fusion, the authors prefers a midline approach.

Spondylolisthesis (With Scoliosis)

There are two separate situations which must be distinguished. The first is the patient with true idiopathic scoliosis who also happens to have a spondylolisthesis. Here the two entities are treated strictly according to the needs of each.

The second situation is the spondylolisthesis patient with a "spasm" scoliosis, a curvature caused by the lumbosacral problem. In such a case, treatment of the spondylolisthesis by fusion and cast immobilization will solve the scoliosis problem (Fig. 5).

Spondylolisthesis (With Severe Displacement)

This is one of the most controversial areas in spine surgery, and certainly the author does not propose to know the final answer. Common sense and a considerable experience with this entity during recent years has, however, resulted in some clearing of the confusion.

All too often there has been a tendency to "operate on the radiograph" rather than to operate on the patient. This particularly refers to the patient who has low back pain, mild shortening of the waistline, but remarkably little external deformity despite a slip of 80 to 100 per cent. Careful analysis will show this patient to have one of two situations: either a) a marked displacement but a relatively normal slip angle, or b) an increased slip angle, but a very significant retrolisthesis of L4 on L5 and an angular compensation at the L4-L5 level so that the L4-S1 slip angle is almost normal.

If either of these situations exist, then no attempt need be made to "reduce" the slip but rather only an L4-S1 transverse process fusion is necessary. In the adolescent, a meticulous L4-S1 transverse process fusion with cast immobilization for six months will usually suffice. If at that time a pseudarthrosis exists, it should be promptly repaired posteriorly (Fig. 6).

In contrast to the above situations, there are patients who present with severe displacement (80 to 100 per cent) in whom these naturally occurring compensatory mecha-

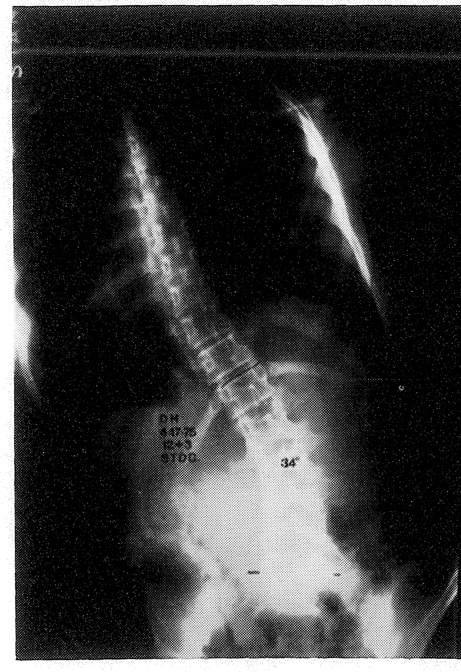

Figure 5a
A scoliosis due to spondylolisthesis in a twelve year old girl.

Figure 5b
A standing full-length lateral view of the trunk shows the L5-S1 slip, but more importantly shows the total thoracolumbar lordosis with forward displacement of the torso relative to the pelvis.

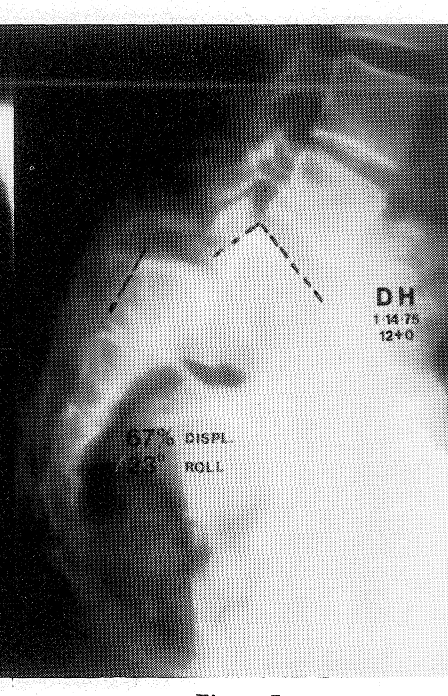

Figure 5c
A spot view of the lumbosacral area shows a 67 per cent displacement (slip), and a 23 degree L5-S1 slip angle (roll). Note the elongation of the pars plus the pars defect.

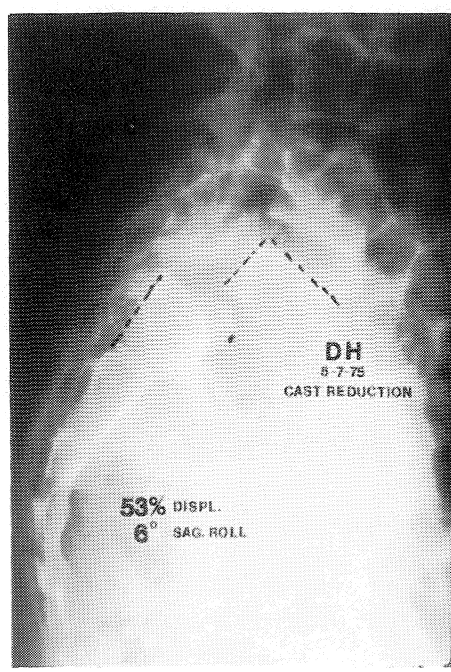

Figure 5d
In a double pantaloon cast, the slip is 53 per cent and L5-S1 slip angle 6 degrees. The L4-S1 slip angle is −10 degrees, and there is retrolisthesis of L4 on L5.

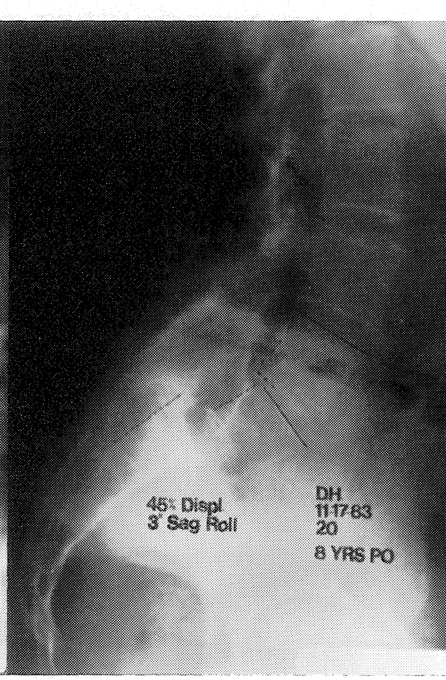

Figure 5e
An eight year follow up film shows a solid L4-S1 fusion, a 45 per cent slip, a 3 degree slip angle, and a retrolisthesis of L4 on L5. She was pain free and showed no external deformity.

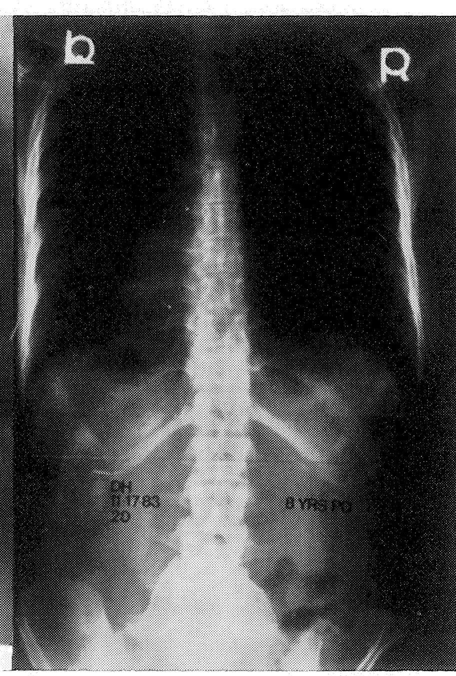

Figure 5f
An AP radiograph eight years after fusion shows no scoliosis and a very solid L4-S1 transverse process fusion.

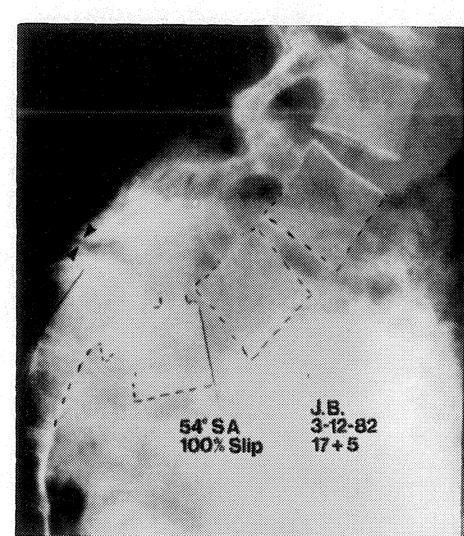

Figure 7a
This sixteen year old girl presented with a severe, 100 per cent slip and a 50 degree slip angle with forward displacement of the torso. A previous attempt elsewhere at an L3-S1 fusion had failed with a pseudarthrosis at L5-S1.

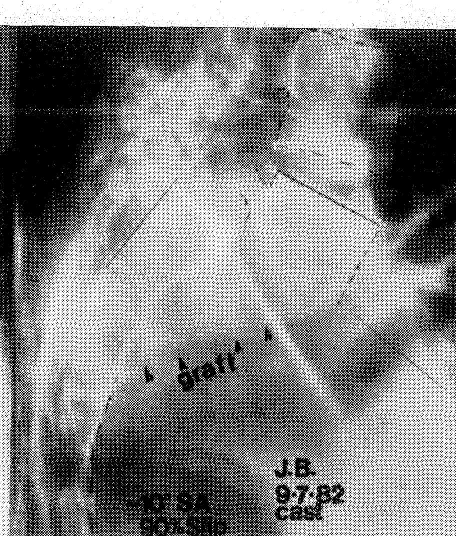

Figure 7b
After wedge resection of the L5-S1 pseudarthrosis plus osteotomy at L4-L5, halo-femoral traction was applied and a sling placed under the pelvis. Two weeks later an anterior fusion of L5-S1 was done with an iliac tricortical graft. One week after that, a double pantaloon hyperextension cast was applied and the halo and femoral pins removed. This film was taken supine in the cast showing a slip of 90 per cent, and the slip angle of −10 degrees.

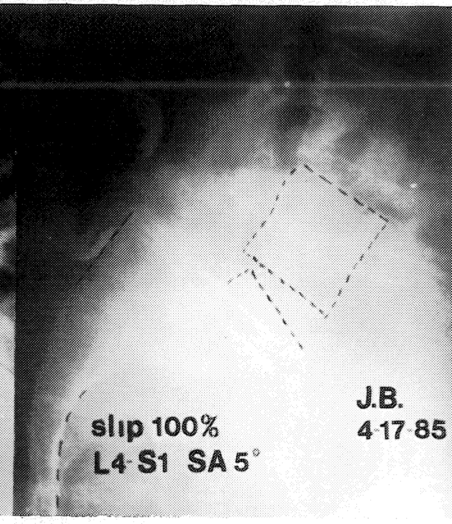

Figure 7c
The follow up film three years later shows a slip of 100 per cent and a −7 degree slip angle of L4-S1.

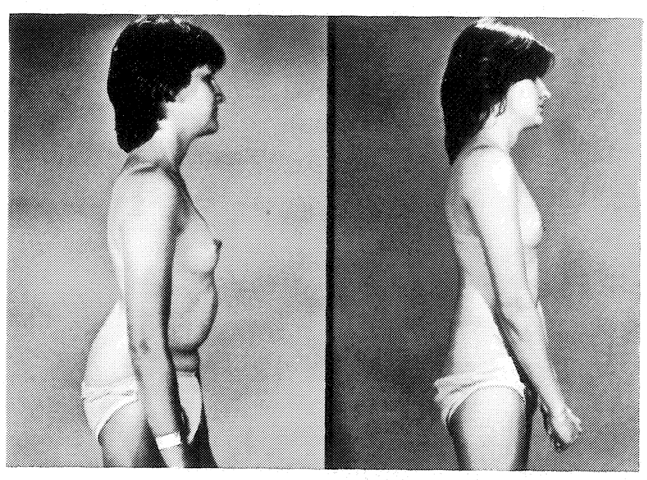

Figure 7d
The clinical photographs show the significant preoperative deformity, and the nearly normal postoperative appearance despite a persistng 100 per cent slip.

PARTIAL REDUCTION BY CASTING

A very simple method to manage the moderately displaced situation is the use of a double pantaloon cast in hyperextension applied about four to five days after the L4-S1 fusion. The patient remains in bed for four months in this cast, and then is placed in a one-leg body cast and ambulated. This is left on for two to three months, providing a total of six to seven months of immobilization. Pseudarthroses should be surgically repaired if noted on radiographs at this time (Fig. 5).

PARTIAL REDUCTION BY HALO-FEMORAL TRACTION AND CASTING

For more severe displacements in children and adolescents, halo-femoral traction can provide a very pleasing improvement. The fusion of L4 to S1 is done in the standard manner, and under the same anesthetic the halo and femoral pins are applied. Only ten to fourteen days of traction are usually needed and then the hyperextension double-pantaloon cast is applied. Anterior interbody strut graft fusion is indicated only in the most severe cases and only after improved alignment has been gained by the halo-femoral traction. A vertically oriented tricortical iliac crest graft is favored by the author. The defect in the crest is grafted with bank bone (Fig. 7).

SUMMARY

Spondylolysis and spondylolisthesis are common orthopaedic problems in adolescents and older children. Many are totally benign and require no treatment. Others with pars defects or low-grade slips can be rendered pain-free by conventional non-operative treatment methods. Patients with chronic symptoms or major degrees of slip should have surgical treatment. It is foolish to deny treatment and allow a child to remain disabled when safe and reliable treatment is available.

Figure 6a
This fourteen year old boy presented with severe low back pain and tight hamstrings, but little external deformity. His torso is well balanced over his pelvis.

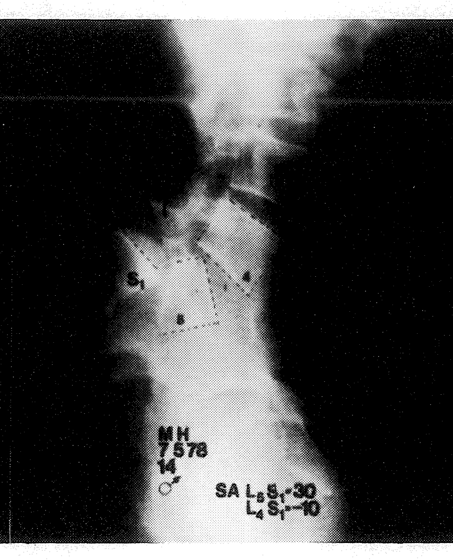

Figure 6b
The lateral radiograph shows a severe slip of 100 per cent, a slip angle of L5-S1 of 30 degrees, but due to the retrolisthesis of L4 on L5, a slip angle of − 10 degrees of L4-S1.

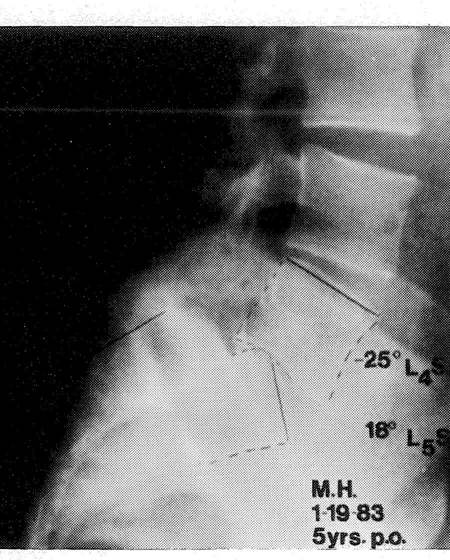

Figure 6c
He was fused in-situ and had cast immobilization. This film was taken five years later and shows the persistent severe slip at L5 but the normal L4-S1 relationship. He was a star high school baseball player following his fusion.

nisms are absent. These patients show a very vertical sacrum, a high L5-S1 slip angle, and an L4-S1 slip angle which is nearly as bad as that at L5-S1. The torso is displaced forward of the hips and there is a long lordosis extending high into the thoracic spine. Not only are these patients physically miserable, they also are psychologically upset by their marked clinical deformity. It is this select and rare group in which efforts at significant reduction are worthwhile.

In between these two groups is a third group, those with increased slip angle of moderate degree. In these patients, a modest effort directed toward reduction of the slip angle is worthwhile and safe, but the heroics required for the second group are not justifiable.

METHODS OF REDUCTION

It should be emphasized at this point that it is the *angulatory kyphosis* which merits reduction, not the slip itself. Once a "bayonet" relationship of L5 and S1 is achieved, then fusion at that point is the only further thing required. If in the course of reducing the slip angle, some reduction of the displacement also occurs, so much the better.

Because the primary deformity is one of kyphosis (a flexion deformity), the primary treatment is one of hyperextension. The prime problem is how to achieve extension of the sacrum. The first effort along this line was by Harris[3] who used longitudinal femoral pin traction coupled with an upward lifting of the sacrum by means of vertical skeletal traction applied to the iliac wings. Taillard in 1954[10] applied head halter and leg skin traction with the patient prone in a hyperextended alignment, also achieving some reduction.

Daymond, of Australia, began in 1969 to apply halo-femoral traction with the patient supine and the hips in extension. His early results were presented in 1976[2]. Meantime, Scaglietti, et al. had developed a system of serial casting with traction and hip hyperextension, and demonstrated some remarkable reductions[8]. In 1980, McPhee and O'Brien[7] and Bradford[1] simultaneously published papers describing the technique of reduction using halo-femoral traction in hyperextension, a modification of the technique originally described by Daymond.

Subsequently other authors have described a whole host of techniques beyond the scope of this paper to describe. Most of these have not withstood the test of time, have been associated with an excessive rate of neurologic complications, are simply too new, or have series of inadequate numbers to allow evaluation. Harrington instrumentation, quite in vogue a few years ago, has been abandoned in most centers due to two factors, an increased neurologic complication rate and especially the tendency to displace the patient forward, removing the normal compensatory mechanisms.

Some patients with major slips can be managed well by fusion-in-situ providing their external appearance preoperatively is one of general good alignment and balance. Those with major deformity clinically deserve partial reduction to achieve a reasonable alignment. Total reduction is neither necessary nor safe.

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THE NATURAL HISTORY OF SCOLIOSIS IN THE SKELETALLY MATURE PATIENT

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Adolescent idiopathic scoliosis affects about 2 to 3 per cent of the at-risk population ages ten to sixteen years[1,7,8,9,12,20,21,30,31,50,51,52,56,58,59,61,62,68,73]. The prevalence amongst males and females is equal in small curves but with increasing curve magnitude there is an overwhelming female predominance[2,7,8,11,31,35,36,56,59,63,71,73]. Epidemiologic, prevalence and natural history studies indicate that less than 10 per cent of positively screened patients (curve greater than 10 degrees) will require active treatment[1,7,8,36,56,71]. It is this small group of patients who are the focus of our attention. Increased public awareness and school screening clinics have resulted in increased numbers of children referred for orthopaedic opinion. Curvatures are being detected at less severe magnitudes, treatment is instituted at an earlier time, and decreased numbers of patients seem to be requiring surgery[36,63].

Physicians being consulted by patients with scoliosis must be knowledgeable about the disease and the implications of having the condition. In addition, with the availability of modern orthoses and with the ever increasing development of spinal instrumentation devices enabling better surgical correction of deformity, it is imperative that physicians treating patients with scoliosis have a thorough knowledge of the natural history of this condition. Any treatment offered must alter the natural history in a positive way.

It is the purpose of this paper to outline the natural history of adolescent idiopathic scoliosis after skeletal maturity; specifically with reference to back pain, psychosocial effects, mortality, effect on pulmonary function, pregnancy, and prognostic factors in curve progression.

The natural history presented here applies only to adolescent idiopathic scoliosis, and not to scoliosis of other etiologies. These entities have their own natural histories and associated problems that may significantly affect the ability of the patient to meet demands of daily life[5,13,41,72]. It is also important in studying the natural history of adolescent idiopathic scoliosis that the various curve patterns (thoracic, lumbar, thoracolumbar, double) be separated, for each curve pattern has its own particular characteristics and predicted course[14,16,34,53].

Modified from Weinstein, S.L.: The Natural History of Scoliosis in the Skeletally Mature Patient. In Dickson, J.H. (ed.): Spinal Deformities. THE SPINE: State of the Art Reviews, Philadelphia, Hanley and Belfus, Inc. 1986, in press.

Back Pain

Natural history studies of patients with adolescent idiopathic scoliosis reveal that about 40 to 60 per cent of these patients complain of back pain[5,16,17,22,26,27,32,33,42,43,45,46,47,49,69]. This incidence is comparable to the incidence of back pain in the general population. Jackson et al.[17] reported the incidence of back pain in the general population to be 80 per cent, while Kostuik and Bentivoglio reported a 60 per cent incidence[33]. Horal in an epidemiologic study of back pain in Gothenberg found that 81 per cent of patients had some spine pain with 66 per cent complaining of lumbar pain and showed that scoliosis was not over-represented[26]. Bjure & Nachemson[5] reported a 60 per cent incidence of back pain in the general population while Frymoyer reported a 67 per cent incidence of backache in 292 subjects; 21 per cent of these individuals were having severe pain[22].

In the Iowa study of 161 living patients with adolescent idiopathic scoliosis followed an average of forty years, 80 per cent of the scoliotic patients complained of some back ache, while 86 per cent of a sex and age matched control group of 100 patients complained of back ache (Table I)[69].

	Back Pain Scoliotics (161 patients)		Control Group (100 patients)	
Never	20%		14%	
Rarely (1-5 times in life)	19%	80%	25%	86%
Occasionally (few days/year)	24%		36%	
Frequently (few days/month)	20%		19%	
Daily	17%		6%	
Visited Doctor for Back Pain	24%		30%	
Hospitalized for Back Pain	6%		16%	

TABLE I

Symptoms varied from mild to severe. Most commonly patients complained of mild back ache at the end of a strenuous day or after unusual activities, with the pain relieved promptly by rest. Only 4 patients were unemployed and on disability, none from scoliosis. In addition, three Swedish long term studies with greater than 90 per cent patient follow-up at more than thirty years demonstrated that low back pain was not a significant complaint[32,42,49].

The location of pain in the scoliotic patients was variable and generally unrelated to curve location or magnitude. The pain was also unrelated to the severity of roentgenographic osteoarthritic changes, except for areas of translatory shifts in lumbar and the thoracolumbar curves (Fig. 1, 2, 3). Thirty-eight per cent of these patients had osteoarthritic changes on roentgenograms ranging from minimal osteophyte formation and mild intervertebral disc space narrowing to moderate facet joint sclerosis and rarely, to spontaneous fusion on the curve concavity. The severity of these changes was unrelated to the degree and location of the spinal curvature[46,69]

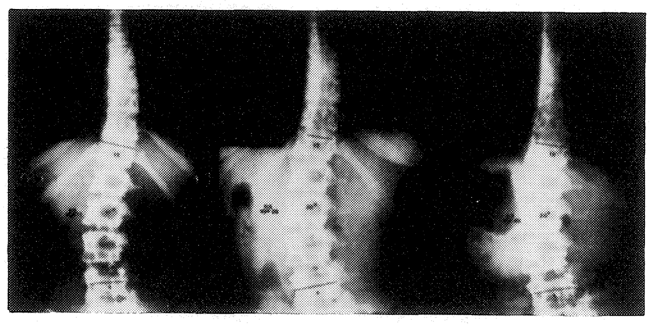

Figure 1
Patient R.S. *Left* Female age 17, Risser grade 5, 17° left lumbar curve from T12 to L4. *Center* Age 39, curve has increased 3° to 20°. *Right* age 49, curve remains stable at 20°. Patient complains of daily low backache for as long as she can remember.

Figure 2
Patient D.F. *Left* Female age 15, Risser grade 4, 42° left lumbar curve from T11 to L3. *Center* age 42, curve has increased 30° to 72°. *Right* age 52, curve has increased 6° to 78°. Patient denies ever having backache.

Lumbar and thoracolumbar curves, particularly those with translatory shifts at the lower end of the curve, tend to have a slightly greater incidence of back ache than other curve patterns (Fig. 3)[66,69]. Pain may also develop over the long term in compensatory lumbosacral curves below a lumbar or thoracolumbar curve[17,27,43]. It is estimated that one per cent of patients with scoliosis will require surgery specifically for backache, an incidence similar to that for the general population[17,43]. The etiology of back pain in the adult scoliotic is unknown but may be spondylogenic or discogenic in origin[33].

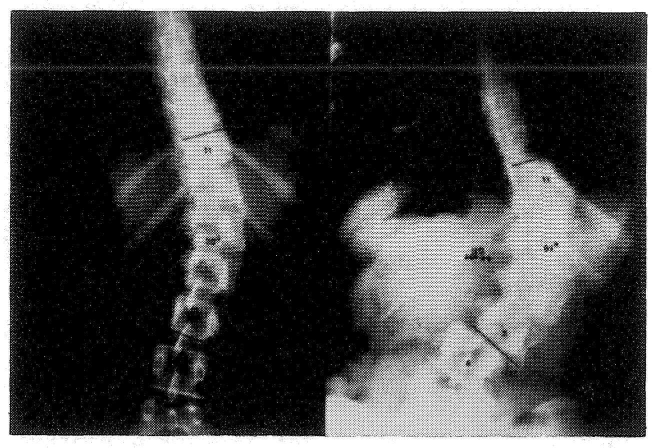

Figure 3
Patient H.G. *Left* 16 year old white female with a 38° right lumbar curve from T11-L3. She is grade 5 on the Risser scale. *Right* at age 39. Her right lumbar curve has increased to 61°. Note the translatory shift of L3 on L4 (arrows).

Some adults presenting with back pain and a lumbar curve may not be as a result of adolescent idiopathic scoliosis. These patients may have degenerative scoliosis; for lumbar curves may arise de novo in the adult[33,55]. These curves may progress and cause significant symptoms (Fig. 4) requiring active treatment.

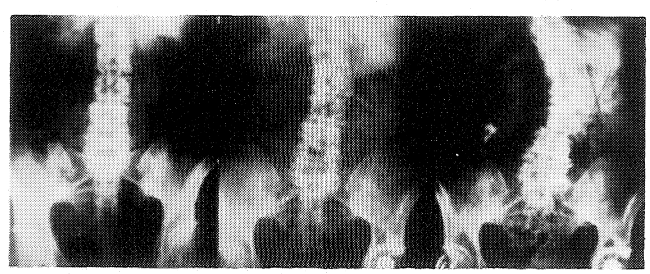

Figure 4
Degenerative scoliosis. Left age 61, Center age 67, right age 77. Note the development of a severe lumbar curve with marked degenerative changes and clinically increasing back pain.

Pulmonary Function

Scoliosis affects pulmonary function only in patients with thoracic curves[3,24,25,29,34,38,60,70,72,75]. Only in thoracic curves is there a direct correlation between increasing curve severity and decreasing vital capacity (Fig. 5). The same is true of PaO_2 (Fig. 6). The pattern with the nonsmoker is uniformly that of restrictive lung disease[69]. In addition, in nonsmokers significant limitation of forced vital capacity and of forced expiratory volumes in one second (FEV_1) does not occur until the curve approaches 100-120 degrees. In all other curve patterns there is no correlation between pulmonary symptoms, spirometry results, and curve severity[69].

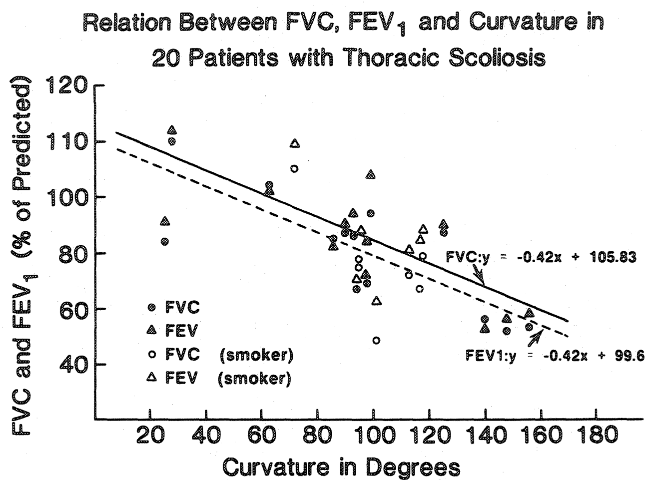

Figure 5

Relationship between forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and size of the curve in twenty patients with thoracic scoliosis, using a line of regression. From Weinstein, S.L.; Zavala, D.C.; and Ponseti, I.V.: Idiopathic Scoliosis Long Term Follow up and Prognosis in Untreated Patients. J. Bone and Jt. Surg., 63A:702-712, 1981. Reprinted with permission.

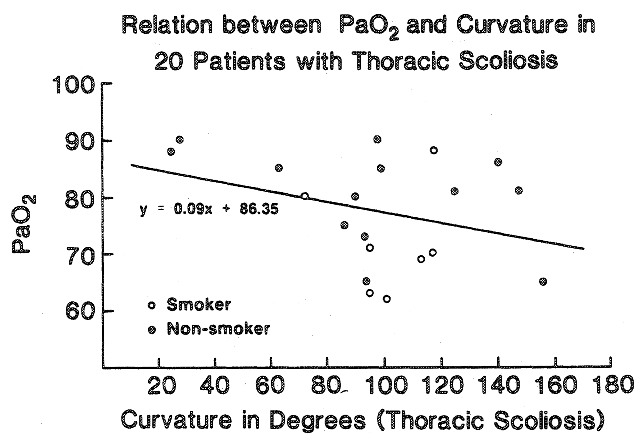

Figure 6

Relationship betweeen PaO_2 and size of the curve in twenty patients with thoracic scoliosis, using a line of regression. From Weinstein, S.L.; Zavala, D.C.; and Ponseti, I.V.: Idiopathic Scoliosis Long Term Follow up and Prognosis in Untreated Patients. J. Bone and Jt. Surg., 63A:702-712, 1981. Reprinted with permission.

Mortality

The mortality rate for adolescent idiopathic scoliosis is comparable to that of the general population[46,69]. In the Iowa series, thirty-three of 219 patients had died—a 15% mortality rate[69]. The predicted death rate for a comparable population of patients is 17 per cent[65]. Death certificates and information from post-mortem exams were obtained in all but six patients (none of the six had a thoracic curve). In only one patient could cor pulmonale secondary to scoliosis be implicated as the cause of death. In the long term scoliosis study by Kolind-Sorensen the mortality rate in patients with curves from 40-100 degrees was comparable to that of the general population. In patients with curves greater than 100 degrees, however, the death rate was twice that of the general population[32]. Thus, if we consider the aforementioned information on pulmonary function, we can conclude that only in thoracic curves greater than 100 degrees is there an increased risk of morbidity and mortality secondary to pulmonary hypertension and right heart failure[32,42,46,49,66,69].

Psychosocial Aspects

Much has yet to be learned concerning long term psychosocial effects of scoliosis. There are many studies published but most conclusions are based on clinical judgement rather than empiric data[5,19,69]. The cosmetic deformity of scoliosis is much better accepted by older patients. Most patients were very self-conscious in their adolescent years, but with age came to "accept" the deformity[69]. Some adults with moderate to severe deformity may however become psychologically disabled by their deformity[5]. There is however, no correlation between the location and degree of curvature and the psychosocial effects. Some patients with minimal deformity express severe psychosocial limitations while others with severe curves are not bothererd at all[69]. It is clear that this is an area requiring further investigation.

Effect of Pregnancy

The effect of pregnancy on scoliosis is unknown. Nachemson et al. demonstrated a statistically significant effect on curve progression in patients having multiple pregnancies prior to age twenty-three[44]. They recommended avoidance of pregnancy in the early twenties, particularly in brace treated patients. Blount and Mellencamp, and Berman et al. also demonstrated an adverse effect of pregnancy on scoliosis progression[4,6]. Blount related the effect to the "stability" of the curve[6]. Bunnell, on the other hand was unable to detect any deleterious effect of pregnancy on scoliosis in his natural history study group[10]. In the Iowa series there were only two women who had to have caesarean sections; they attributed significant complications during pregnancy or delivery to their spinal deformity[69]. At present we are therefore unable to say conclusively what effect pregnancy has on the natural history of curve progression. From the obstetrical point of view, however, no adverse effects have been demonstrated in reference to scoliosis and its effect on pregnancy.

Curve Progression

A great deal has been learned about curve progression in the last twelve years[1,10,14,23,35,56,57,66,67,68,69,71]. Originally, it was thought that once skeletal maturity was reached no further progression would occur[15,54]. Duriez in 1967 was the first to demonstrate that curve progression may continue after skeletal maturity[18]. Several other studies confirmed this fact and also identified factors leading to progression after skeletal maturity[1,67,68,69].

In 1978 we made an exhaustive search to locate patients with untreated adolescent idiopathic scoliosis (onset of deformity after age eight) seen at the University of Iowa between 1932 and 1948. We were able to locate 219 patients. Eighty-four per cent were women and 16 per cent were men. The average follow-up was forty years (range thirty-one to fifty-one years) and the average age at follow-up was fifty-three years (range thirty-eight to seventy). One hundred twenty patients had standing AP roentgenograms of the spine taken at that time. Ninety-one of these 120 had comparable roentgenograms available in 1968 for comparison. One hundred two patients had standing AP roentgenograms at skeletal maturity (Risser IV or V)[74] and at final follow-up in 1978. The majority of these patients also had roentgenograms available in 1968 for comparison. Each roentgenogram was evaluated for degree of curvature (Cobb method)[15], per cent rotation[48] and Mehta angle[39]. We also evaluated the relationship between the body of L5 and the intercrest line[37]. By this method the fifth lumbar vertebrae is said to be well seated if the intercrest line passed through the L4-5 disc space or above. Translatory shifts between vertebral bodies[68,69] were recorded as was lumbarization of S1 and sacralization of L5. Each of these parameters was evaluated for its prognostic value.

These studies[68,69] revealed that 68 per cent of the curves progressed (greater than 5 per cent) after skeletal maturity with 37 per cent progressing from 1968-1978. The average curve progression was 13.4 degrees[68]. Curves less than 30 degrees at maturity tended not to progress in adult life regardless of curve pattern. Curves greater than 30 degrees may continue to progress throughout life depending on curve pattern and the interplay of various prognostic factors[57,67,68]. A recent multicenter Italian study (Table II) of 187 untreated scoliotic patients followed an average of thirty-four years seems to confirm this data on curve progression[1].

TABLE II

AVERAGE CURVE PROGRESSION POST-MATURITY

Pattern	Iowa City, group+ (degrees)	Italian group* (degrees)
Thoracic	17	17
Lumbar	10	16
Thoracolumbar	18	14
Double Thoracic	14	13
Lumbar	14	16
All Patterns	13	15

+ Iowa City group-102 Patients, Average Curve 50°, Average Followup 40 years

* Italian group - Multicenter, 187 Patients, average Followup 34 years

Thoracic Curves—(Fig. 7)

Thoracic curves less than 30 degrees at skeletal maturity do not progress further. All of these curves had less than 20 per cent apical vertebrae rotation and Mehta angles of less than 20 degrees. Curves greater than 30 degrees at maturity progressed an average of 19 degrees. The most marked progression was noted in curves between 50 and 75 degrees at skeletal maturity which continued to progress at ¾ to 1 degree/year during the follow-up period.

All of the curves greater than 50 degrees at skeletal maturity had greater than 30 per cent apical vertebrae rotation and all had Mehta angles greater than 20 degrees, with most being in the 30 to 60 degree range. As measured by a plumbline at C7, compensation improved over the years by an increase in compensatory curves. Thus in thoracic curves, the Cobb angle, Mehta angle and apical vertebral rotation were important prognostic factors in curve progression post-maturity.

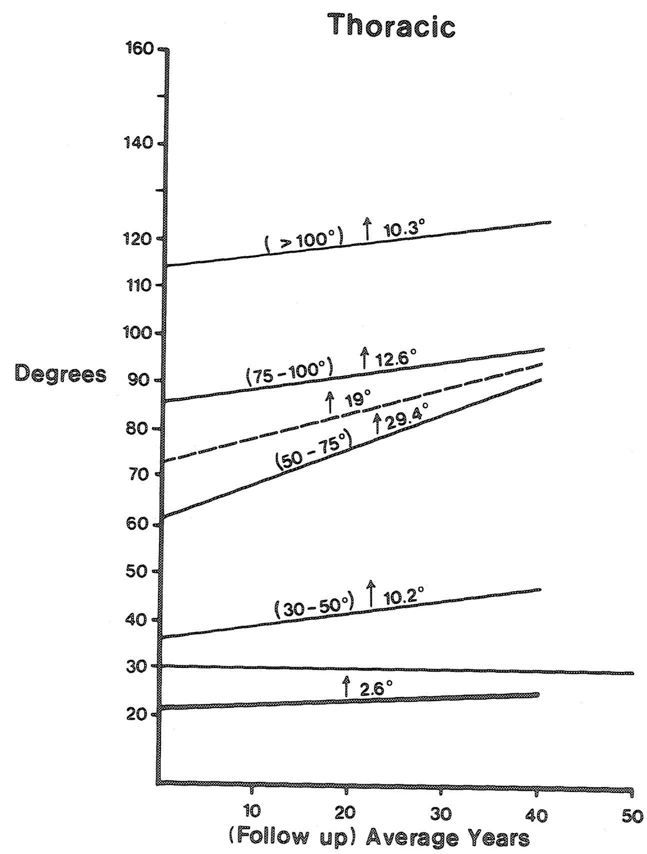

Figure 7

Thoracic curve progression post-skeletal maturity. Thick black line represents average curve progression for all curves less than 30° at skeletal maturity. Thick dashed line represents average curve progression for all curves greater than 30° at skeletal maturity. Thin black lines represent average curve progression for each range in parentheses. Based on data from Weinstein, S.L., and Ponseti, I.V.: Curve Progression in Idiopathic Scoliosis. J. Bone and Jt. Surg., 65A:447, 1983. Progression is not necessarily linear. Lines connect average values at maturity and at average 40 year follow-up.

Lumbar curves (Fig. 8)

In general, lumbar curves less than 30 degrees at maturity don't progress. The average curve progression was 16.2 degrees for curves greater than 30 degrees at maturity over the follow-up period. All curves over 30 degrees had greater than 33 per cent apical vertebral rotation. All but four curves greater than 30 per cent at maturity progressed; these had either a "deeply seated" or a sacralized L5[68]. These curves were the only ones that did not develop translatory shifts at follow-up. These translatory shifts were usually at L3-4 but occasionally occurred at L4-5. Accompanying translatory shifts was lateral tilting of L4 on L5 toward the curve convexity, especially in cases when L5 was not well seated (Fig. 3). Right lumbar curves greater than 30 degrees progressed twice as much as left lumbar curves. Thus in lumbar curves, prognostic factors in curve progression post-maturity included: Cobb angle greater than 30 degrees, degree of apical vertebral rotation, direction of the curvature, and relationship of L5 to the intercrest line. In addition, translatory shifts and lateral tilting of vertebrae below the curve contributed to curve progression.

Thoracolumbar (Fig. 9)

Thoracolumbar curves greater than 30 degrees at maturity progressed an average of 19.6 degrees in the follow-up period. As with the thoracic curves, those measuring between 50 to 75 degrees at maturity progressed the most, averaging 22.3 degrees progression. This group of

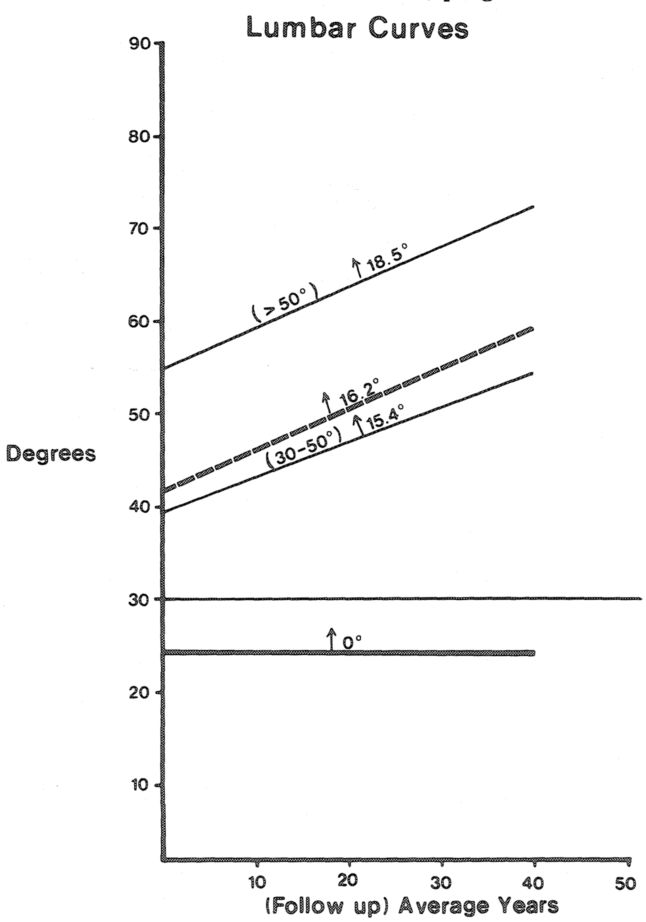

Figure 8
Lumbar curve progression post-skeletal maturity. Thick black line represents average curve progression for all curves less than 30° at skeletal maturity. Thick dashed line represents average curve progression for all curves greater than 30° at skeletal maturity. Thin black lines represent average curve progression for each range in parentheses. Based on data from Weinstein, S.L., and Ponseti, I.V.: Curve Progression in Idiopathic Scoliosis. J. Bone and Jt. Surg., 65A:447, 1983. Progression is not necessarily linear. Lines connect average values at maturity and at average 40 year follow-up.

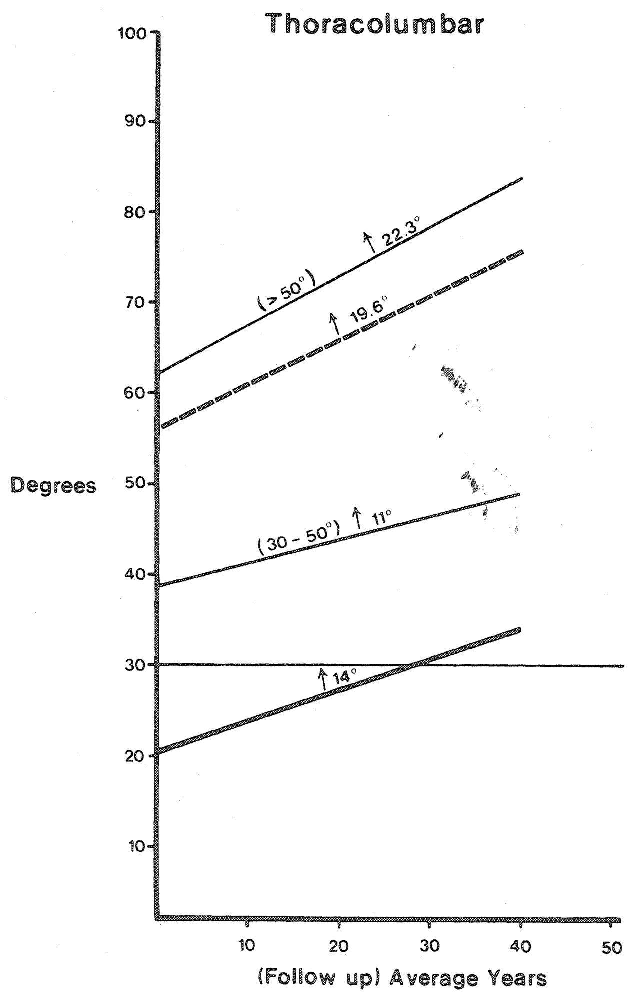

Figure 9
Thoracolumbar curve progression post-skeletal maturity. Thick black line represents average curve progression for all curves less than 30° at skeletal maturity. Thick dashed line represents average curve progression for all curves greater than 30° at skeletal maturity. Thin black lines represent average curve progression for each range in parentheses. Based on data from Weinstein, S.L., and Ponseti, I.V.: Curve Progression in Idiopathic Scoliosis. J. Bone and Jt. Surg., 65A:447, 1983. Progression is not necessarily linear. Lines connect average values at maturity and at average 40 year follow-up.

patients exhibited the most striking examples of high percentage apical vertebral rotation (40 to 64 per cent). This rotation increased with increasing curve severity. As in lumbar curves, translatory shifts between two vertebrae developed at the lower end of these curves. This marked vertebral rotation in combination with translatory shifts at the lower end of the curve led to significant curve progression.

Double Curves (combined) (Fig. 10, 11)

Curve progression post-skeletal maturity in curves greater than 30 degrees averaged 14.2 degrees for the thoracic component and 15.5 degrees for the lumbar component of double curves. In both components the most marked progression occurred in curves measuring between 50 to 75 degrees at skeletal maturity, the lumbar component progressing on average of 23.1 degrees while the thoracic component progressed an average of 18.3 degrees. At maturity the majority of thoracic components were of a larger magnitude than the lumbar components. At follow-up however, the lumbar components tended to have greater curve progression than the thoracic component. Hence over the years double curves tend to balance. Translatory shifts developed at the transition of the two components

(Double) Thoracic Component

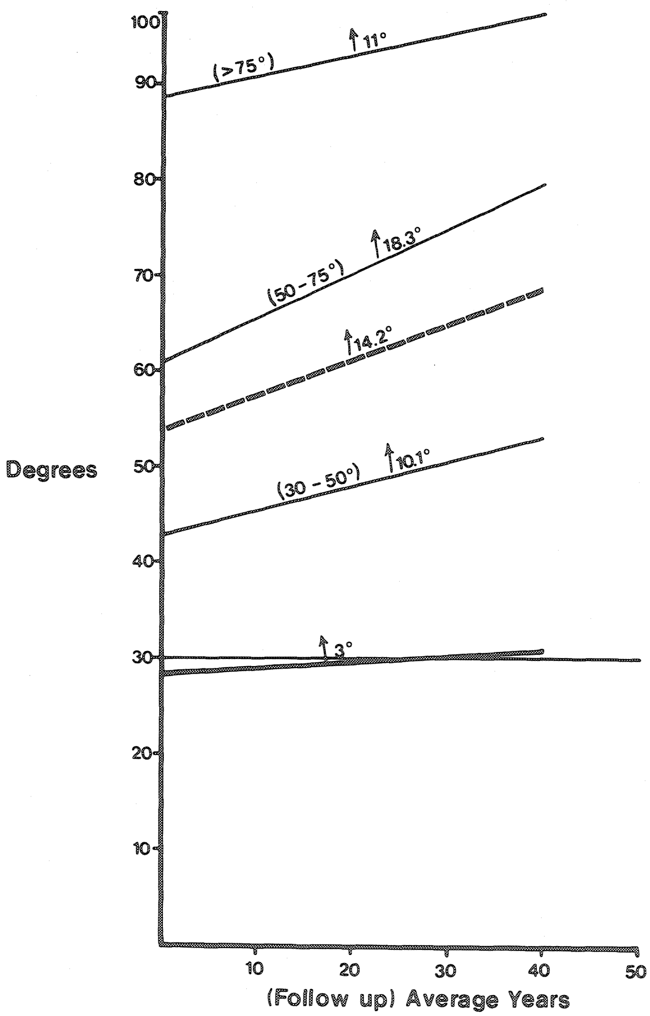

Figure 10

Thoracic component of double (combined) curve progression post-skeletal maturity. Thick dashed line represents average curve progression for all curves greater than 30° at skeletal maturity. Thin black lines represent average curve progression for each range in parentheses. Based on data from Weinstein, S.L., and Ponseti, I.V.: Curve Progression in Idiopathic Scoliosis. J. Bone and Jt. Surg., 65A:447, 1983. Progression is not necessarily linear. Lines connect average values at maturity and at average 40 year follow-up.

(Double) Lumbar Component

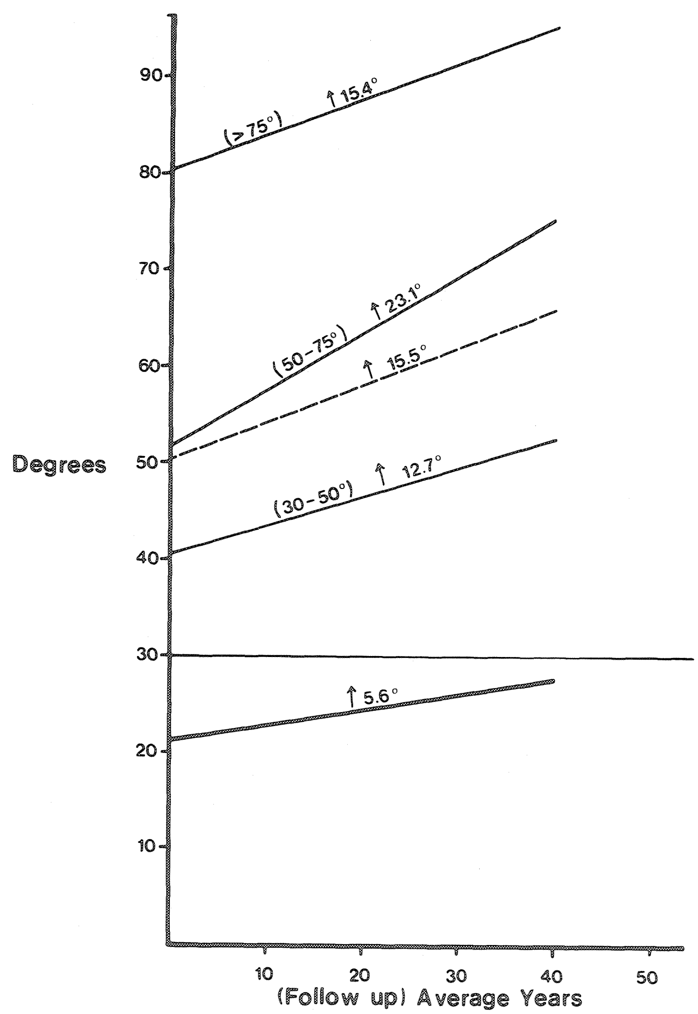

Figure 11

Lumbar component of double (combined) curve progression post-skeletal maturity. Thick dashed line represents average curve progression for all curves greater than 30° at skeletal maturity. Thin black lines represent average curve progression for each range in parentheses. Based on data from Weinstein, S.L., and Ponseti, I.V.: Curve Progression in Idiopathic Scoliosis. J. Bone and Jt. Surg., 65A:447, 1983. Progression is not necessarily linear. Lines connect average values at maturity and at average 40 year follow-up.

of curves greater than 50 degrees. The per cent apical vertebrae rotation, Mehta angle, and the relationship of the fifth lumbar vertebrae to the intercrest line did not correlate with curve progression. The extreme degrees of rotation seen in lumbar and thoracolumbar curves were not seen in double curves and unlike in large magnitude primary thoracic curves, in combined curves the ribs usually remained level.

When one evaluates this large group of patients and examines the times when progression occurred, it is readily apparent that the major period of progression occurs between curve detection and skeletal maturity (Fig. 12). The next most rapid period of progression occurs from skeletal maturity to thirty year follow-up and finally the least progression occurred from thirty to forty year follow-up (Fig. 12)[67,68,69].

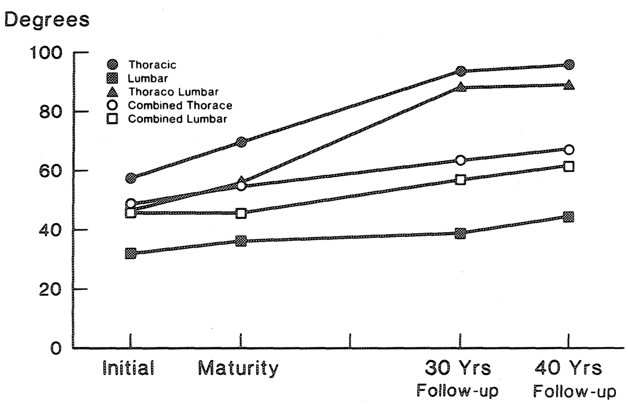

Figure 12

Average curve progression by curve pattern from initial detection to skeletal maturity, to 30 and then 40 year follow-up. Based on data from reference 67, 68, 69.

Except for lumbar curves, this group of patients had curves of severe magnitude at initial detection[67,68,69], an occurrence today prevented by school screening and increased awareness of scoliosis by the lay public and primary care physicians. Although "flexibility" of the spine may play a role in long-term progression, no definite objective supportive evidence exists[40]. All curve patterns tend to become better balanced with age by the development of compensatory curves.

As our knowledge of the natural history of adolescent idiopathic scoliosis expands, treatment decisions can be based on objective rather than subjective data. Any proposed treatment of this condition must have a reasonable chance of altering the natural history in a positive way. It must be kept in perspective that the information available on natural history has been accumulated on relatively small groups of patients and the conclusions presented represent generalities. In all probability, especially with reference to curve progression, there are probably many "natural histories". Hence with respect to treatment, decisions must be individualized. Long term results of various treatments for scoliosis must be viewed in the light of the natural history of the disorder.

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REGIONAL GROWTH DISORDERS AND THE PATHOGENESIS OF CLUBFOOT

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There are several clinical entities that have as one characteristic the failure of normal symmetrical growth of a region of the body. The entities I refer to show normal tissue differentiation in the affected regions of the body, that is, the full complement of bones, muscles, connective tissues, blood vessels and nerves is present. Conditions without all normal tissues present such as tibial agenesis and congenital amputations are not growth disorders of the type to be discussed. Furthermore, conditions causing growth disturbance with identified intrinsic tissue abnormalities such as bone dysplasias and metabolic diseases are not to be considered.

The purest example of these regional growth disorders are the hemi-hypertrophies and -atrophies and the idiopathic leg length discrepancies. These disorders may have deformity as well as size difference depending on the location and quantity of affected tissue. However, the gross anatomy of the affected region is complete and the microanatomy of the affected tissue is normal. I will present an argument and some evidence that idiopathic clubfoot might reasonably be considered such a regional growth disorder and suggest a possible etiology. Before I begin that discussion, however, I will first review existing theories of etiology of clubfoot and the evidence underlying them.

Most theories of clubfoot pathogenesis developed since 1800 are derived from gross anatomical and histological studies. Using anatomic techniques, investigators have proposed molding in utero[5,32,41], primary muscle lesion[2,29,30,36], primary bone lesion[26], primary joint lesion[4], primary vascular lesion[27], primary nerve lesion[6,8], developmental arrest[3,35], and abnormal tendon insertion[16,23] as the cause of clubfoot.

Clearly anatomic studies are open to extremely varied interpretations as to what constitutes a primary and what a secondary lesion.

Some investigators have found histologic abnormalities (especially of muscle)[2,20,25,29,30,36] whereas others have found the microanatomy of muscle, nerve, vessels, spinal cord and tendon insertions to be normal[16,17,20,26]. Ponseti and Ippolito in a careful histologic study of five fetal clubfeet found increased fibrous tissue in the ligaments, fasciae, tendon sheaths and muscles in the posterior and medial aspects of the clubfoot and suggested that primary fibrotic contraction of muscle tendon units and soft tissues might cause clubfoot[24]. Similarly, ultrastructural analysis has been inconsistent. Isaacs et al.[25] and Handelsman and Badalamente[20] found ultrastructural muscle abnormalities, whereas Tonnis[39] and Henkel et al.[21] did not.

Hypotheses suggesting a major environmental influence are based on three types of information. First, limb malformation can be created in animals by exposure of the fetus to various chemical agents or malnutrition[9,39]. The relevance of these studies to human clubfoot is uncertain. There is no evidence for selective exposure of mothers of children with clubfoot to certain drugs or environmental conditions.

Second, genetic epidemiological studies led some investigators to conclude that clubfoot is a multifactorial trait[42]. This is a statistical argument that is far removed from the biology of clubfoot. One selects multifactorial causation only when a disease clusters in families but does not meet simpler inheritance patterns. This is a causal model which cannot be confirmed by direct evidence. Furthermore, various interpretations of population data are possible. Palmer[31] interpreted his clubfoot data to show autosomal dominance inheritance with reduced penetrance in families with positive family histories and no genetic inheritance in families without a history of clubfoot. Our present genetic theories are probably not adequate for evaluating this type of disorder but support of an environmental cause on the basis of indirect evidence from a statistical model is also tenuous.

Finally, I will discuss the intrauterine molding hypothesis which in recent years has seemingly been regarded as an established fact in both the orthopaedic and pediatric literature. The major evidence for the creation of congenital postural deformities by intrauterine mechanical factors comes from the work of Dunn[10,11,12,13,14,15]. Before this work, as Dunn himself states, "the supporting evidence (for this theory) tended to be anecdotal"[15]. Dunn examined 4745 consecutively born infants in 1960 and 1961 and correlated findings with the mother's pregnancy history and the infant's follow-up records.

Dunn found an increased incidence of foot deformities in first pregnancies, breech presentation, and pregnancies complicated by oligohydramnios and concluded, therefore, that all foot deformities including clubfoot were caused by intrauterine molding.

However, Dunn lumped all foot deformities into the single category of "talipes". This included talipes equinovarus, talipes calcaneovalgus, metatarsus adductus, and, I assume, any other unclassified foot deformity. This is not a reasonable classification, as clubfoot, calcaneovalgus and metatarsus adductus have different clinical characteristics. Children with clubfoot typically have a smaller foot and leg on the affected side which is not true for calcaneovalgus and metatarsus adductus. Clubfoot may recur, even after adequate casting correction, during the major growing period of the foot. Calcaneovalgus and metatarsus adductus do not. Most metatarsus adductus and virtually all calcaneovalgus feet resolve spontaneously. Clinically, calcaneovalgus and metatarsus adductus behave like mild, late pregnancy molding deformities. Clubfoot does not.

What data does Dunn's lumping of various foot deformities generate? Dunn found that 62 per cent of infants with "talipes" were firstborn children. Both Wynne-Davies[42] and Alberman[1] in studies of comparable numbers of foot deformities to Dunn's, found no increased incidence of clubfoot among the firstborn. Both authors did find an increased incidence of firstborn children with calcaneovalgus. The bias created by Dunn's categorization process is clear. Further, Dunn found 22 per cent "talipes" with breech presentation. Alberman found no significant correlation between clubfoot and breech presentation.

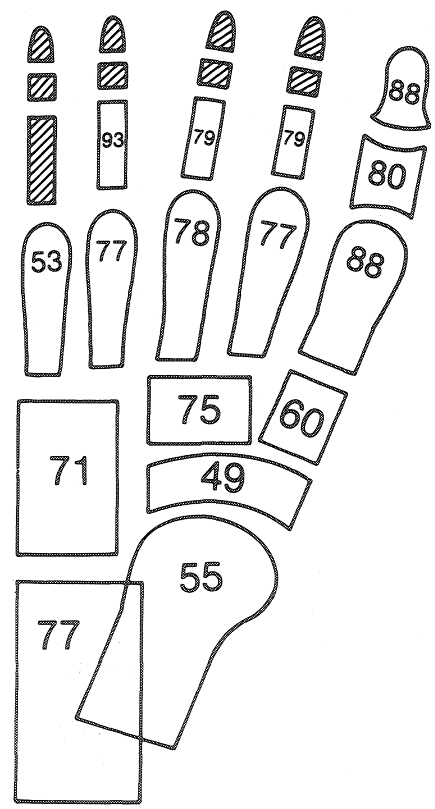
Dunn argues that oligohydramnios causes "talipes". Yet he presents no real evidence. Dunn states that "this is a difficult subject on which to obtain objective data, as even simple clinical observations tend to be poorly recorded. However, from my own experience over the years there seems no doubt that there is positive correlation between oligohydramnios and deformation"[10]. Dunn found eleven children born of mothers with chronic amniotic fluid leakage. Four of these children had "talipes". Whether any were idiopathic clubfeet is unstated.

Dunn also argues that postural deformities are rarely seen before twenty weeks of gestation. Yet, in reports of fetuses with clubfoot, many are less than twenty weeks old[2,24].

A final argument against the intrauterine molding hypothesis comes from the work of Ponseti and Ippolito who observed an infolding of the posterior ankle ligaments into the joint in a nineteen week old fetal clubfoot rather than a shortening which would be expected if the deformity were caused by an abnormal intrauterine foot position[24].

The clinical evidence for considering idiopathic clubfoot to be a regional growth disorder is of two types. First, the leg and foot in clubfoot are invariably small. The more severe the deformity the more marked is the reduction of foot and leg size. In a long term follow up of seventy clubfeet who were mostly treated with cast correction and percutaneous tendo Achilles lengthening, Ponseti and Laaveg found average foot length reduction of 1.3 cm, a foot width reduction of .4 cm and leg circumference decrease of 2.3 cm in clubfeet[28]. The vast majority of fetal clubfoot dissection reports have commented on the decreased size of the tarsal bones and the leg musculature although quantitative assessments of size were not done. The second reason for considering clubfoot a growth disturbance is that recurrence of corrected clubfeet occurs only during the rapid growth period of the foot.

To begin evaluation of this hypothesis I performed a dissection of a twenty-seven week fetus with a right clubfoot and a normal left foot. Each of the tarsal bones and muscles of these were dissected and weighed. A decreased mass of all the bones of the clubfoot compared with normals was found. The medial tarsal bones are approximately 50 per cent the weight of the normal talus, navicular and first cuneiform whereas the lateral tarsals are about 80 per cent the size of normals (Fig. 1). Also the tibial nerve innervated muscles in the clubfoot were 67 per cent of the normal's weight whereas the peroneal innervated muscle were 80 per cent the weight of the normals.



% by Weight of Clubfoot vrs. Normal

Figure 1

This does not speak directly to the question of primary vs. secondary deformity, but if one conceives of this disorder as a growth disturbance mainly affecting the posteromedial foot, one has a ready explanation of the deformity, of the resistance to treatment, and of recurrence seen clinically. The relatively smaller size of the posterior and medial aspects of the leg and foot could explain the observed deformity and its resistance to manipulative correction. Furthermore, recurrences can be explained as resulting from a more rapid growth of the anterolateral foot around the more slowly growing posteromedial foot. This is in concert with observed clinical facts about the nature of recurrence as recurrences are most common in the first year or two and occur with decreasing frequency to age five or six. Recurrences are rare after this age. This parallels the period of rapid foot growth; the foot being 50 per cent of its adult size by two and a half years of age and 70 per cent of the adult size by five years of age with relatively slow growth after this time.

Other evidence exists for a growth difference between the anterolateral and posteromedial foot in clubfoot. In a study done at the University of Iowa we quantitatively compared cellular characteristics between anterior tibial and posterior tibial tendon sheaths in clubfeet and normal feet[7]. Tendon sheaths were harvested at the time of posteromedial release in four patients. Two controls were obtained post mortem within a few hours of death. We used stereologic techniques to quantitate cell number, and cytoplasm and nuclear volume (Fig. 2).

We found that clubfoot posterior tibial tendon sheaths had a lesser cell number and cell volume than did their anterior tibial sheaths; whereas, normal posterior tibial sheaths had a greater cell number and cell volume than did their anterior sheaths (Figs. 3 and 4).

We interpreted these findings as showing a cellular hypoplasia in the posterior tibial tendon sheath. We feel this might be a reflection of a generalized tissue hypoplasia of the posteromedial as compared to the anterolateral foot in clubfoot.

What might cause a regional growth disturbance? Because the most affected tissues are in the area of the foot subtended by the tibial nerve, we wondered whether a peripheral nerve abnormality might affect the growth rate of the tissues it innervates. Handelsman and Badalamente performed a semi-quantitative histochemical study of the muscle fiber types in clubfoot and found an increase in Type I muscle fiber in the tibial innervated and some of the peroneal innervated muscle of clubfeet as compared to normals. Since fiber types are neurally determined they felt some sort of primary nerve abnormality might be the cause of clubfoot.

Limb development however, has been stated to be independent of nerve supply based on studies of amphibians and chicks[16,18,19,38]. These studies focussed on differentiation of limb tissues and not on growth. We, therefore, performed a study of the effect of peripheral denervation on limb growth after differentiation in an amphibian model.

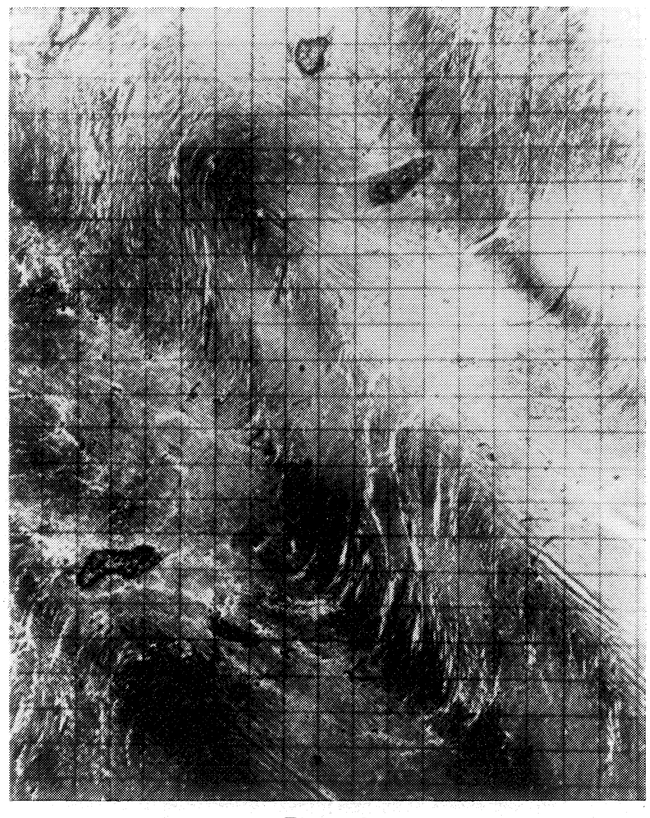


Figure 2
A photomicrograph (X 1,000) of a tendon sheath with superimposed counting grid. The points formed by the upper right hand grid line intersections are the test points. Each point falling on tendon sheath is used as a reference. Each point falling on cell, nucleus, or cytoplasm is tabulated. Also, nuclear profiles are tabulated.

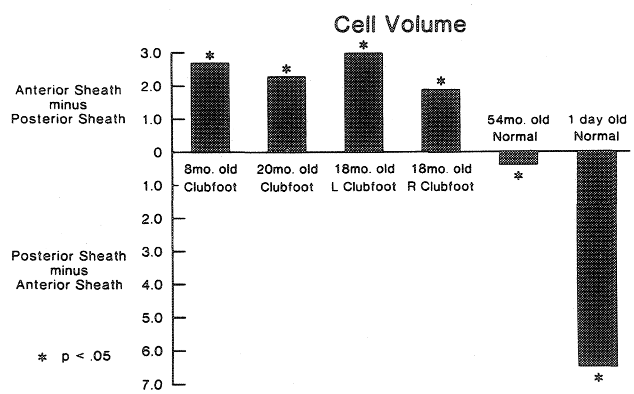


Figure 3
Histogram I: Cell volume. Units are percentage of tissue volume occupied by cells.

In this study twenty-four laboratory raised Rana pipiens tadpoles at developmental stage XIV (Fig. 5) underwent a resection of a 2 mm segment of sciatic nerve on the left leg and an identical procedure without nerve injury on the

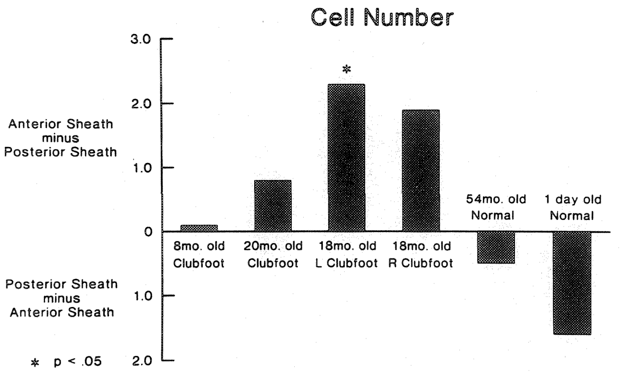


Figure 4
Histogram II: Cell number. No units. Dimensionless numbers for comparison only.

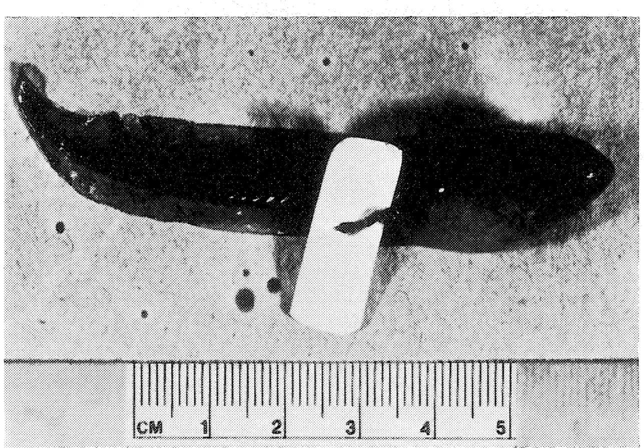


Figure 5
Stage XIV animal.

right leg. Animals were then raised to Stage XIX-XXIV (Figs. 6 and 7) and sacrificed.

Bone and muscle development were assessed as follows: Tibia lengths were measured. Quantitative microscopic analysis was performed on midtibia cross sections to determine surface area, osteocyte number, and osteo-

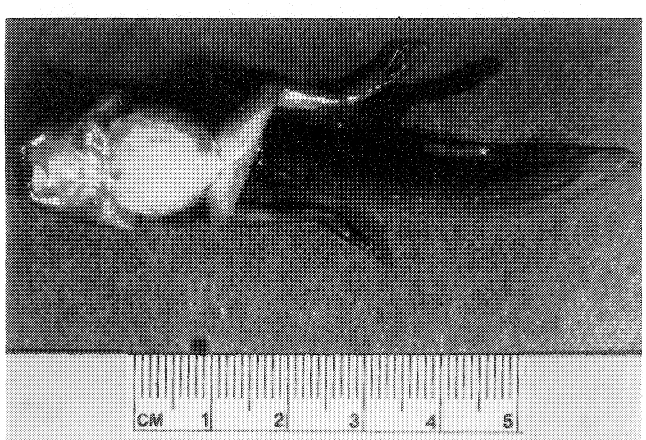


Figure 6
Stage XIX animal.

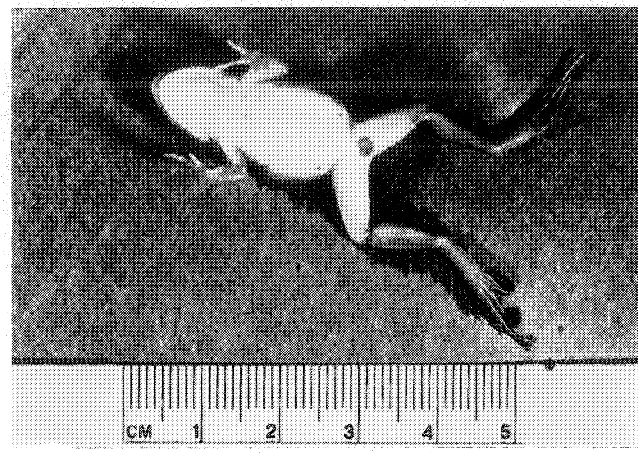


Figure 7
Stage XXIV animal.

cyte density. Quantitative microscopic analysis was also done on mid-gastrocnemius cross sections to determine surface area, muscle fiber number and muscle fiber density.

The following results were obtained.

1. Denervated limbs had a 15 per cent decrease in tibial length compared with control limbs.
2. Denervated limbs had an 18 per cent decrease in tibial cross-sectional area at mid-tibial level.
3. Denervated limbs had a 20 per cent greater osteocyte density.
4. Denervated limbs had a 32 per cent decrease in gastrocnemius cross-sectional area at mid-gastrocnemius level.
5. Denervated limbs had a 40 per cent greater muscle fiber density.

Two other interesting bone findings were noted. First, cartilage anlage were seen in three denervated limbs and only one control limb (Fig. 8). The anlage were only seen in animals sacrificed before stage XXII. Second, the cortical structure of denervated tibias was uniformly thicker, more porous and more tortuous on its inside perimeter than the control limb. In the control tibias, cortical bone was more compact with smooth circular inside and outside perimeters (Fig. 9).

To further evaluate the significance of these findings, I compared amputated limbs with more mature limbs from the same animals using the same methods. The findings were similar to a comparison of denervated and control tibias. The bones were shorter in the less mature limbs. The area of a cross section was smaller in the less mature limbs. Cellularity was greater in younger amputated legs than in the more mature legs. Furthermore, cartilage anlage were present only in the immature limb or were larger in the immature than in the mature limb (Fig. 10). Also, the amputated limbs' gastrocnemius had a smaller cross sectional area and a greater muscle fiber density when compared to more mature limbs.

Figure 8a
A temporarily denervated limb's tibia showing a persistent cartilage anlage.

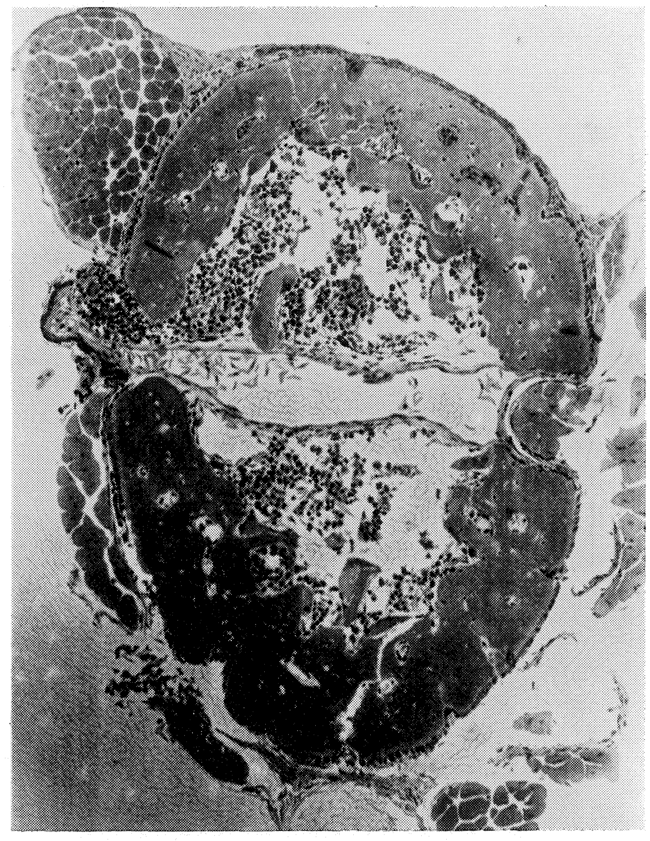


Figure 8b
The same animal's control tibia. The bone is larger and has no cartilage remaining.

The smaller size of the bone and muscle on the denervated limbs demonstrated a growth-promoting influence of peripheral nerve in this model. The similarity of findings between denervated vs. control and amputated vs. mature limbs suggests that the decreased size reflects slower rate of maturation of the denervated limb. Also, the porous unremodeled cortex and persistence of cartilage anlage in denervated limbs, suggests that slowed maturation might be the cause of the decreased size in denervated limbs.

This study does not address the question of whether the growth delay was a direct effect of nerve interaction with limb tissues or simply a result of the absence of normal muscle activity. Since the muscle activity in clubfoot is normal this is an important point. There is evidence that nerves manufacture and release a substance in the peripheral tissues that stimulate the growth and maturation of muscle tissue that is independent of the function of the nerve in carrying electrical impulses and stimulating muscle contraction. This evidence is of two sorts. Sohal and Holt in 1980 showed that chick embryos whose muscle contractions were blocked with bungarotoxin developed differentiated muscle fibers, whereas aneural muscle underwent degeneration and replacement by connective tissue[37]. The second evidence derives from the work of Popiela who has isolated an 80,000 molecular weight protein called neurotrophic factor from peripheral nerves in chickens that stimulated muscle growth and differentiation in tissue culture[34]. No work to date has assessed the effect of this neurotrophic factor on limb tissues aside from muscle. It is possible that peripheral nerves release a substance necessary for normal growth and development of limb tissues that is unrelated to its function in muscle contraction.

This sort of interactional phenomena is well recognized in embryonic development when tissue interactions are necessary for normal tissue differentiation such as the induction of optic lens formation from the ectoderm by contact with the underlying forebrain. The possibility that normal tissue interactions are necessary for growth after the differentiation stage has been little investigated. Investigation of these relationships might shed light on the etiology of human disorders that clinically appear to result from a disorder of growth in a quantitative sense rather than from a disorder of tissue differentiation or function.

Clubfoot may be such a disorder and available clinical and research data are consistent with the hypothesis that clubfoot is a neurally caused growth disturbance of the foot.

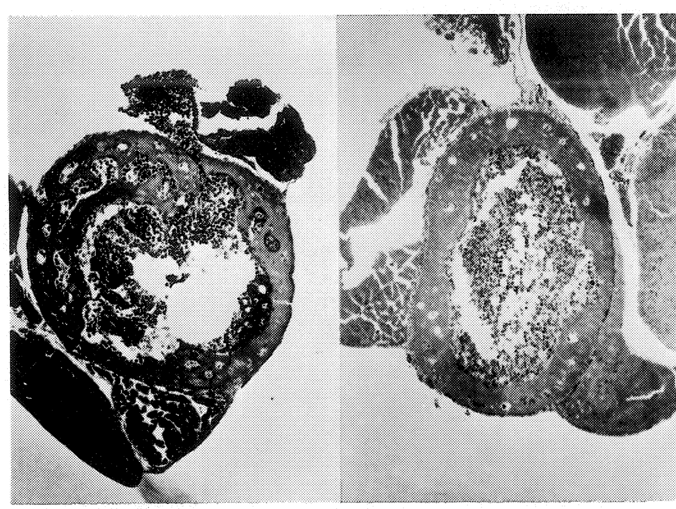


Figure 9a & b
9a demonstrates the typical porous unremodeled cortex of the denervated tibia as compared to 9b, which is the same animal's control tibia.

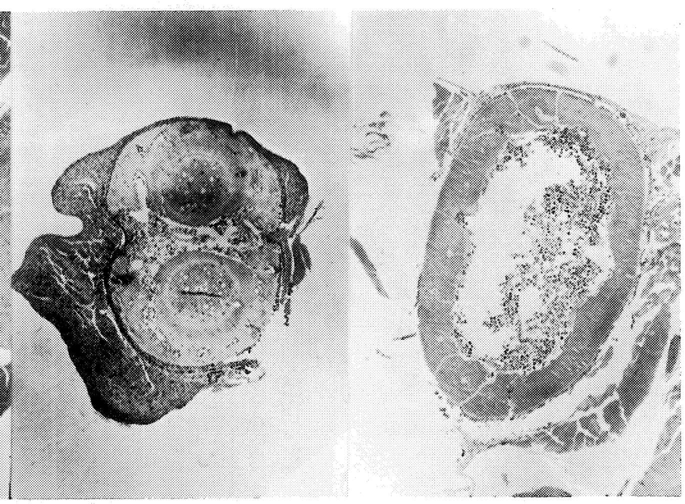


Figure 10a & b
These two tibiae show the most extreme differences as expected since they have the greatest differential in maturity (10a, Stage XIII and 10b, Stage XXIV). The immature tibia is smaller, has an unremodeled cortex, and has a persistent cartilage anlage. 10b shows the mature tibia to be larger, well remodeled, and lacking cartilage.

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THE CASE FOR CEMENTED HIPS

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My assignment today is to defend the continued use of methylmethacrylate for fixation of total hip prostheses. In view of the atmosphere across the country today and the series of papers you have just heard, I feel a little like Daniel must have felt in the lions' den. However, it is important that you understand that none of us seriously studying the problem of fixation really knows which method of fixation is best for a given patient today. To give you a better feel for this dilemma, it might be useful to do two things. First, we'll look at bony ingrowth fixation and some of the remaining unanswered questions. Then we'll review the results of cement fixation, discuss the cause of failure of fixation, and from that make some projections for the future.

It has been well established in animals that bone will grow into appropriate sized holes in prosthetic parts under proper conditions of stability and contact. We assume that if this occurs in humans that fixation will be permanent. This is a reasonable assumption, but still an assumption.

The clinical experience with these devices in humans suggest that adequate fixation occurs in a very high percentage of cases. We don't yet know how to determine if this fixation is due to bone or fibrous tissue ingrowth. While this may not matter in the short term, especially on the acetabular side, it may matter greatly in the long term. Since fibrous tissue ingrowth would permit micromotion at the interface with a huge increase in the likelihood of tissue reaction, this may result in bone destruction and subsequent trouble in the long term. We don't even know the tissue response to the increased surface area of the implant with bone ingrowth in the long run. Since the implant is definitely weakened by the process of creating the porosity, is fatigue failure of the implant going to be a significant problem? We may not know the answer to that for many years. All agree that stress shielding is a concern on the femoral side but we still don't know the incidence, degree, or significance in the long term. We certainly don't know what will happen to the large bone grafts used to fill gaps between bone and prosthesis so commonly used now. Since these questions and others remain unanswered, another look at cement fixation seems in order.

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All agree that prosthetic component loosening, in other words failure of fixation, is the major problem in long term success of total hip replacement. Our experience with total hip replacement in the late 60's and early 70's was with either the Müller prostheses or the Charnley prostheses. Both used a metal femoral prosthesis, a high density polyethylene acetabular prosthesis, and methylmethacrylate fixation. However, the femoral stem design, the head size, and consequent acetabular prosthetic thickness and therefore stiffness were signficantly different.

Sutherland et al. reported the ten year results of total hip replacement using the Müller prostheses and radiolucent cement done at the Cleveland Clinic (Table I)[15]. The revision rate was 25 per cent. Component migration was the only available radiologic indication of component loosening. Combining the radiologically loose and revised components the rate of loosening was 29 per cent on the acetabular side and 40 per cent on the femoral side. Since the incidence of radiologic loosening with radiopaque cement by the most generous definition is at least twice the incidence of component migration, the rate of failure due to prosthetic loosening at ten years with the Müller prosthesis is extremely high.

Table I

THR With Müller Prostheses

	Revision	Loose Femoral Prosthesis	Loose Acetabular Prosthesis
Sutherland et al.	25%	40% (80%)	29% (58%)

The great majority of prostheses used in this country were of the Müller design and were used by an even greater majority of orthopaedic surgeons. Since we are all most influenced by our own experiences, there is widespread disillusion with the long term results of cement fixation. However, the experience with the Charnley prostheses has been distinctly different. Charnley and Cupic reported a revision rate for component loosening of 3 per cent at nine to ten years[1]. The published ten year results of my own experience[10], the Hospital for Special Surgery[13], and the Mayo Clinic[14] are shown in Table II. The average rate of revision is about 5 per cent and radiologic loosening

Table II

THR With Charnley Prostheses

	Revision	Loose Femoral Prosthesis	Loose Acetabular Prosthesis
Johnston and Crowninshield	1.5%	9%	7.9%
Salvati et al.	4.5%	7.5%	9%
Stauffer	7.4%	19.5%	11.3%

is relatively low. Those of us lucky enough to have selected the Charnley prostheses in the 60's are much less pessimistic about cement fixation.

Since the results of these operations with the Charnley prostheses have been quite good, it seems reasonable to improve rather than abandon the operation. If we are going to attempt to improve the operation and prevent this loosening, we must develop some understanding as to why the loosening occurs. It is my belief that loosening results from mechanical failure of one or more of the materials in the prosthesis-cement-bone complex. This is based on my clinical experience looking at x-rays of many of these patients, my findings at the time of revision, and the results of our studies in the Biomechanics Laboratory at the University of Iowa, including both theoretical finite element studies and experimental strain gauge studies[2,3,4,5,7,8-], as well as the reported clinical and laboratory experience of others[11,16].

Cement and possibly trabecular bone are the weakest links in the prosthesis-cement-bone complex on the femoral side. Trabecular bone and probably cement are the weakest links in the prosthesis-cement-bone complex on the acetabular side. Materials fail from overload at the point of peak stress. Therefore, the incidence of component loosening can be reduced by those changes in the surgical technique and implant design which tend to decrease the peak stresses and increase the strength of these materials.

I offer, as an hypothesis, that chronic mechanical overload of cement or bone is the primary problem in total hip replacement failure. Other hypotheses have been presented. Some believe that chronic mechanical underload of bone and resultant disuse atrophy is the primary problem. Still others believe that a biological problem such as aseptic necrosis or tissue reaction to foreign body is the main concern. For example, the histiocytic response to loose methylmethacrylate may be the primary problem.

Let's test these hypotheses against some known facts (Table III). The first known fact is that it seems to take less time for the prosthesis to loosen on the femoral side than the acetabular side. This is compatible with the first hypothesis, maybe with the second, and probably not with the third since the biologic reaction should be similar on both sides of the joint.

Table III

What is the Primary Problem in Prosthetic Loosening?

Known Facts	Chronic Mechanical Overload of Cement or Bone	Chronic Mechanical Underload of Bone	Biologic Reaction
1. Increases with time	+	+	+?
2. Less time on femoral side than acetabular	+	+?	–
3. Higher with Müller than Charnley	+	–	–
4. Most stems loosen prior to stem failure	+	+	+

Another known fact is that there is a higher incidence of loosening with the Müller prosthesis than with the Charnley as pointed out earlier. Studies in our laboratory, both theoretically and experimentally, have indicated that the stress in proximal cement is much greater and stress in proximal bone somewhat greater with the Müller device than with the Charnley. These studies have been done with several different mathematical models and several strain gauge experiments. They have been confirmed by others. These facts are compatible with the first hypothesis but are not compatible with the second hypothesis in that the bone in the proximal femur is stressed to a somewhat greater extent with the Müller prosthesis than it is with the Charnley. Therefore, if the second hypothesis is true, the Charnley should fail more often or at least as often as the Müller. It is certainly not compatible with the biologic hypothesis because there is no apparent difference in the biology. The failure rate would be the same if the biologic hypothesis were true.

Another known fact is that most stems loosen prior to stem failure. This is compatible with all of the hypotheses.

It is apparent that the known facts as I have outlined them are all compatible with the first hypothesis that I have proposed: The primary cause of loosening and failure in total hip replacement is chronic mechanical overload of cement or bone. Some of these facts are incompatible with each of the remaining hypotheses. Therefore, unless it can be shown that these facts, as presented, are incorrect, or unless additional facts can be found that are incompatible with the first hypothesis, then that hypothesis is acceptable and becomes a thesis. Furthermore, the remaining hypotheses are then disproven. Therefore, we will proceed with the understanding that the primary cause of loosening and failure of total hip replacement is chronic mechanical overload of cement or bone and that this loosening can be reduced by changes in surgical technique and implant design which tend to decrease the peak stresses and increase the strength of the materials. If the stress applied to the material does not exceed the fatigue strength of the material, then failure will not occur, loosening will not occur, and the resultant of total hip replacement will be successful.

With this in mind, let's try to project the future based on the past. Fatigue strength of bone cement and the stress needed for failure decrease as the number of cycles increases. The logistics of studying the fatigue properties of cement are difficult. However, based on the studies that have been done, and knowledge of other materials, both metals and plastics, it is reasonable to assume for conceptual purposes that the fatigue strength of cement looks something like what is shown in Figure 1, with the stress needed for failure on the vertical scale and number of cycles on the horizontal. If it is assumed that number of cycles is the same year after year, then the horizontal scale can become years postop with four, eight, twelve, etc. respectively. The heavy line indicates the average fatigue strength of methylmethacrylate. The presence of those factors known to weaken the cement would account for the distribution below the heavy line and absence of those factors would account for the distribution above the line. The narrower lines represent a reasonable range. Those factors known to reduce the strength of methylmethacrylate are lack of containment by bone because of the presence of blood, debris, or weak trabecular bone, voids within the cement, or excessive porosity of the cement. Therefore, those cases done with what we now would consider good technique (removal of flimsy trabecular bone and removal of debris without creation of voids at the cement-bone junction or within the cement) tend to be above the heavy line. Reduction of cement porosity by centrifugation or other means may move the average close to the upper line.

Figure 2 shows the relationship between the stress developed by a Müller prosthesis, a Charnley prosthesis, and an Iowa prosthesis on the femoral side. A similar, though more dramatic picture could be drawn for the acetabular side so the conclusions apply to both sides of the

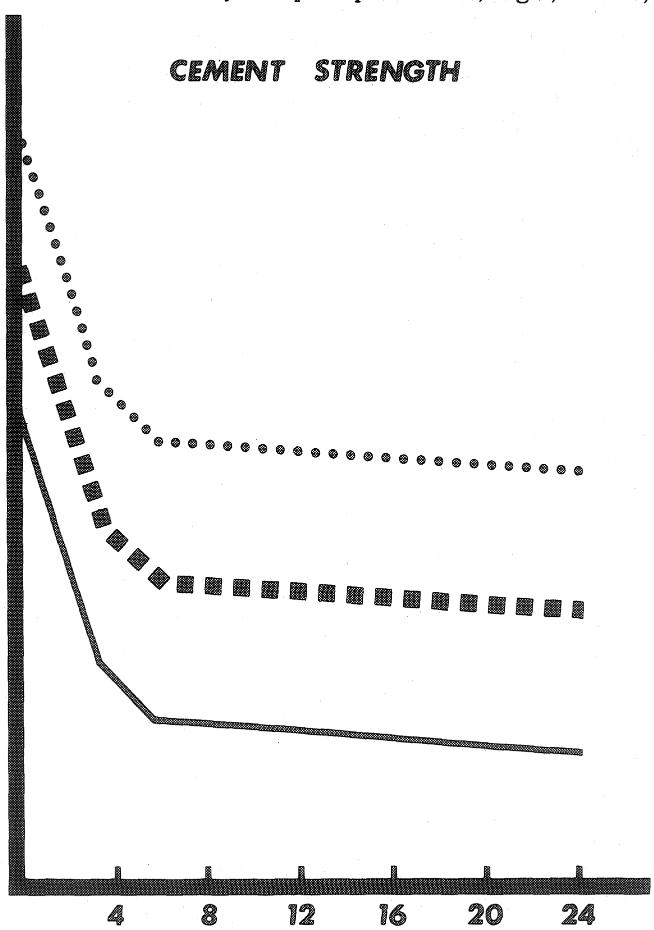

Figure 1
Conceptual fatigue strength of methylmethacrylate.

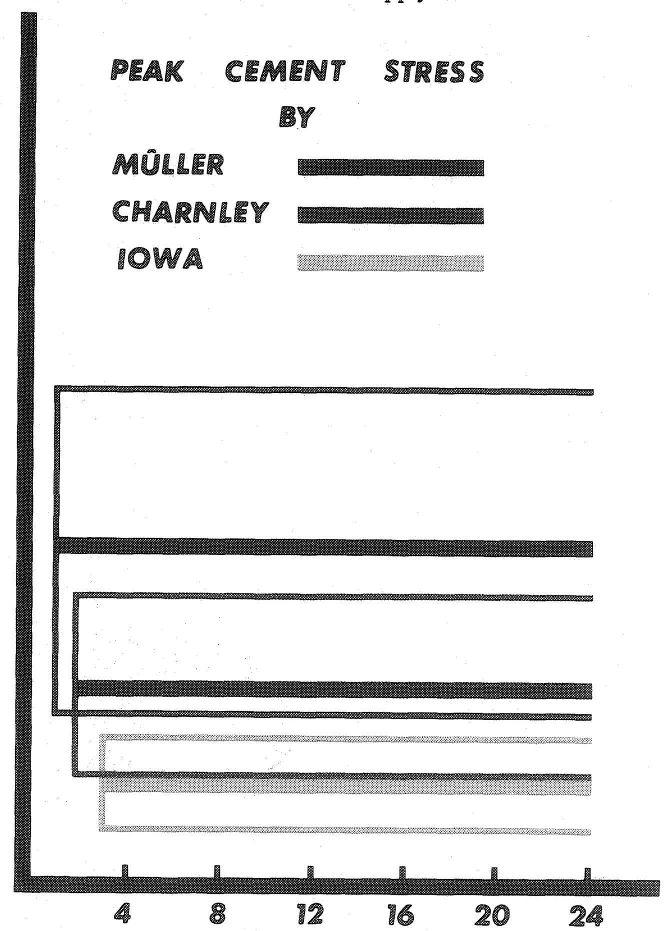

Figure 2
Peak cement stress developed by Müller, Charnley and Iowa prostheses.

joint[6,12]. However, the in vitro assumptions for analyzing the acetabular side of the joint may be more tenuous than on the femoral side. Studies in our lab and others suggest that the peak stress developed by a Müller is about 64 per cent to 75 per cent greater than the peak stress developed by a Charnley. Studies in our lab suggest that an Iowa prosthesis or any other prosthesis that incorporates the same design principles would develop a peak stress of about 50 per cent the peak stress of a Charnley. These design principles include high modulus of elasticity metal such as cobalt chrome, increased stem length, proximal stem cross-sectional shape broad medially and still broader laterally, and precoating of the proximal stem with methylmethacrylate to increase the strength of the bond between prosthesis and cement. All of these features distribute load more evenly and thus reduce the peak stess in cement and bone. Therefore, I am comfortable with the relationship between the heavy green, blue and red lines. The thin lines represent a plus or minus 50 per cent which accounts for differences in patient size, activity, and differences in geometry created at the time of surgery.

Now, if Figures 1 and 2 are superimposed, we get something like what is shown in Figure 3. There are no units on the vertical scale because of the difficulties in measuring cement strength and because the relative stress developed by the different prostheses is much more accurately determined than the absolute stress. However, if one superimposes them in this manner and then looks at the relationships at ten years as indicated by the vertical black line, one finds that the average stress developed by a Müller exceeds the average strength of the cement. One would expect the great majority of the prostheses to have failed, which is in fact what has happened. If one looks at the Charnley, the average stress developed is well below the average strength of the cement. One would expect that only a relatively small percentage would have failed, which is in fact the case. Therefore, it seems reasonable to conclude that the graphs have been properly superimposed.

Now if one removes the Müller and Charnley prostheses from the graph, assuming that we will use one of the newer prostheses, and if one removes the lower half of the cement strength from the graph, assuming that we will use the cement in a better than average manner based on

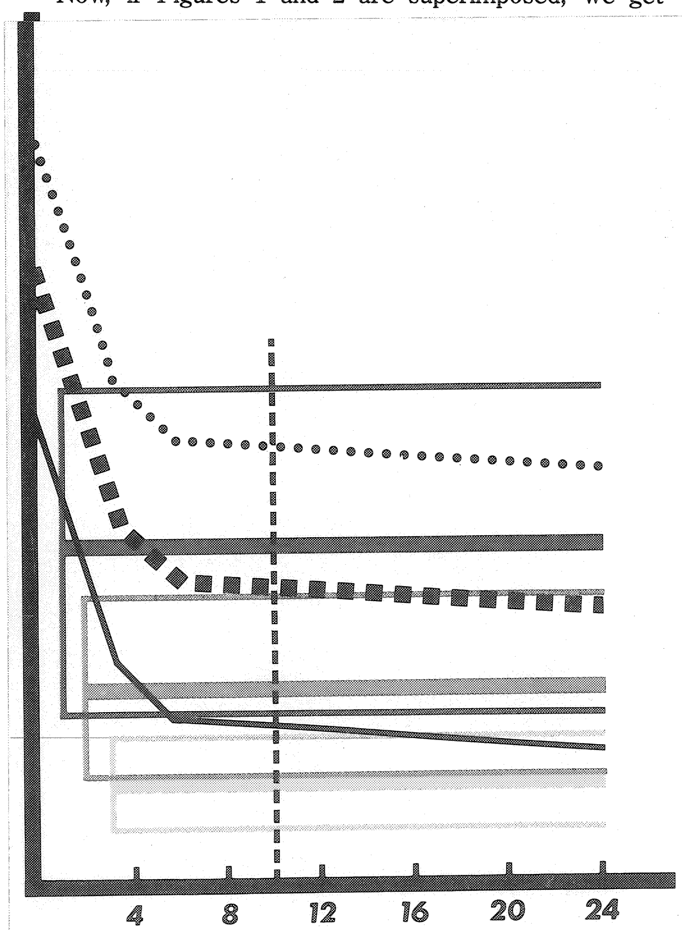

Figure 3
Graphs from figures 1 and 2 superimposed.

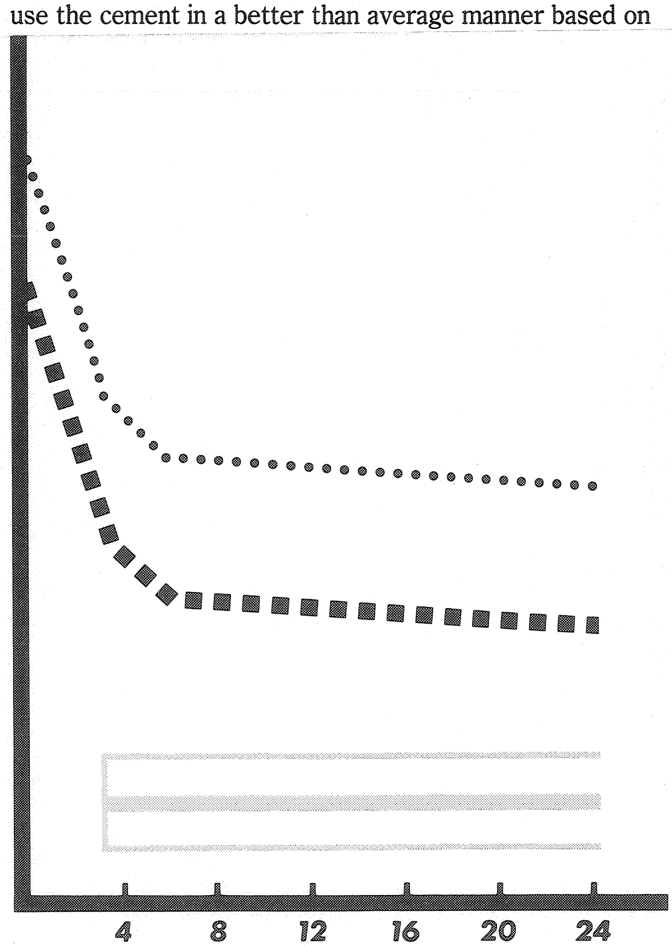

Figure 4
Figure 3 with Müler and Charnley prostheses removed and lower half of cement strength removed.

1970 standards, then one gets the picture as depicted in Figure 4. It can be seen that the strength of the cement as projected out over twenty-four years and the stress applied by the prosthesis are far apart and one would not expect failure. As a matter of fact, there is a nice margin of safety. This margin of safety is, of course, necessary because the graphs were not superimposed with great precision and because we don't know the exact shape of the cement strength curve. It may be more sloping in the later years. Nevertheless, the margin of safety seems sufficient to conclude that if a total hip replacement is done with all efforts made to prepare the bone and handle the cement in a manner to avoid weakening the cement, and if a prosthesis incorporating those features that tend to reduce the peak stress in the cement is used, that the chances for failure should be very small and success should be quite predictable. Therefore, it seems quite reasonable to me to persist with methylmethacrylate fixation. The results of the first decade's experience with methylmethacrylate fixation should make us very optimistic rather than pessimistic for it's future.

I would like to close with a plea that we not get involved in bickering about which method of fixation is best, with claims that bony ingrowth fixation is the wave of the future and cement fixation is obsolete or counter-claims that bone ingrowth fixation is reckless experimentation and/or crude commercialism. Rather we should continue to carefully report the results of our clinical research with both forms of fixation. We as clinicians should continue to carefully analyze these reports and continue to make considered judgements of the current optimal management of the unique situation in each individual patient. Simultaneously, I hope that our basic research will continue to improve cement fixation and enhance bone ingrowth while searching for other forms of fixation such as osseous integration or chemical bonding as well as improved understanding of the pathophysiology of hip disease.

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REIMPLANTATION FOR SALVAGE OF THE INFECTED HIP UTILIZING A STANDARDIZED INTRAVENOUS ANTIBIOTIC REGIMEN

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Fourteen years have passed since Charnley advised against performing total hip arthroplasty in a hip with current or previous infection[2]. Since that time two approaches have developed in an attempt to salvage the infected hip by reimplantation. The use of antibiotic impregnated cement has been pioneered by Buchholz[1], Lindberg[12], and Murray[13]. Antibiotic therapy along with non-impregnated cement has been reported by Hunter[10], Talbott[18], Cherney[3], Fitzgerald[6], Jupiter[11], and Wilson[21]. Turner[19] has recommended a standardized triple antibiotic regimen but only Salvati[17] has recommended a standard regimen based on the activity of the antibiotic against the infecting organism. The following study reports the results using this regimen.

The Hospital for Special Surgery in New York has been committed to the study of the reimplantation of infected hip joints since 1968. Approximately 120 infected hip arthroplasties have been reimplanted. The earlier experience included cases reimplanted primarily in one stage, with antibiotic therapy selected by the treating orthopaedic surgeon[9,21].

Since 1976, as an essential part of the treatment of the infected hip by reimplantation of total prosthetic arthroplasty, a standardized six week intravenous regimen was instituted[17]. Antimicrobial therapy, based on tube dilution studies, was administered parenterally for six weeks in doses sufficient to attain a peak serum bactericidal titer of at least 1:8. Determination of these titers required bacteriologic isolation of the patient's organism from a clinical specimen. The choice of drug and dosage was dependent on the sensitivities of the organism, with consideration given to the ability of the drug to penetrate and kill, as opposed to inhibit. The test was terminated at the highest dilution of serum causing 99 per cent destruction of a standard inoculum of the infecting organism. A serum bactericidal level of 1:8 or greater was set as the adequate antibiotic level to resolve the infection, on the basis of the accepted effectiveness of similar titers in the treatment of bacterial endocarditis[8]. These studies were performed under the supervision of a single consultant in Infectious Disease (B.D.B.).

Patients undergoing reimplantation had to meet the following criteria: a minimum 1:8 serum bactericidal level, adequate medical health including no immunodeficiency or immunosuppression, adequate bone quality and soft tissue for reconstruction, and good potential for rehabilitation.

MATERIALS AND METHODS

Between January 1976 and March 1982 at The Hospital for Special Surgery in New York, thirty-two hips in thirty-one patients were reimplanted with total hip arthroplasties to salvage infected joints. All of these patients were studied prospectively and received a standardized antibiotic regimen supervised by a single Infectious Disease consultant (B.D.B.). Only hips reimplanted with this regimen and supervised by this consultant were evaluated.

Thirteen patients were male and eighteen female. Twenty right hips and twelve left hips were reimplanted. The mean age at index procedure which became infected was 62.6

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years (range twenty-eight to eighty-two years), mean age at reimplantation was 64.7 years (range twenty-eighty to eighty-five years). Mean age at follow up was 68.8 years (range thirty-five to eighty-eight years).

Diagnosis at index procedure is listed in Table I. The index procedures which became infected are listed in Table II. Mean time from index procedure to reimplantation was twenty-five months (range two months to thirteen years). Seven patients underwent a previous hip operation prior to the index procedures which became infected. Three of these previous procedures were total hip replacements, hence the index procedures were revision total hip replacements. Three of the twenty patients with infected total hip replacements had recurrent dislocations. Ten patients had their index procedure done at The Hospital for Special Surgery. Preexisting medical problems are listed in Table III.

Organisms grew on both broth and agar plate medium in all cases at the time of one stage reimplantation or at the first stage debridement in two stage reimplantation. The organisms cultured are listed in Table IV. Cultures were negative in the second stage of all two stage reimplantations.

Preoperative Laboratory Studies

The mean sedimentation rate was 42 mm per hour (range 8 mm to 108 mm). Twenty-two patients had sedimentation rates greater than 30 mm, four patients between 20 and 30 mm, and five patients less than 20 mm. Hence, 84 per cent had values above normal for our laboratory (greater than twenty). The mean white cell count was 8,500 per cubic mm (range 3,700 per cubic mm to 15,700 per cubic mm). Only seven patients had white blood cell counts greater than 10,500 per cubic mm. Twelve patients had a left shift (greater than 75 per cent neutrophils and greater than three bands). Twenty-six patients had one or more of the three above mentioned abnormalities in their blood count.

Nineteen patients had a preoperative hip aspirate[14]. Fifteen of these had a positive culture from an aspirate where fluid was obtained after needle introduction. In the four "dry" taps where no fluid was obtained until saline was injected into the hip joint, only one grew out a positive culture. All cultures were the same as those obtained at the time of surgery. Thirteen hips were not aspirated either because the diagnosis of infection had been made elsewhere (six hips) or infecton was not suspected before surgery (seven hips). Aspirates are done under sterile technique with fluoroscopic control. After the aspirate is obtained an arthrogram is performed. When the aspirate is dry and if dye collects in the greater trochanteric area or any other localized area, another needle is placed in these areas of fluid accumulation. This has helped us identify infecting organisms when the hip joint aspirate was dry. (Fig. 1).

Of the ten patients who underwent the operative procedure which became infected at The Hospital for Special Surgery, preoperative laboratory values revealed six patients

Table I

Diagnosis at Index Procedure	
Hip fracture	11
Osteoarthritis	9
CDH	3
Rheumatoid arthritis	2
Aseptic necrosis	2
Hematogenous infection	2
Ankylosing spondylitis	2
Paget's disease	1

Table II

Index Procedure	
Total hip replacement	20
Uncemented endoprosthesis	5
Cemented endoprosthesis	4
Debridement for hematogenous infection	2
McLaughlin nail	1

Table III

Pre-existing Medical Conditions	
Cardiovascular disease	7
Hypertension	6
Diabetes mellitus	2
Hypothyroidism	2
Malignancy	1
Multiple sclerosis	1
Gout	1
Rendu-Osler-Weber (multiple telangiectasia)	1

Table IV

Causative Organisms	
Staphylococcus epidermidis	17*
Staphylococcus aureus	5*
Pseudomonas aeruginosa	2
Enterobacter	2
Microaerophilic streptococcus	2
Escherichia coli	1
Propionibacterium acnes	1
Bacteroides fragilis	1*
Staphylococcus epidermidis and enterococcus	1

*Recurrence

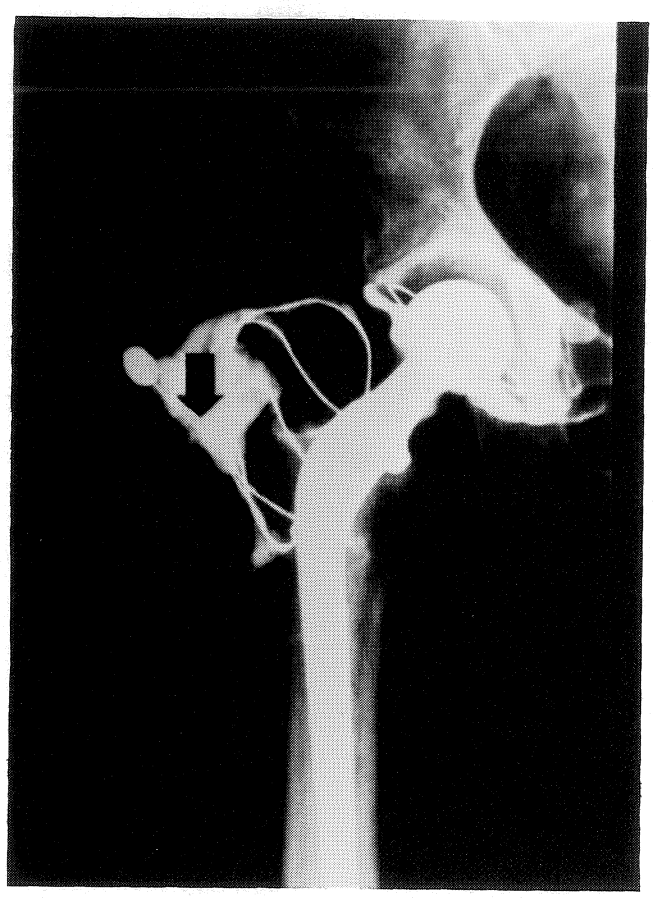

Figure 1
Arthrogram where fluid and positive cultures were obtained only after inserting a needle in the greater trochanteric area where dye had accumulated.

with lymphocyte counts less than 1500 cells per cubic millimeter. Three of these six patients also had albumin levels less than 3.5 gram per deciliter. Low albumin and low lymphocyte counts have been associated with malnutrition and poor healing[4].

All ten of these patients received intravenous oxacillin for 48 hours as prophylaxis at the time of the index total hip arthroplasty. Two patients had continued wound drainage after surgery. One case, a revision total hip replacement, had drainage from which Staphylococcus epidermidis was cultured. The patient was treated with incision and drainage and a one month course of intravenous oxacillin. The drainage ceased but one and one half years later the patient had increasing symptoms and Staphylococcus epidermidis was cultured, hence requiring two stage reimplantation. This patient did not have a low albumin or lymphocyte count, however she had undergone two previous procedures to the hip prior to the index procedure. The second patient who continued to drain postoperatively also developed urinary retention which required emergency transurethral prostatic resection. E. Coli was cultured from the wound. After incision and drainage and intravenous antibiotics the wound failed to heal, and the patient underwent two stage reimplantation. This patient had a normal serum albumin but decreased lymphocyte count. One patient developed a postoperative enterococcus urinary tract infection which was treated with oral antibiotics. She presented with an Alpha Streptococcus hip infection five years later. This patient had both a low albumin and a low lymphocyte count. A rheumatoid patient with bilateral total knee replacements who underwent total hip replacement was the only patient of these ten known to have developed a hematogenous infection. Two years after index total hip replacement she developed a Staphylococcus aureus knee infection which required fusion. Five months later the ipsilateral total hip replacement became infected with Staphylococcus aureus. Two stage reimplantation was performed. Prior to the index hip arthroplasty the patient had both low lymphocyte and albumin count.

Of the remaining six patients who had their index procedure at our hospital, three had low lymphocyte counts and one of the three also had a low serum albumin. None of these patients had postoperative wound or systemic problems after their index procedure. Overall there were four Staphylococcus aureus, four Staphylococcus epidermidis, one E. Coli and one Alpha Streptococcus infection in this group of ten patients.

Surgical Management of Infection

A transtrochanteric approach was used in twenty-nine cases and a posterior approach in three. In all cases of infected total hip replacements a transtrochanteric approach was used. Fourteen cases were performed in one stage. A one stage reimplantation was limited to those infections caused by very sensitive bacteria with negative intraoperative gram stain and benign tissue by macroscopic and frozen section observation. In addition, the seven infections not suspected at surgery had a one stage reimplantation. Eighteen hips were performed in two stages with the second stage done two weeks to eleven months after the first stage (mean 4.3 months), and during the same hospitalization in nine cases (50 per cent).

At the time of debridement a careful and meticulous effort was made to remove all necrotic, devitalized tissue, sinus tract, prosthetic components, wires, other foreign bodies, and acrylic cement. In several cases this required windows made in the anterior surface of the femur. (One surgeon used a Cloward drill to make round windows, Fig. 2.) If there was uncertainty concerning complete cement removal, an intraoperative radiograph was performed. No patient received preoperative antibiotics. They were administered only after all cultures were obtained.

In all thirty-two hips, intraoperative gram stain, and aerobic and anerobic cultures were taken of the intraarti-

Figure 2
Multiple windows were made on the anterior aspect of the femur with a Cloward drill to remove acrylic cement.

cular fluid. Multiple tissue samples were sent from the acetabulum and femur for frozen section, culture, and permanent section. Intraoperative cultures grew out infecting organisms in both broth and agar in all thirty-two hips. Acute inflammation was seen on tissue pathology in twenty-five cases. In the other seven cases only chronic inflammation or reactive tissue was demonstrated.

At the second stage, cultures of the fluid and tissue were again sent to microbiology and pathology. None of these cultures were positive. Tissues did not show acute inflammation.

In two stage reimplantation, closed tube suction irrigation with saline was instituted for two to four days following the first stage. Most patients were placed in proximal tibial skeletal traction for three to four weeks. In five cases long stem femoral components were required to bypass previous defects in the femur, i.e. windows or perforations. Two cases required acetabular shells and one case required acetabular bone grafting with screw fixation. There were no intraoperative femoral fractures. No antibiotic was mixed into the new acrylic cement.

Medical Management of Infection

All patients were given intravenous antibiotics for a minimum of six weeks following one stage procedures or following the first stage of two stage procedures. All antimicrobial regimens were selected on the basis of quantitative in vitro sensitivity studies, in which the minimun bactericidal concentrations of a variety of appropriately selected antibiotics were determined for each infecting organism. Once therapy had been instituted, its adequacy was confirmed by testing the serum bactericidal titer, using a serial tube dilution method to determine the ability of increasingly diluted concentrations of the patient's serum to kill the infecting organism. If necessary, the initial antibiotic treatment was changed and/or synergistic drugs were added in order to obtain adequate serum levels. This change was made in seven cases. The dilution titers obtained are listed in Table V. Titers obtained on the three organisms which recurred are indicated.

Table V

Achieved Bactericidal Titers

Titers	#Hips
1:8	3
1:16	8[a]
1:32	4[b]
1:64	4
1:128	4[c]
1:256	3
1:512	3
1:1024	2
1:2048	1

(a) recurrence Staphylococcus aureus
(b) recurrence Bacteroides fragilis
(c) recurrence Staphylococcus epidermidis

In two stage reimplantation, at the second stage, antibiotics were given after intraoperative cultures had been obtained and they were continued until the results of those cultures were known. Since all the cultures were negative in this group of patients, the antibiotics were discontinued on the fourth or fifth postoperative day. Only two patients, at their insistence, received any oral antibiotics after the initial parenteral antibiotic course.

Systemic Complications

There were three urinary tract infections which resolved with adequate therapy.

Local Complications

There were three postoperative dislocations, all becoming stable after closed reduction. Six patients developed

Grade I heterotopic bone, one patient Grade II, one Grade III and one Grade IV. No drugs or radiation therapy were administered to prevent heterotopic bone formation. Only one patient had a leg length discrepancy greater than 1 cm.

RESULTS

All thirty-one patients with thirty-two hips were followed a mean of 4.1 years (range two to eight years). Both clinical and radiographic results were obtained at last follow-up on all hips. One patient died two and one half years after reimplantation with an excellent clinical and radiographic result. This patient had been seen at two year follow-up and was included in the results.

Clinical evaluation of results using The Hospital for Special Surgery Hip Rating Scale was completed preoperatively and at last follow-up. The following four parameters were rated in a scale from zero (worst) to ten (best): pain, walking, motion and muscle power, and function. Preoperative pain rating mean was 2.97 (range two to eight, S.D. = ± 1.75) and at last follow-up pain rating mean was 9.22 (range six to ten, S.D. = ± 1.04). Preoperative walking rating mean was 4.63 (range two to eight, S.D. = ± 1.5), and at last follow-up walking rating mean was 8.31 (range four to ten, S.D. = ± 1.87). Preoperative motion and muscle power rating mean was 5.41 (range two to six, S.D. = ± 1.19), and at last follow-up motion and muscle power rating mean was 7.62 (range six to ten, S.D. = ± 1.26). Preoperative function rating mean was 4.53 (range two to eight, S.D. = ± 1.48), and at last follow-up function rating mean was 8.25 (range four to ten, S.D. = ± 2.11). Preoperative total score mean was 17.59 (range ten to twenty-six, S.D. = ± 3.78), and at last follow-up total score mean was 33.22 (range twenty-two to thirty-eight, S.D. = ± 4.87). These values are listed in Figures 3 to 8. The results have been classified as excellent when the sum of the four evaluations is thirty-two or more, good when it is twenty-four to thirty-one, fair when it is 16 to twenty-three, and poor when it is fifteen or less. At last follow-up twenty-two hips were rated excellent, eight good, and two fair (Fig. 9). The results in the twenty infected total hips reimplanted were fifteen excellent, three good, and two fair. There were three recurrences of infection and their clinical rating is included.

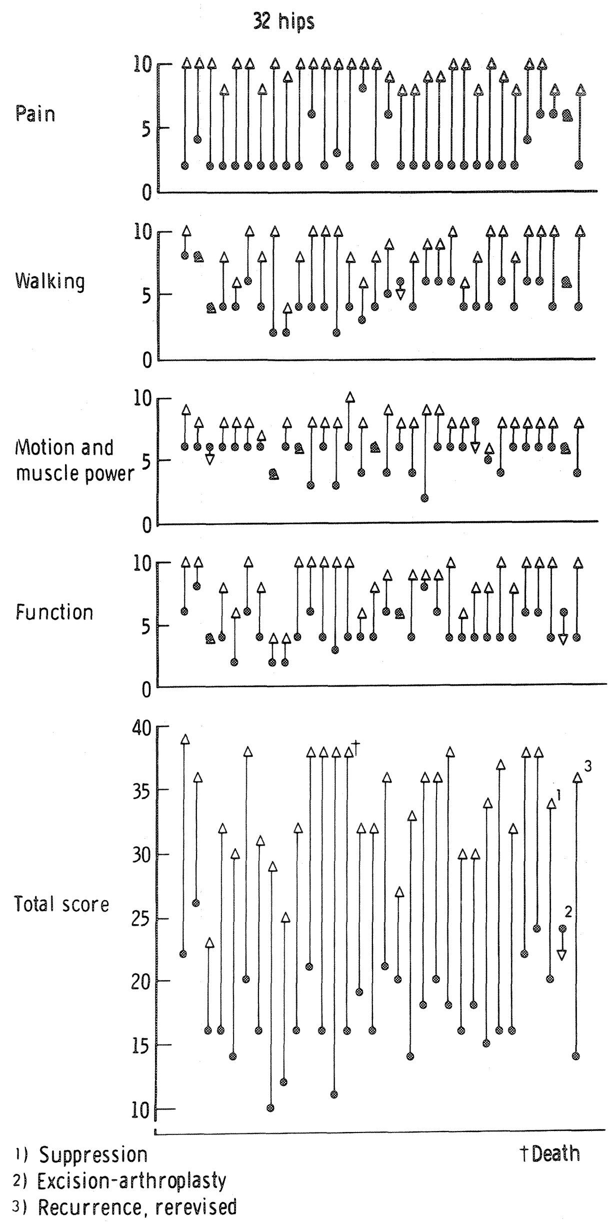

Figure 3-7

The graphs represent the preoperative hip rating (black dot), and the postoperative result at last follow-up (end of arrow) according to pain, walking, motion and muscle power, and function. Each arrow represents one hip. The total score is also given for the preoperative hip rating and last follow-up result.

Recurrences

There have been three recurrences of infection to date. The first patient is a fifty-six year old white female who underwent (at another institution) a right total hip replacement for osteoarthritis in 1976. This was complicated by persistent pain. Sixteen months postoperatively, an aspiration of the hip revealed a Staphylococcus epidermidis infection. The patient underwent one stage reimplantation at our hospital, followed by six weeks intravenous oxacillin. One year postoperatively she developed increasing hip pain and a hip aspirate revealed a recurrence of the Staphylococcus epidermidis infection. She was initially treated with antibiotic suppression but a year later due to persistent pain, she underwent a two stage reimplantation with a surgical interval of seven months. Once again Staphylococcus epidermidis was cultured at the first stage.

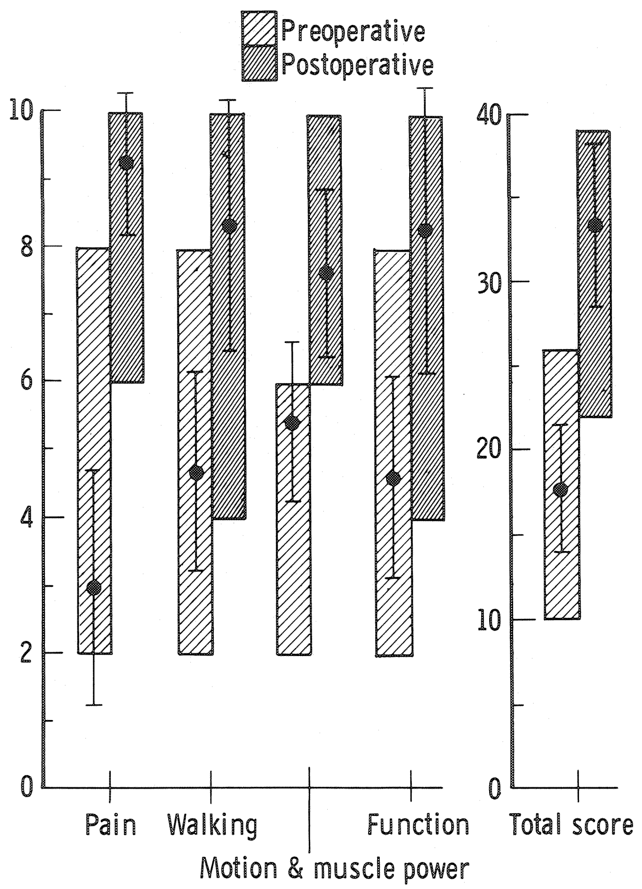

Figure 8
Preoperative and postoperative mean and standard deviation for all hips, including pain, walking, motion and muscle power, function and total score.

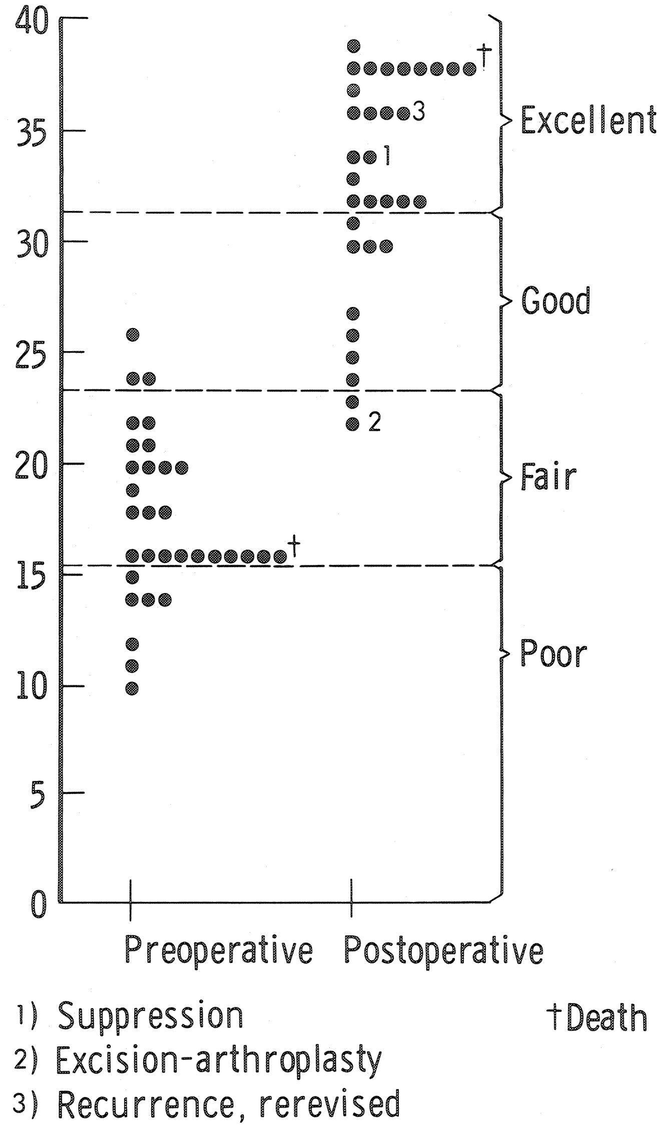

Figure 9
Preoperative and last postoperative rating of each hip.

Recently, five years after reimplantation this patient was reoperated for trochanteric wire removal. Hip aspiration and cultures taken at that time were negative. On radiographs the patient does have a 2 mm acetabular circumferential radiolucency with slight acetabular migration. On clinical examination she has mild groin pain and minimal capsular tenderness. Her hip rating is eight, ten, eight, ten. Her symptoms may be due to acetabular loosening (Figs. 10a, b, c, d, e).

The second recurrence occurred in a thirty-five year old white male with rheumatoid spondylitis who underwent bilateral staged total hip arthroplasty (at another institution). Both hips became infected, requiring removal (the right in 1978 and the left in 1979). The patient presented at our institution three years post right hip removal and two years post left hip removal. Both hips were reimplanted two weeks apart, in 1981. Intraoperative left hip cultures obtained at the site of retained femoral acrylic cement grew Bacteroides fragilis. As the intraoperative culture was still positive, this is considered a one stage reimplantation for this study. Five months after surgery the patient had increasing left hip pain and cultures of a hip aspirate revealed Bacteroides fragilis. The patient was treated with intravenous antibiotics for one week followed by nine months of oral Clindamycin and three months of Flagyl. He has been without antibiotics for two years, and has remained asymptomatic on both hips. His hip rating on the right is ten, ten, eight, ten and on the left is eight, ten, eight, ten (Figs. 11a, b, c).

The third recurrence was a sixty-two year old white male, who had a total hip replacement at our institution in 1980. He had excruciating right hip pain and rapidly destructive arthritis. Due to the severity of the pain he underwent an intraarticular injection of steroids and local anesthetic three weeks prior to total hip replacement. In addition he had chronic anemia from Rendu-Osler-Weber

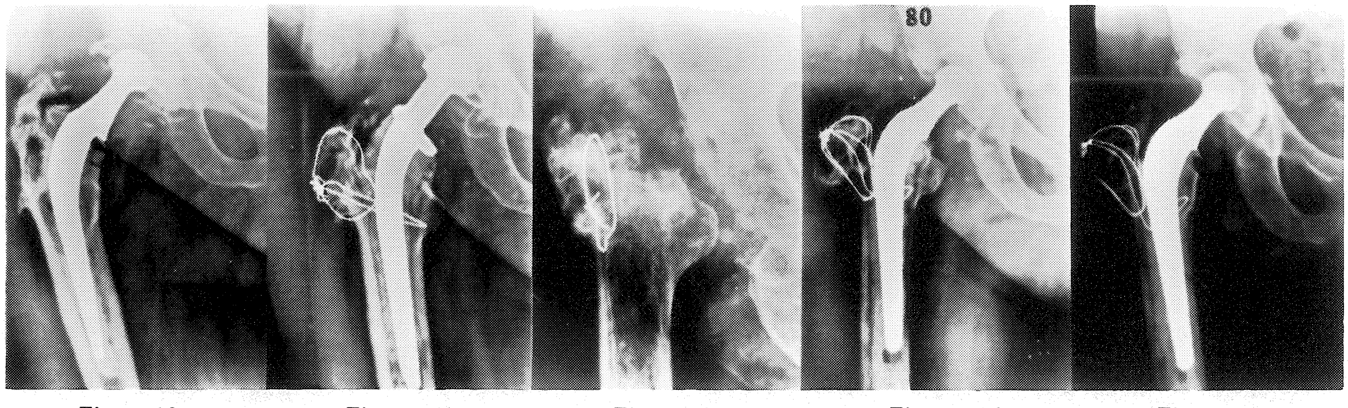

Figure 10a
Infected total hip replacement.

Figure 10b
Recurrence of infection after a one stage reimplantation.

Figure 10c
After removal of prosthetic components and acrylic cement.

Figure 10d
Initial postoperative film after two-stage reimplantation.

Figure 10e
Radiograph obtained four years after reimplantation prior to removal of wires.

Disease (hereditary hemorrhagic telangiectasia). Intraoperative cultures grew Staphylococcus aureus. Careful review of laboratory, radiology, pathology and bacteriology findings at the time failed to clarify whether this positive culture represented a true infection or a contaminant[5,7]. In retrospect, we believe it represented a true infection. The patient was treated with parenteral antibiotics while in the hospital and was discharged on oral antibiotics. The patient discontinued the oral antibiotics one week after discharge. Severe hip pain developed two months after surgery. The hip aspirate revealed Staphylococcus aureus and the patient underwent a two stage reimplantation with a surgical interval of six weeks. Eight months postoperatively he again developed pain in the hip and a hip aspirate cultured Staphylococcus aureus. The prosthesis was removed and the patient was put on six weeks intravenous antibiotics. Three years after surgery his hip rating is six, six, six, four. He has no wound drainage. This is the only patient now functioning with a Girdlestone arthroplasty (Figs. 12a, b, c, d, e).

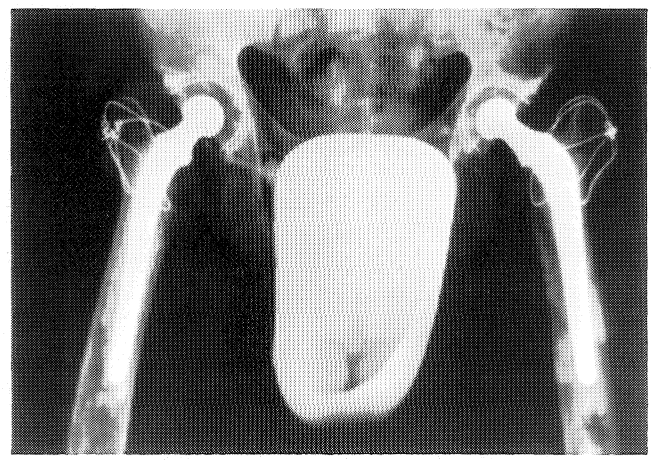

Figure 11b
Initial postoperative radiographs after bilateral reimplantation.

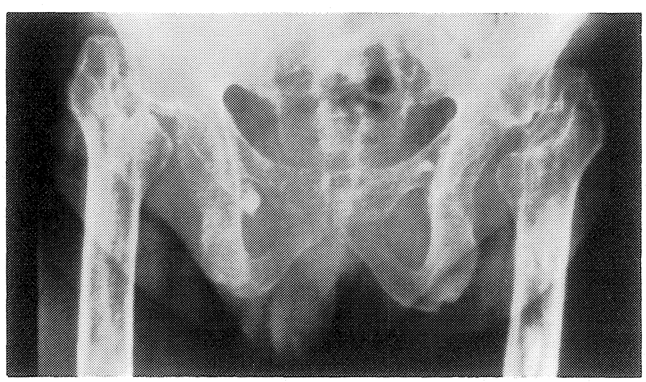

Figure 11a
Bilateral resection arthroplasties, after infected total hip replacements. Note retained acrylic cement in the left femoral shaft. Intraoperative culture of this site grew Bacteroides Fragilis.

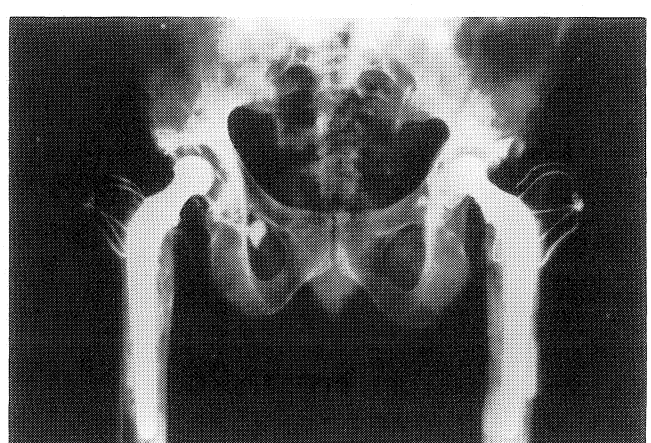

Figure 11c
Radiograph obtained three years after reimplantation.

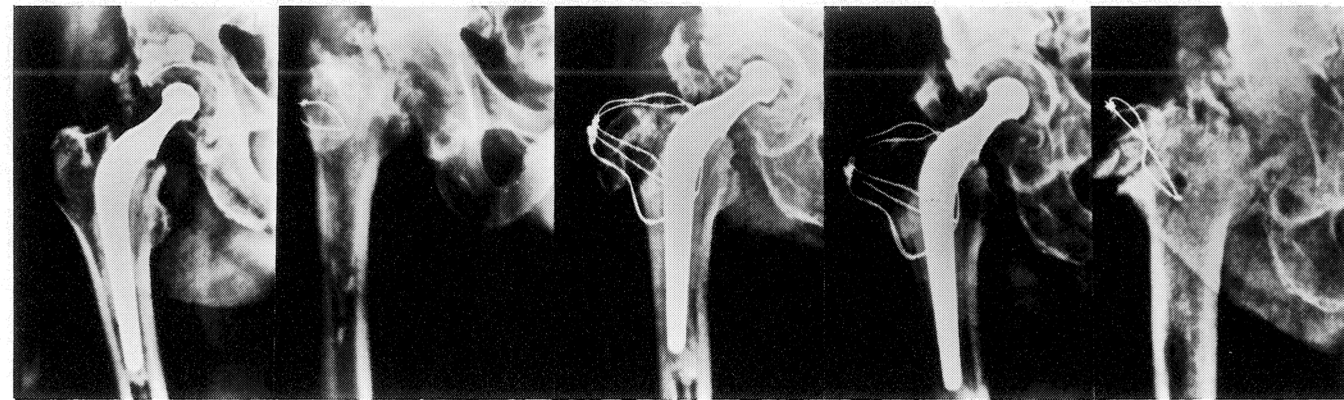

Figure 12a
Infected total hip replacement.

Figure 12b
Radiograph obtained after removal of prosthetic components and acrylic cement.

Figure 12c
Radiograph obtained after two-stage replacement.

Figure 12d
Radiograph obtained prior to removal due to recurrence of infection.

Figure 12e
Present Girdlestone arthroplasty.

Radiographic Evaluation

Radiographs were analyzed comparing the first good quality postoperative anteroposterior radiograph with the last follow-up radiograph. Initial postoperative and follow-up radiolucencies on the acetabular and femoral sides are pictured in Figures 13 and 14. There was progression of acetabular radiolucencies in four hips (13 per cent). Two hips have circumferential acetabular radiolucencies of 1 mm or less, one hip has circumferential radiolucencies of 1-2 mm and one hip has circumferential radiolucencies of 2 mm with slight acetabular migration. Only this last patient is symptomatic and she has had a recent negative hip aspirate (already discussed; see first recurrence).

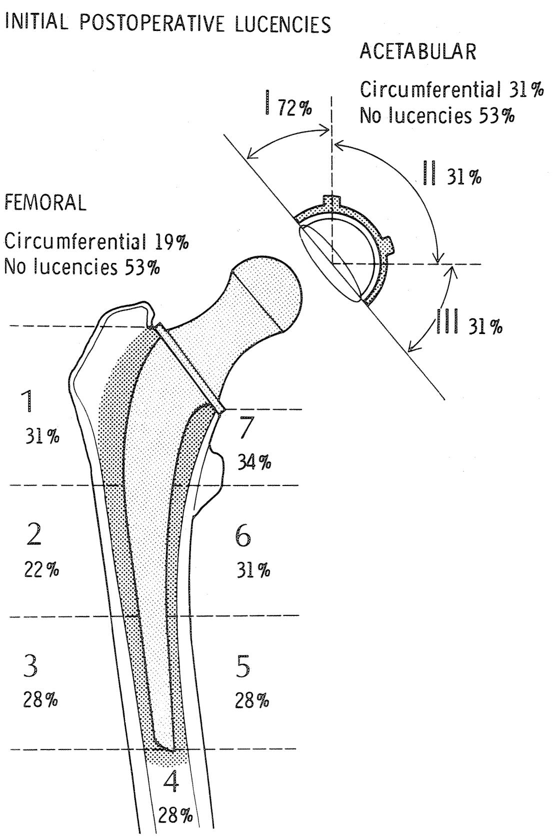

Figure 13
Initial postoperative acetabular and femoral radiolucencies.

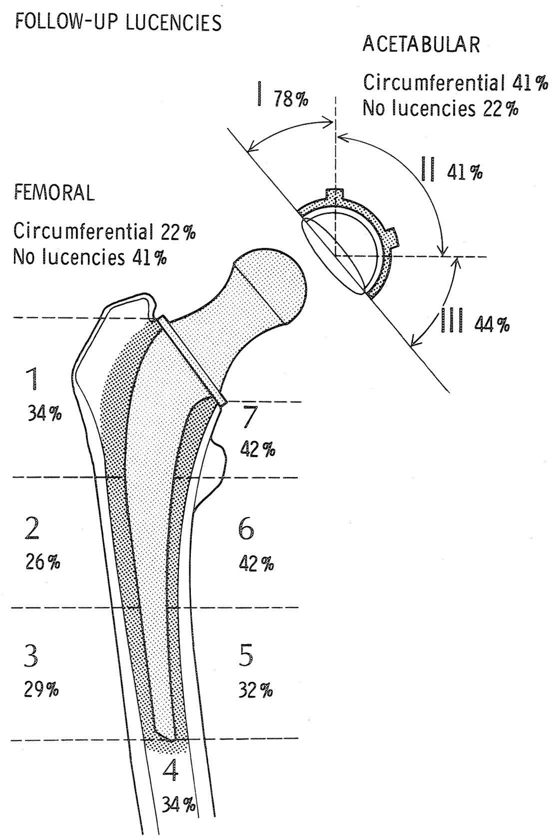

Figure 14
Last follow-up acetabular and femoral radiolucencies.

Five hips reveal femoral progressive radiolucencies (16 per cent). Only one of these hips has radiolucencies measuring between 1 and 2 mm, the rest are less than 1 mm. There has been no femoral subsidence and none of these hips are symptomatic.

DISCUSSION

Reimplantation for salvage of the infected hip has been considered a reasonable option at our institution since 1968; our observations being in agreement with those of Petty, that poor functional results are obtained with Girdlestone arthroplasty[16]. Based on studies using antibiotics in the treatment of endocarditis, the present standardized therapy was instituted and prospectively studied. This therapy requires a knowledgeable infectious disease consultant to orchestrate the selection, dosage, and synergistic combinations of drugs on the basis of serum bactericidal levels determined periodically during treatment. The antibiotics should be selected to maintain adequate bactericidal levels with the least toxicity. As mentioned, in seven of our cases, antibiotic therapy was changed based on the inability to obtain optimal levels with the initial antibiotics. Hence, the need for accurate monitoring is evident.

Adequate antibiotic therapy cannot substitute for meticulous surgery. We feel it is imperative to remove all foreign bodies and acrylic cement during debridement even if it requires windows in the femur or intraoperative radiographs to assure complete removal. Acetabular shells, long stem femoral components, and bone grafting may be necessary to fill and bypass bony defects. They must be available at the time of reimplantation and good preoperative planning may prevent situations where the appropriate component is not in the operating room inventory. Presently, most of our reimplantations are done in two stages. If there are no contraindications, reimplantation is usually performed during one hospitalization.

None of these patients have as yet developed definite evidence of aseptic mechanical failure. In this regard, these results are better than those of revision for mechanical failure at our institution[15]. Possible explanations include that the present group of patients is small; not all reimplantations were done for infected total hip arthroplasties. The average age at reimplantation was 64.7 years compared to 61.2 years for aseptic mechanical failure revisions and the activity level was lower in the infected group.

SUMMARY

Use of a standardized intravenous antibiotic regimen, sufficient to obtain a peak bactericidal serum titer of at least 1.8, has been highly effective in the treatment of infected hips by reimplantation with total hip arthroplasty. The regimen appears to have eradicated infection and allowed good function in twenty-nine of thirty-two hips (90.6 per cent). It was effective in all twelve cases of infected hardware, infected endoprostheses (cemented and uncemented), and hematogenous infections (100 per cent). It was effective in seventeen of twenty infected total hip replacements (85 per cent). Finally, twelve of fourteen one stage (96 per cent) and seventeen of eighteen two stage reimplantation (94.5 per cent) demonstrated no recurrence.

We recognize the limited number of cases studied and the innumerable variables involved. However, we feel that these cases probably represent the best results which we can obtain by careful selection, meticulous surgery and strictly controlled intravenous antibiotic therapy. To date no study reveals better success in eradicating infection and restoring hip function by reimplantation, unless they include antibiotic impregnated cement (Table VI). Future studies with antibiotic impregnated cement will have to be judged against these results. We presently use both optimum intravenous antibiotic therapy as described and antibiotic impregnated cement as adjuncts to meticulous debridement in reimplantation for salvage of the infected hip.

Table VI

Comparison of Percent Infection-Free Hips in Various Reports

With Antibiotic-Impregnated Cement	1 Stage #	1 Stage %	2 Stage #	2 Stage %
Buchholz et al., 1981[1]	667	77.00	—	—
Lindberg, 1981[12]	59	90.00	18	78.00
Murray, 1981[13]	13	38.50	22	95.50
Turner et al., 1982[19]	101	86.00	—	—
	840	72.90	40	86.75
Without Antibiotic-Impregnated Cement				
Hunter, 1979[10]	55	18.00	10	60.00
Talbott et al., 1980[18]	—	—	25	80.00
Cherney & Amstutz, 1981[3]	5	80.00	28	64.00
Fitzgerald, 1981[6]	—	—	111	90.00
Jupiter et al., 1981[11]	18	78.10	—	—
Present Study	14	86.00	18	94.50
	110	65.52	202	77.70

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THE EFFECT OF ACETABULAR POSITION ON TOTAL HIP COMPONENT LOOSENING RATES

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Low friction arthroplasty of the hip has been a significant advance in reconstructive surgery of the hip producing excellent short-term results. However, as follow-up periods have increased, so has the incidence of component loosening. The reported incidences and relative frequencies of femoral versus acetabular component loosening have varied, but few would question that loosening is the major long-term problem[1,3,9,11,16,27,28,30-32]. Many factors appear to contribute to the risk of loosening. Factors related to the patient include weight, age, sex, activity, and diagnosis[7,18,26-28,31]. Component design is believed to contribute to loosening based both on theoretical and empirical grounds[13-15,32]. Critical surgical factors include cement technique and positioning of the femoral component[1,3,7,11,12].

Recent clinical and theoretical evidence suggests that the position of the acetabulum (i.e., the location of the hip center of rotation) influences the mechanical forces exerted upon the hip components[2,6,19,21,22]. One could reasonably expect that if the acetabular component is placed so that these forces are increased, the subsequent risk of loosening on a long-term basis would also increase. This, however, has not been clinically documented. The purpose of this study was to determine whether or not acetabular component placement influences the risk of loosening.

MATERIALS AND METHODS

From 1969 to 1973, 338 Charnley total hip arthroplasties were performed in 277 patients at the University of Iowa Hospitals. Various staff surgeons and residents performed the surgery. Trochanteric osteotomy was routine until 1973. Cement was packed with fingers into the femur and acetabulum after various amounts of reaming.

Ninety-three patients with 116 total hip replacements were included in this study for statistical analysis. Reasons for excluding some of the 277 hips from this study were: 1) One hundred twenty-nine of the patients' x-rays were destroyed by our Department of Radiology because they had not been seen for five years. No attempt was made to contact these patients because we could document neither the original position nor changes in the position of the components. 2) Five patients were excluded because their hips became infected. 3) Two patients were victims of motor vehicle accidents and had fractures of the femur around their prosthesis. 4) Fifteen patients were known deceased. 5) Twenty-four patients could not be located by phone or letter. 6) Nine patients could not return for evaluation for health reasons. All of these reported little or no clinical symptoms.

Fifty-four of the 116 hips were in males and sixty-two in females. There were sixty-nine right hips and forty-seven left hips. The average time from surgery to follow-up was 9.1 years (range six to twelve years). The average weight of the patients was 73.4 kg with a range of 40 kg to 111 kg. The average age at surgery was sixty-three years with a range of twenty-eight to eighty years. The diagnoses included: seventy-six with osteoarthritis, twenty-one with previous hip surgery (failed bone graft, failed endoprosthesis, painful cup arthroplasty, and others), eight with rheumatoid arthritis, six with primary aseptic necrosis, two with congenital dislocation of the hip, two with previously septic hip joints, and one with old slipped capital femoral epiphysis. An Iowa Hip Rating[24] was determined at the time of follow-up in all patients.

RADIOGRAPHIC INTERPRETATION

For each hip, we reviewed initial AP pelvic radiographs, two or three interval radiographs, and final follow-up radiographs. The first good quality radiograph during the first year was accepted as the initial radiograph.

Position of the acetabular component was assessed by the perpendicular distance from the center of rotation of the prosthesis to a horizontal line drawn between the tips of the tear drops (or the top of the obturator foramen if the tear drops were not apparent): this measurement was called "cup height" (Fig. 1). The distance from the tip of the tear drop to the previously described perpendicular line was called the "cup horizontal distance". Cup orientation was measured in degrees as the angle between the

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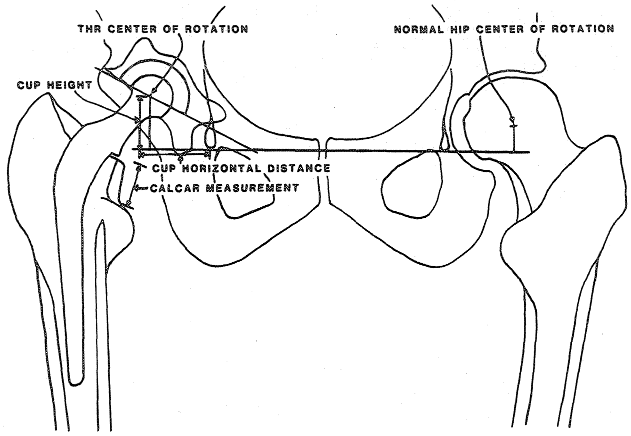

Figure 1

Diagram demonstrating measurements of acetabular and femoral component position. The position of the acetabular component was recorded by determining the center of rotation of the component, then measuring inferior and perpendicular to a horizontal line drawn between the tips of the tear drops or the top of the obturator foramen if the tear drops were not apparent (Fig. 1). (The distance using the tear drops as reference points were felt to be most reliable, influenced the least by magnification and rotation and were therefore used in the analysis for determining the center of rotation.) This measurement was called cup height. A vertical line was drawn from the center of rotation, perpendicular to the horizontal line and intersecting the horizontal line. The distance from the tip of the tear drop to the intersection of the vertical and horizontal line was called the cup horizontal distance to the tear drop. Cup orientation was measured in degrees as the angle between the horizontal line drawn through the tear drops and the edge of the cup.

horizontal line drawn through the tear drops and the edge of the cup. We recorded the distance between the anterior superior iliac spines in an attempt to account for magnification differences from film to film. The distances using the tear drops as reference points were felt to be most reliable, influenced the least by magnification and rotation, and were therefore used in the analysis for determining the center of rotation. Changes in position of the components and cement fracture were based on the measurements and interpretations of the serial radiographs.

The "calcar" measurement was defined as the distance from the medial aspect of the collar to the top of the lesser trochanter and was used to identify subsequent subsidence (i.e., femoral component position change). We determined whether or not there was resorption or gross osteopenia of the proximal medial femoral cortex. Varus, valgus, or neutral position of the femoral component was assessed by comparing the orientation of the component relative to the femoral shaft. As with the acetabular components, change in position over time was noted.

"Cement quality" included measures of whether or not and how well cement filled the femoral canal. Particular attention was paid to the distal lateral area and proximal medial areas shown to be important by Beckenbaugh and Ilstrup[3]. If radiolucent bone remained in these areas, we judged that cement did not fill the canal. The distance that the cement extended past the tip of the prosthesis was recorded. The width of cement in the proximal medial femoral region was estimated. Significant voids (any area or bubbles greater than 2 mm) were noted.

The width of initial lucencies in the femur in four quadrants, proximal lateral, distal lateral, proximal medial, and distal medial were recorded in millimeters at the bone-cement and cement-prosthesis interfaces. In establishing the presence of a lucency, we took into account the "Mach effect" which is the presence of an apparent, but not real, lucency at the interface of materials of differing radiodensities (i.e., cement-prosthesis interface)[17,20,23]. For the acetabular component, the width of lucencies in millimeters and extent of lucencies were recorded. The extent of lucency was divided into two categories: 1) partially around prosthesis, and 2) entirely around prosthesis.

Thirty-five hips had an increase in the "calcar" measurement of 1 to 3 mm over time. Since this should not occur, and did not seem to actually occur based on interpreting the radiographs, we assumed that this increase was owing to differences in magnification of the serial films, and assumed that linear measurements of 3 mm or less were unreliable. Therefore, we defined a loose femoral component as one with a lucency in any quadrant with a generally linear configuration greater than or equal to 2 mm, or one with a position change equal to or greater than 4 mm, or one with a cement fracture. In looking at serial films, acetabular component positions and orientations sometimes varied (i.e., increased and then decreased or vice versa) as much as 4 mm or 4 degrees without any lucency or other apparent sign of loosening. We assumed that position changes of 4 mm or 4 degrees or less were unreliable owing to magnification and rotation errors from film to film. Therefore, a loose acetabular component was defined as one with any lucency entirely around the acetabular component greater than or equal to 2 mm, or a position change greater than 4 mm or 4 degrees.

To determine the effect of hip center location on loosening, we divided the patients into the following seven categories (variables) and noted the frequency of loosening of the components in each category.

1. Cup height greater than 30 mm
2. Cup height 20 to 30 mm
3. Cup height less than 20 mm
4. Cup horizontal distance from tear drop greater than 30 mm
5. Cup horizontal distance from tear drop 26 to 30 mm
6. Cup horizontal distance and cup height greater than 30 mm (HD-CH >30)
7. Cup horizontal distance and cup height less than or equal to 30 mm (HD-CH <30)

Since loosening can be affected by many factors, it is important to distinguish which factors are actually responsible since any two factors may be closely related (e.g., weight and sex). Therefore, we used a logistic regression model[25] to determine which of the above seven categories (if any) and seven other risk factors best predicted loosening (see Table 1 for a listing of these risk factors). In the logistic model, the probability of loosening (p) is assumed to be related to risk variables $X_1, X_2, \ldots X_n$ through the equation

$$\log\left(\frac{P}{1-P}\right) = \log(\text{odds}) = b_o + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n \qquad (1)$$

The risk factors are used on the right side of the equation to predict the logarithm of the odds of loosening. The BMDP[4] statistical software is used to estimate the coefficients in the equation and to provide a measure of the goodness of fit. Candidate predictor variables included the seven categories above and the seven other risk factors. A stepwise variable selection procedure selected the variables which best improve the prediction of loosening. At each step the program selected the variable having the smallest p-value associated with the chi-squared statistic. Variable selection stopped when no other variable had a p-value less than 0.05.

RESULTS

Clinical Results

Iowa Hip Ratings did not apear to deteriorate with time. The average Iowa Hip Rating was 88.2 at four to six years follow-up, 86.5 at seven to nine years follow-up, and 88.2 at ten to twelve years follow-up. On the Iowa Hip Scale, thirty-five points are assigned if the patient has no pain, and thirty points if the patient has mild pain with fatigue. The average pain rating was 32.8 at four to six years follow-up, 31.8 at seven to nine years follow-up, and 32.9 at ten to twelve years follow-up. In the absence of infection, the known revision rate was very low. One hip was revised at the University of Iowa for a loose femoral component. Two were revised elsewhere for loosening. The revision rate for loose components was therefore 2.5 per cent in the hips we have followed. Two acetabular components were revised early for recurrent dislocation and subsequently did well.

Initial Radiographic Measurements

When the opposite hip was normal, the position of the center of rotation of the normal hip was measured. In thirty-three hips, the average height of the center of rotation was 14 mm with a range of 8 to 20 mm and a standard deviation of 3 mm. The average horizontal distance of the center of rotation to the tear drop was 42 mm with a range of thirty-three to fifty-five and a standard deviation of 5.8 mm.

The average cup height for the prosthetic acetabula was 29.5 mm with a range of 14 mm to 51 mm and a standard deviation of 7.2 mm. The cup horizontal distance from the tear drop averaged 33 mm and a standard deviation of 5.8 mm. The Charnley total hip replacement, on the average, moved the center of rotation of the hip superiorly about 15 mm and medially 9 mm in these 116 patients. Technically, it would have been possible to position the prosthesis so that the center of rotation would be closer to the average of the normal hip, but this was not the practice at that time.

Radiographic Loosening Rates

Using our previously described definitions of loosening of the components, forty-one of 116 hips or 35 per cent of femoral components were loose and twenty-four of 116 hips or 21 per cent of acetabular components were loose at an average follow-up of nine years (Table 1). The twenty-four loose acetabular components included three hips with prostrusio acetabulae in which the cups were placed in a protruded position, a situation known to predispose to loosening. When these three hips are excluded, twenty-one of 113 hips or 19 per cent of the acetabular components loosened. Using the same definitions of loosening at four to six year follow-ups, 21 per cent of femoral components were loose and 6 per cent of acetabular components were loose. Table 1 also demonstrates the frequency of loosening with the various risk factors, such as weight, age, and sex.

From a simple frequency analysis, not taking into account the other variables, the risk of femoral loosening seemed to be related to cup height, cup horizontal distance, and cup height and horizontal distance combined (Table 2). On the other hand, the risk of acetabular loosening did not appear to be related to those variables.

Using the stepwise logistic regression model, the prediction equation for no femoral loosening was estimated to be:

$$\begin{aligned}\log(\text{odds}) = {} & 2.72 - .041(\text{weight}) + .52(\text{cement fills canal}) \\ & + 0.28(\text{cement past tip of prosthesis}) - .52(\text{cement voids}) \qquad (2) \\ & - .70(\text{HD-CH} > 30)\end{aligned}$$

where a +1 indicated the factor was present and a −1 indicated the factor was not present. These relationships can be more easily explained in terms of odds ratios for the risk variables. For example, the estimated odds ratio of loosening from not filling the canal was 2.8. This means that if the canal is not filled, the odds of femoral loosening were 2.8 times the odds of loosening if it is filled. The odds of loosening increased 1.5 times for each 10 kg addi-

Table 1

Summary of Femoral and Acetabular Loosening Rates (Average Nine Year Follow-up)

Variable	Number of Hips	Femoral Loosening	Acetabular Loosening*
All Hips	116	41 (35%)	24 (21%)
Sex			
Male	54	26 (48%)	10 (19%)
Female	62	15 (24%)	14 (23%)
Weight			
Weight < 60 kg	18	3 (17%)	5 (28%)
Weight 60-69.9 kg		9 (27%)	7 (21%)
Weight 70-79.9 kg		12 (40%)	6 (20%)
Weight > 80 kg		17 (49%)	6 (17%)
Age			
Age > 60 years	86	31 (36%)	15 (17%)
Age < 60 years	30	10 (33%)	9 (30%)
Diagnosis			
Osteoarthritis	75	27 (36%)	6 (8%)
Rheumatoid Arthritis	8	0 (0%)	1 (12%)
Previous Hip Surgery	22	5 (23%)	4 (18%)
Other	14	9 (64%)	3 (21%)
Proximal-Medial Femoral Cortex Resorption			
Resorption	46	13 (28%)	9 (19%)
No Resorption	70	24 (34%)	5 (7%)
Femoral Component Position			
Varus	39	17 (44%)	—
Neutral	45	16 (36%)	—
Valgus	32	8 (25%)	—
Cement Quality			
Cement Filled Canal	75	18 (24%)	—
Cement Did Not Fill Canal	41	23 (56%)	—
Prox-med Cement Width < 3 mm	21	8 (38%)	—
Prox-med Cement Width Between 3 & 5 mm	58	21 (36%)	—
Prox-med Cement Width > 5 mm	37	12 (32%)	—
Cement Not to Tip of Prosthesis	5	5 (100%)	—
Cement > 10 mm Past Tip	75	21 (28%)	—
Significant Voids	48	25 (52%)	—
No Significant Voids	68	16 (24%)	—
Good Cement Quality (see text)	32	4 (12%)	—
Collar-Calcar Contact			
Yes	40	9 (24%)	—
No	76	32 (42%)	—

*Includes three hips with protrusio placed in protruded position

tional weight. If cement voids were present, the odds were 2.8 times greater than in absent. The odds ratio was 4.1 if the cup height and horizontal distances were greater than 30 mm and 1.3 for each 10 mm decrease in the distance of the cement beyond the tip of the prosthesis.

A problem in this analysis is that the natural relationships of weight to sex and weight to cup height make it difficult to disentangle these variables in a prediction model.

One approach is to initially put sex and cup height in the model to see if weight is useful in addition to sex and cup height. The results from this analysis show that, given sex and a high cup initially in the model, a well-filled canal and absence of voids improve the prediction. Once these terms are in the model, sex is dropped (p = 0.18) and weight is entered (p = 0.02). In this way we arrive at a model that is very similar to the above model (i.e., equation 2), except that the cup height above 30 mm is used instead of cup height and horizontal distance. So while it is not clear whether cup height or cup height and horizontal distance is more closely related to loosening (both are statistically significant), it appears that weight is a better predictor than sex.

DISCUSSION

Loosening has proven to be the most common long-term problem with total hip replacements. Unfortunately, it has not always been easy to conclusively determine which factors are definitely associated with loosening. As follow-up times increase, many if not most patients develop radiographic changes (either lucencies or component position changes). However, most patients with these changes do not have pain and relatively few of them have required revision, at least at the time of follow-up[8]. Therefore, it is difficult to know precisely what the radiographic changes will ultimately mean, and it would take studies with very large numbers of patients followed over many years (at least ten to twenty years) to make this determination.

Additionally, there are inherent problems in interpreting radiographs and in defining the "loose" total hip reconstruction. First, radiographic interpretation of lucencies are prone to interobserver variability[5]. While one experienced investigator might more reliably make such observations, he or she might also introduce systematic error. Second, there are problems in reliably determining position changes[32]. It is likely, based on both this study and that of Sutherland et al., that position changes of less than 4 to 5 mm or less than 4 to 5 degrees cannot be reliably assessed on the usual clinical radiographs. Third, any radiographic definition of loosening is somewhat arbitrary. While some rationale can be provided (such as excluding changes which cannot be reliably assessed), these definitions do not include clinical criteria. Furthermore, it might not be substantially less arbitrary to include clinical factors such as pain, since it would not be known whether or not the pain was causally related to the radiographic findings. It is also obvious that the definition of loosening will affect the loosening rates[31].

Finally, it is difficult to be certain from simple analyses (i.e., those which determine only the differences in loosening rates between a group with one factor present and a group with that same factor absent as in Table 2), which of many potentially interrelated factors might be most closely related to loosening. Caution should therefore be exercised in the interpretation of statistical analyses. This analysis assumes that a linear function of the variables can predict the logarithm of the odds. The selection procedure does not guarantee that the best prediction equation will be found. It must also be remembered that the p-values stated are only appropriate for comparisons of one model to one other model. In the stepwise logistic regression procedure, a number of models are considered so that the p-values probably overestimate the significance of the variables in the model.

Nonetheless, most investigators believe that radiographic lucencies and components position changes are

Table 2

Variable	Number of Hips	Femoral Loosening	Acetabular Loosening*
Cup Height**			
> 30 mm	44	22 (50%)	10 (23%)
20 to 30 mm	56	17 (29%)	11 (19%)
< 20 mm	16	2 (14%)	3 (21%)
Horizontal Distance			
> 30 mm	69	27 (39%)	13 (19%)
26 to 30 mm	38	13 (34%)	8 (21%)
< 25 mm	9	1 (11%)	3 (33%)
Cup Height and Horizontal Distance***			
> 30 mm	29	16 (55%)	7 (24%)
30 mm or less	32	8 (25%)	8 (25%)

*Three hips with protrusio acetabuli placed in protruded position included
**$p > .05$ significant difference of variable
***$p > 0.01$ for significant difference of variable

of prognostic value and virtually all clinical series investigating the loosening of total joint replacements have used one or both of these criteria. Our definitions of loosening are similar (although not identical) to those used by such studies[3,9-12,16,18,27-28,30-32]. While the numbers of hips in our study is relatively small (116), the similar loosening rates in this series compared to those in the literature suggest that the definitions are reasonably comparable and suggest that our patient population is likely similar to those in the literature.

The hip center of rotation is determined by both acetabular component position and by the diameter of the head of the femoral component. Using Charnley total hip replacements (with its small head size and relatively small cup size), it was quite natural for the surgeons to place the cup so that the center of rotation was medial and superior compared to the normal hip as shown in this series. However, it would have been possible during reaming and cementing to position the cup inferior so that the center of rotation would have been at or below the level of the normal center of rotation.

The location of hip center of rotation influenced the rate of loosening of femoral, but not acetabular components in this series. The femoral component in hips with the center of rotation placed inferior or inferior and medial loosened at a lower (and statistically significant) rate than hips with the center of rotation superior and lateral. This was presumably due to decreased mechanical forces generated in hips with cups placed inferior and medial[21]. The relative importance of the center of rotation location was less than weight and cement technique, but greater than the other factors.

While we did not demonstrate statistical significance for acetabular loosening rates, trends did occur with a decreased incidence of acetabular loosening as the cup was moved inferior. One might not expect that the acetabular component would be as sensitive as the femoral component, since the cement and bone on the acetabular side are subjected principally to compressive rather than tensile loading[29]. Three hips had their cups cemented in the protrusio position and all three loosened, thus reducing the already small number of loose acetabular components available for including and perhaps further confounding the analysis of acetabular loosening.

Not surprisingly, weight and the cement quality variables were strongly associated with femoral loosening. Males did not develop femoral loosening any more often than females when weight was taken into consideration. Collar-calcar contact and femoral component position did not significantly affect the odds of loosening in the logistic regression model when the other variables were taken into account, although on first glance at Table 1, one might conclude that they did. This demonstrates how the wrong conclusions might be drawn when using a simple analysis.

It is difficult to identify the major influences in a multifactorial problem when known factors are difficult to quantify and when there are likely unidentified factors. One might argue that the hips placed more superior or lateral were hips that were more diseased preoperatively or that were more aggressively reamed (thus removing "good" bone stock) and thereby prone to loosening. However, this should affect only the acetabular component loosening rate and not the femoral loosening rate. Additionally, the recent study of Callaghan et al.[6] has demonstrated a similar sensitivity to acetabular component position in revision total hip arthroplasty.

The effect of location of the hip center on the forces generated within the component has been shown in previous studies[2,19,21,22]. Most recently, Johnston et al.[21] demonstrated with a mathematical model that the center of rotation influences hip forces. Specifically, they found that the forces were minimized by placing the center of rotation inferior, medial, and anterior. This long-term study supports this theory.

In conclusion, it would seem prudent, based upon this study and previous theoretical investigations, to position the acetabular components as inferior and medial as possible within the constraints of the original acetabulum. Charnley[10] advocated "anatomic" placement of the prosthetic cup, but for the purpose of reducing the risk of dislocation rather than reducing the joint loads and the risk of loosening. Correct component positioning combined with advanced prosthetic design and cement techniques should reduce the incidence of loosening.

Note

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TOTAL-CONDYLAR KNEE ARTHROPLASTY: AN 8 TO 11 YEAR FOLLOW-UP

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The Total-Condylar prosthesis, which was designed and initiated into use at The Hospital for Special Surgery in March 1974, remains the oldest unmodified total knee replacement design presently in extensive use[6]. Ranawat and Rose reported favorable early clinical and radiographic results in knee arthroplasty patients with three to eight years of follow-up[15]. Similarly, favorable results were also reported by Insall et al. in a five to nine year follow-up study of 100 consecutive patients who underwent Total-Condylar knee arthroplasty[8]. Our study presents results of an eight to eleven year follow-up period of Total-Condylar knee arthroplasty.

MATERIALS AND METHODS

Our study consisted of the first 112 consecutive Total-Condylar knee arthroplasties (eighty-six patients) performed by the senior author between 1974 and 1977. The minimum follow-up was eight years and the maximum was eleven years, with an average follow-up period of 9.5 years. Eight patients in the study had died (twelve knees), and six patients (ten knees) could not be reached for follow-up. Thus, ninety knees in seventy-two patients were available for review.

The sample was comprised of fifteen males and fifty-seven females, ranging in age between thirty-one and seventy-nine years; the average age was sixty-one. Average weight among the patients was 69.1 kg, with a range between 45.5 and 96.4 kgs. The preoperative diagnosis was osteoarthritis in thirty-four patients and rheumatoid arthritis in thirty-eight patients. Eighteen patients underwent one-stage bilateral procedures, and all but one (two knees) had patellar resurfacing.

There were twenty knees in varus with a maximum deformity of 35 degrees. Twenty-one knees were in valgus with a maximum deformity of 38 degrees. Biplane deformities, in either varus or valgus associated with flexion contractures were present in twenty-nine knees. The maximum flexion contracture was 40 degrees. Two knees were in neutral alignment.

All patients were examined by the senior author and rated according to The Hospital for Special Surgery Knee Disability Score Sheet[5,12], which takes into account activity, pain relief, range of motion and stability. By our scoring criteria, a score of eighty-five to 100 points represents an excellent result; seventy to eighty-four, a good result; sixty to sixty-nine, a fair result; less than sixty represents a poor result.

Standing anteroposterior and lateral radiographs of each knee were obtained at the follow-up visit to assess tibiofemoral alignment, component position, and radiolucent zones along the bone-cement interface of the tibial component according to size and location[13].

The zones under the tibial component and around the peg were numbered 1 through 7. Zones, 1, 2, 3, and 4 are under the tibial condyle; 5 and 6 are on either side of the peg, while Zone 7 lies under the peg itself (Fig. 1). The

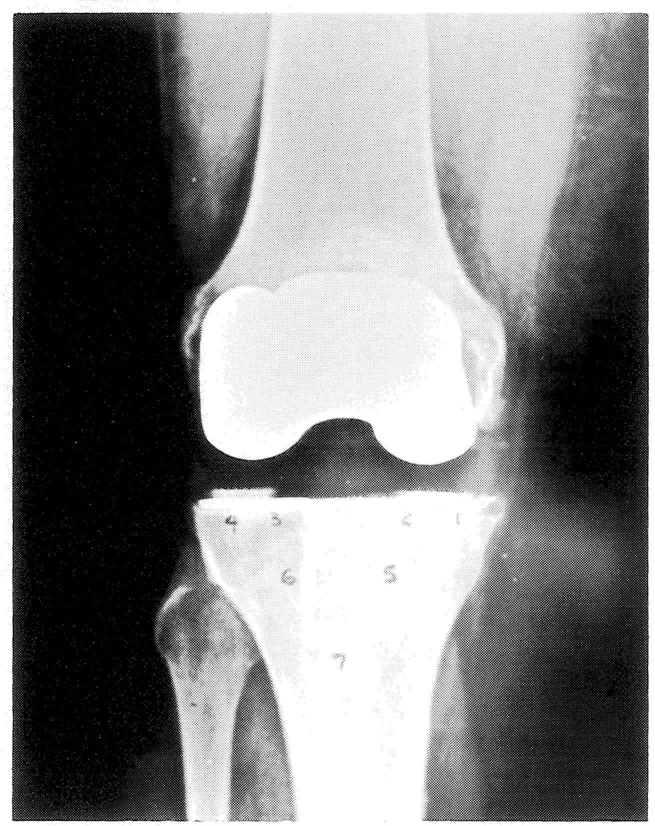

Figure 1
Zonal distribution of cement-bone interface demarcation or radiolucency. The tibial component is divided into seven zones. Zones 1 through 4 are under the medial and lateral tibial plateaus. Zones 5 and 6 are around the intramedullary fixation peg; Zone 7 is under the peg.

width of the radiolucencies was graded 1 through 4. Grade 1 represented no radiolucency; Grade 2, 1 mm or less; Grade 3, 1 to 2 mm; Grade 4 represented global radiolucency around the tibial component with or without component shift. Grade 4 radiolucency was thus considered a failure of component fixation. The patella was evaluated with a skyline view roentgenogram with the knee flexed at 60 degrees. The femoral component was not amenable to such radiographic assessment due to difficulties in recognizing the bone-cement interface.

The techniques involved in Total-Condylar knee arthroplasty, including the technical modifications for proper patellar tracking, proper releases for fixed deformities, and improved cementing techniques have been extensively reported[6,15].

RESULTS

Our sample of seventy-two patients (ninety knees) had an average follow-up of 9.5 years. The average preoperative score for all knees was 44.5 (range = fourteen to seventy-eight), and the average postoperative score was 83.3 (range = fifty to ninety-eight). There were forty-eight excellent results (53.3 per cent), thirty-five good (39 per cent), three fair (3.3 per cent), an four poor (4.4 per cent) results. No revisions were required for aseptic loosening, although one knee was found to have a loose tibial component and another a loose patella (Fig. 2).

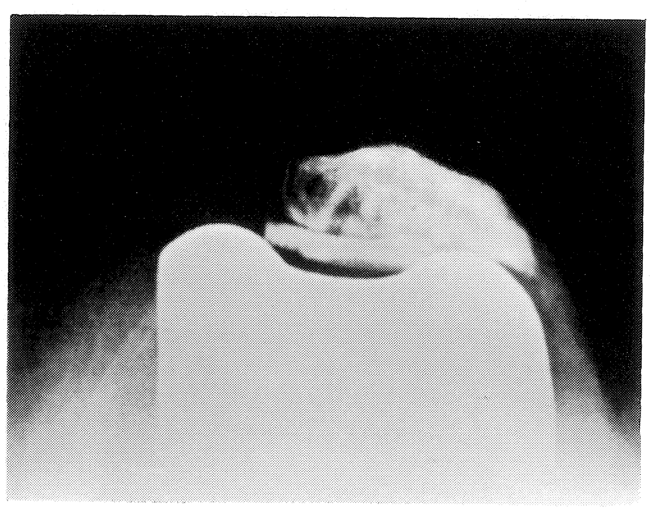

Figure 2
Skyline view of the patella with loss of fixation (nine year follow-up).

Three knees in two patients were rated fair. In one patient, multile medical problems, including cardiopulmonary compromise limited functional use of the replaced knee. The other patient was a rheumatoid arthritic with multiple joint involvement and significant disability limiting her function. Both patients experienced only mild pain in the replaced knee.

Four arthroplasties in our study were rated poor. One deep wound infection occurred as a late complication, eight years after surgery, in a fifty-seven year old female with rheumatoid arthritis. The infection was attributed to E. Coli colonization of the urinary tract. The infected TKR was successfully converted to an arthrodesis following a six week course of antibiotics, removal of the prosthesis, and wound debridement.

Another poor result was due to severe rheumatoid arthritis with multiple joint involvement. This patient was wheelchair-bound, although no component loosening was radiographically detectable. The third failed arthroplasty occurred in an overweight female with osteoarthritic involvement of multiple joints and concomitant limitation of function. The patient's knee radiographs revealed well-fixed and properly aligned components at follow-up. Both of these patients had only mild knee symptoms. The fourth poor result was in a patient whose painful knee was caused by a loose patellar component. The patient has refused revision surgery. Thus, overall poor results were noted in four patients. Infection and a loose patellar component were the causative factors in two cases, and poor general health in the other two.

Radiographic Results

The postoperative range of alignment of all knees was 3 degrees varus to 10 degree valgus angulation, with an overall alignment of 5 degrees valgus. Twenty-seven knees were between 3 degrees varus and 4 degrees valgus (ten knees were between 0-3 degrees varus and seventeen knees between 0-4 degrees valgus). The rest were between 5 and 10 degrees valgus. Both anteroposterior and lateral projections of the knees showed the tibial components had been placed at 90 degrees ± 6 degrees to the long axis of the tibia, while the femoral component measured 5 degrees ± 5 degrees valgus on the AP projection.

Forty per cent of the knees (N = 36) remained well-fixed without evidence of radiolucency (Fig. 3A-B). The remaining fifty-four knees (60 per cent) had radiolucencies of varying widths in any of the seven different zones under the tibial component (Table 1). In thirty-six knees, there was complete absence of radiolucency (Grade 1). Thirty-seven knees showed less than 1 mm (Grade 2) of radiolucency. Sixteen knees had 1-2 mm of radiolucency (Grade 3), and one knee exhibited over 2 mm of radiolucency (Grade 4). The zonal distribution of the radiolucencies of fifty-four knees was as follows: There was one symptomatic knee with radiolucency in all seven zones (Fig. 4); eleven knees with radiolucencies in Zones 1 through 6, and forty-one knees with radiolucencies under the tibial condyle in Zones 1 through 4. Thus, seventy-nine out of ninety knees had stable fixation. Five of eleven knees with radiolucency had symptoms, but the patients were satisfied with the outcome of surgery. The remainder were

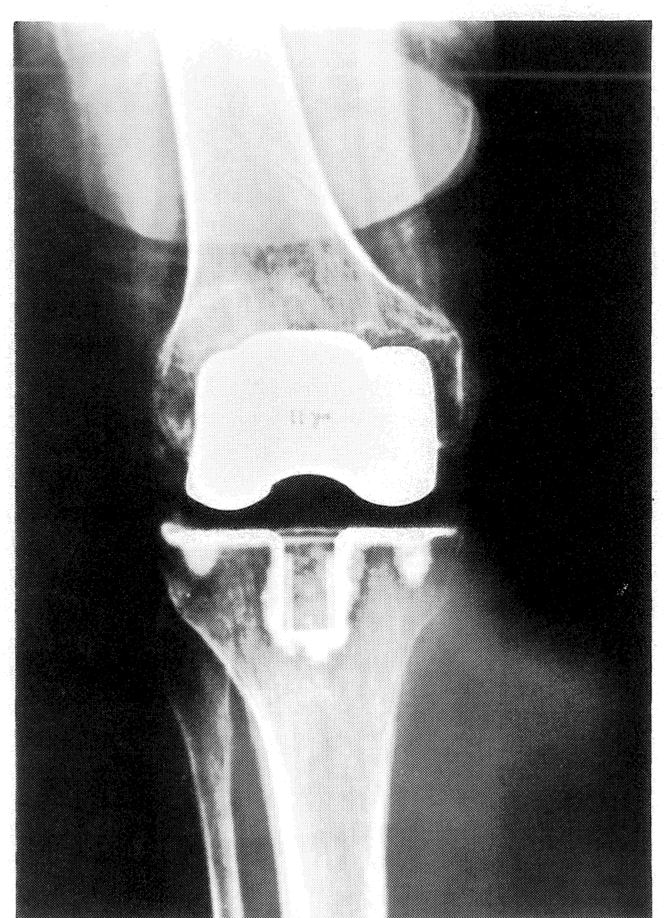

Figure 3a
Anteroposterior radiograph of a well fixed knee without any cement-bone interface demarcation (at the eleventh year of follow-up).

Figure 3b
Skyline view of patella of the same knee. The patella is well-centered in the groove of the femoral component.

asymptomatic. The average knee score in this group of eleven knees was 75.5 (range = sixty to eighty-eight).

Using multiple regression analysis to assess the variance in radiolucency scores for such factors as age, sex, diagnosis, and weight, only excess weight was found to

Table 1
Radiographic Results of Knees by Radiolucent Width and Grade

Knees (N = 90)	Radiolucent Width	Grade
36	0	1
37	< 1 mm	2
16	1-2 mm	3
1	> 2 mm	4

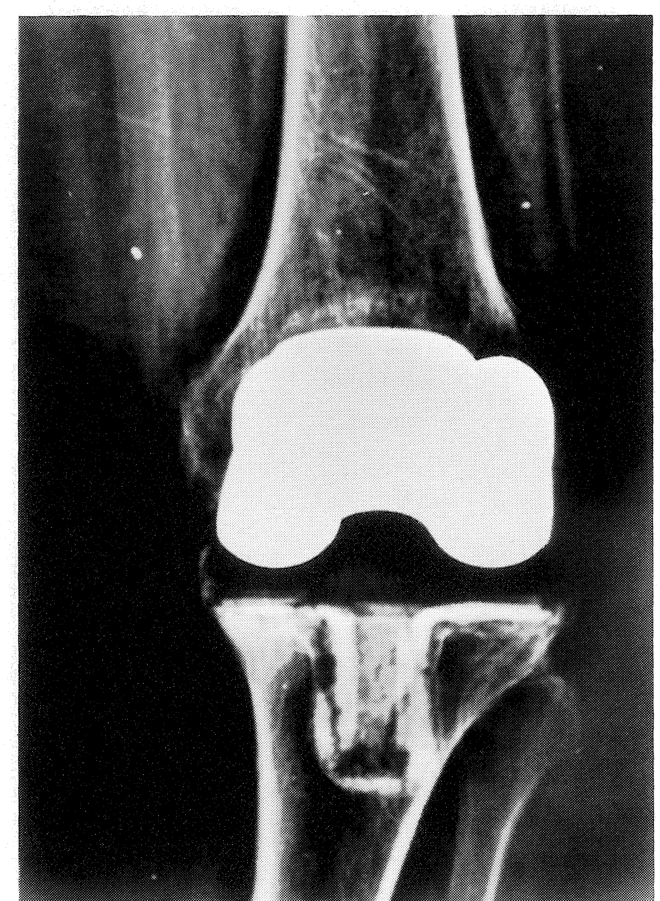

Figure 4
Anteroposterior radiograph of a knee with Grade 4 radiolucency. Radiolucency is present in all zones with shift of component position (eight years of follow-up).

influence the development of radiolucencies under the tibial zones. In our series, excess weight accounted for 14 per cent of the variance in radiolucencies. However, among the thirty-six knees without radiolucencies under the tibial plateau, the mean weight was 63.5 kg compared with a mean of 74.9 kg for knees with radiolucencies ($p = 0.001$).

Variations in the placement of the tibial component in relation to the tibial axis were not found to significantly influence the development of tibial radiolucencies. The average amount of bone excised from the proximal tibia was 5 mm (range = 1-13 mm). No correlation was apparent between the amount of resected tibial bone and radiolucency.

In thirteen knees cement, with or without screw fixation, was used to fill bone defects. Of these, eleven knees developed bone-cement demarcations of 1-2 mm in width (Fig. 5); the remaining two knees had no radiolucencies.

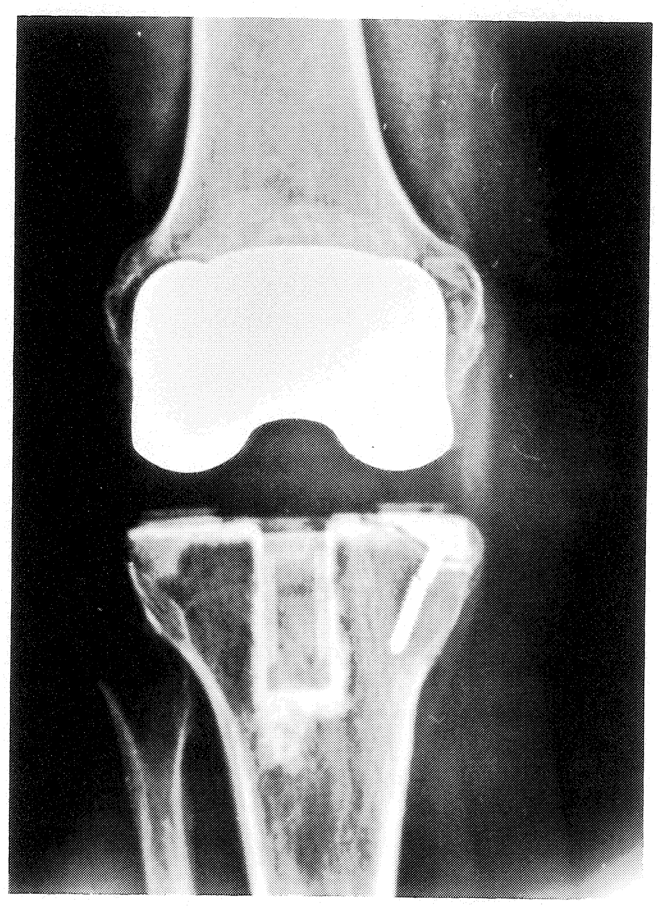

Figure 5
Anteroposterior view of a knee showing Grade 3 radiolucency in Zones 1 and 2 with a broken screw.

Complications

Wound drainage problems occurred in 5 per cent of the knees; these were managed with local wound care and immobilization since no infective agent was cultured. Of the ten deceased patients, one knee developed early infection which was treated with two stage reimplantation. Two patients developed uncomplicated myocardial infarctions and three patients developed nonfatal pulmonary emboli. No immediate postoperative deaths occurred.

DISCUSSION

The clinical and radiographic results of the Total-Condylar knee arthroplasty have been reported by Ranawat and Insall in their respective studies. Both studies yielded highly favorable results—in the range of 90% to 93% good to excellent follow-ups[6,8,15].

Our report is based on a longer follow-up period than any previously reported for Total-Condylar knee arthroplasty. Over the longer period, the results remained in the good to excellent range in 93 per cent of the cases. Our results are comparable to those of earlier, short-term follow-up studies of other types of total condylar prostheses[1,3-9,11,12,16].

An earlier report[15] on Total-Condylar knee arthroplasty showed that patients with osteoarthritis scored better than rheumatoid patients (eighty-seven vs eighty-three); this continues to hold true even eight to eleven years later. Rheumatoid patients usually suffer concomitant involvement of major joints, muscle weakness, atrophy, and often, medical problems which limit overall functional ability. It was therefore not unusual to find that these patients scored between five and ten points lower than osteoarthritic patients. The results in two patients, one fair and the other poor, were attributed to rheumatoid arthritis. Assessment of the quality and durability of the arthroplasty in osteoarthritics was similar to that reported earlier for this group by Ranawat and Rose[15].

In 60 per cent of the arthroplasties, radiographic evaluation showed the presence of radiolucencies under the tibial condyle at the bone-cement interface. This rate is similar to that reported by Laskin[9], and higher than the 22 per cent rate reported by Insall et al.[6].

Most radiolucencies were in Zones 1 through 4. Eleven knees showed radiolucency in Zones 1 through 6, but only one knee had radiolucency in all seven zones. Thus, this knee was categorized as a Grade 4 or global radiolucency and therefore radiographically loose.

No significant association was found between such factors as sex, age, diagnosis, thickness of cement layer, level of tibial bone resection, or component alignment and the appearance of bone-cement demarcation at the tibial plateau. Excess weight seemed to be the only factor with some influence on the development of radiolucencies under the tibial component. Our regression analysis showed that, in taking the group as a whole, weight accounted for 14 per cent of the variance in the development of radiolucencies. Yet when patients with radiolucencies were considered separately from those without radiolucencies, there was a statistically significant difference in their weights ($p = 0.001$).

The development of radiolucencies may also be related to the cementing techniques employed at the time of implantation, since these arthroplasties were done before the advent of modern cementing techniques. Radiolucency is also related to alignment and constraint built into the design.

Patients whose operations were performed after 1977 have benefited from careful attention to proper bone preparation, thorough cleansing with pulsatile lavage, and proper drying contributing to increased penetration of cement in the cancellous bone. The use of newer cementing techniques which utilize digital pressurization, or other methods of pressurizing doughy cement allow uniform cement penetration of 2-5 mm into the cancellous bone for a better microinterlock between the trabecular bone and the cement[10]. With these newer techniques, appearance of radiolucency has been reduced to 19 per cent[15].

The 93 per cent success rate of our eight to eleven year follow-up study of Total-Condylar arthroplasty, reveals it to be a safe, durable, and reliable procedure. With strict adherence to the surgical techniques that permit proper alignment, stability, and use of modern cement techniques, we can expect to further increase the longevity of knee arthroplasty.

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DER WELK ARM
(The Withered Arm)

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World War I was the start of a new, modern kind of war. It was a war of annihilation and destruction, a war to the finish. Gone were the limited wars, the costumed pageantry, and chance for "heroism" of bygone days.

This was a war to change the face of Europe and the world, a war to change the destiny of mankind. We know this without mistake, and yet much of it all started with a series of miscalculations that need never have happened. It is always tempting to speculate about history — "What if—". Here, speculation has a strong basis in fact.

An altogether happy occasion was in the making. It was 1858, and two great royal houses were to be united in marriage. Victoria ("Vicky"), Princess Royal and daughter of Queen Victoria of England, married Frederick William of Prussia. It was not until 1888 that Vicky became German Empress. This was but one example of the intermarriages that linked the Royal houses everywhere.

On 27 January, 1859 their marriage was blessed with its first issue. *Here* began the problems that affected the rest of the world!

The child, William II, was to become Kaiser (the German derivation of Caesar!) Wilhelm. The labor was difficult, and overzealous efforts were eventually necessary to complete the extraction. At first the family was overjoyed. By the child's third day of life, the joy was tempered with sorrow. Then it was perceived that his left arm was paralyzed, and lay limp at his side.

Doctors have not changed that much. He was a royal child and the center of intense attention. The prognosis was gloomy. With "the shoulder socket torn away and the surrounding muscles so severely injured, no doctor would venture to attempt the readjustment of the limb[4,7]!"

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Wilhelm Erb (1840-1921) was the foremost German neurologist of the era. The first neurologist to use a flex hammer, he was one of the originators of electrodiagnosis and electrotherapy to treat neurologic disorders[1]. With the literature available to us, we were not able to definitely establish the connection: it does seem highly probable that Erb was consulted at some time regarding William II's disability.

Erb's palsy, you see, is an injury to the upper portion of the brachial plexus, classically of the fifth and sixth cervical nerve roots. Its etiology is most frequently excessive traction on the affected arm during obstetrical manipulation. Fortunately the incidence of obstetrical palsy of any kind has gradually decreased due to the improved management of cephalopelvic disproportion. When Erb's palsy does occur, the injury is frequently mild. Resulting disability and deformity are minimal when treated conservatively using stretching exercises to prevent contractures. More severe cases may require reconstructive and tendon transfer procedures to improve mobility and function of the arm. Untreated cases may develop the classic "porter's tip hand" (Fig. 1).

After the initial vacillation, William did receive the best that medicine had to offer but to no avail. Despite electrical stimulation to the withered arm, the limb remained essentially useless and any further attempts to strengthen it were abandoned. Vicky never forgave the imperfection of her eldest child and openly displayed a preference for her healthier children despite the entreaties of Queen Victoria[2]. Many historians feel that the tension between mother and son, coupled with William's physical disability, was the ultimate explanation for his taut and irresolute character.

With his maturity he became a man obsessed with proving himself a man among men. He always felt underrated and patronized everyone. His hates were many, and he voiced them all. He traveled widely and always appreciated

Figure 1
Kaiser Wilhelm in full military dress. Note the position of his left arm. (From Army Uniforms of World War I, by Andrew Mollo and Pierre Turner, Blandford Press Ltd. 1977.)

an obsequious, servile reception. Somewhat contemptuously (and *very* privately) the German people referred to him as the "reise Kaiser"—"the traveling Kaiser". One of the voiced regrets of his life was that he was never invited to Paris, as *other* royalty were, to be decorated!

This state of mind, this sense of inferiority, this warped personality were to lead to the most grievous political consequences. A change in the entire course of history was soon to hinge on that medical misadventure and on that orthopaedic deformity.

In 1914, Archduke Ferdinand was assassinated at Sarajevo. International tensions ran high. Kaiser Wilhelm, ever the "man", acted like a "man" and heeded the unfortunate advice of his militaristic advisors. He saw himself as a man of destiny and action; he encouraged Austria to take uncompromising action against Serbia. This advice failed to heed accepted methods of diplomatic negotiation. All of the Kaiser's worst traits came into action.

The tough warrior-king persona did not come naturally to him, yet he felt he must live up to this role. He was regarded as having one of the least inhibited tongues in all of Europe. His speeches could shatter the nerves of diplomats[5]. He encouraged rather than challenged the grandiose plans of his generals that ruled out all chance of a peaceful compromise. War came, and Germany was in the thick of it.

After initial triumphs came stalemate and increasingly hard times for Germany. By 1916, the German people wanted nothing more than a peaceful end to their struggles. The Kaiser, though filled with uncertainty, supported his generals because he was unwilling to appear any less bold than his commanders[6].

The war dragged for two more painful years and to destruction for Germany with loss of much of a generation of her men. All was lost at Versailles. The face of Europe had changed. Gone were the ancient royal houses.

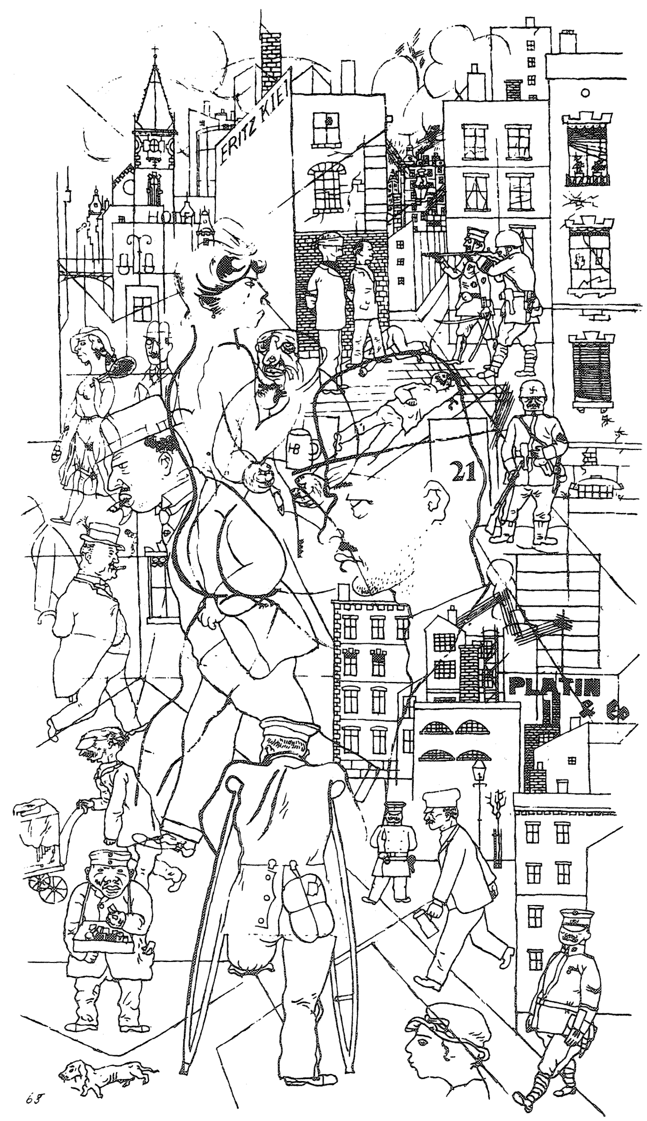

Figure 2
A typical George Grosz painting characterizing the ruin of Germany after World War I. (From Ecce Homo George Grosz, Castle Books, New York, 1965.)

Winds of the future stirred; with the fall of the Russian royalty, Marxist-Leninism was the new creed.

Depression and famine racked Germany. The legends of a wheelbarrow of marks for a loaf of bread were true. Many of you will recall the specimens that Freund left in the Iowa Orthopaedic Pathology museum; unspeakable osteomalacic and rachitic deformities from the starved. Herbert Hoover, a young engineer, mobilized famine relief and saved thousands of unfortunate German citizens. The autobiography of Adolf Lorenz (the famous orthopaedic surgeon) shows a picture of him helping distribute this food[3]. George Grosz' paintings (Figure 2) were a damning documentary of this unstable era.

The unstable, democratic-oriented Weimar Republic was established in 1919, but foundered and fell in 1933 with the rise of Adolf Hitler. The stage was set for World War II as Hitler sought revenge for the defeat of World War I and the humiliation of the Versailles treaty by world conquest.

Again, the sequelae! This conflict left the polarization with Communism that we still face. Turmoil and seventy-one years later, it can fairly be argued that an orthopaedic deformity in an unhappy and limited princeling started it all! What if—.

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A PROPOSED CLASSIFICATION OF PATELLOFEMORAL DISORDERS

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Information concerning the patellofemoral joint has expanded exponentially in the past fifteen years, yet apparently, a generally accepted classification of patellofemoral disorders is still missing. A review of the literature before the 1970's reveals only two diagnostic categories: recurrent dislocation (or subluxation) of the patella and chondromalacia patellae. Conversely, the more recent literature is replete with a frustrating confusion of additional terms describing patellofemoral disorders: subluxing patella, "traumatic" dislocation of the patella, extensor mechanism dysplasia, patellar pain syndrome, patellar malalignment syndrome, patellar tendinitis, adolescent anterior knee pain, patellofemoral stress syndrome, patellar maltracking, excessive lateral pressure syndrome, patellalgia, and many more.

The reason for this dichotomy is three-fold. In 1968 Hughston's classic article[8] emphasized that recurrent dislocation of the patella occurred not only in the typical chubby, knock-kneed, adolescent female, but also in the athletic male as well. He also advocated axial x-rays of the patellofemoral joint (the modified Jaroschy technique) which revealed chronic subluxation of the patella more frequently than the commonly used Settegast technique. Then in the 1970's Ficat et al.[6], Merchant et al.[11], and Labelle et al.[9], all described much more accurate axial radiographic techniques for the patellofemoral joint. These authors maintained that the knees should be flexed only 20 to 45 degrees for the exposure in order to show the patellofemoral relationship in a position where most of the subluxations will be seen. Finally, in the mid to late 1970's, arthroscopy and arthroscopic surgery became more commonly available with their ability to confirm or deny the clinical impressions.

PROPOSAL

A diagnostic classification of patellofemoral disorders is proposed in Table I. Without such a classification a comparison of various treatment protocols from different investigators cannot be made. Furthermore, if the diagnostic categories are too vague or broad, such as "internal derangement" or "chondromalacia", the tendency is to stop looking for the causative factor or factors once the label has been applied. This leads to treating the symptoms using rote techniques rather than individualizing the treatment based upon the causative factors present and each patient's needs.

I would propose that the term "chondromalacia" never be used alone as a diagnosis, but always be qualified with the words "secondary" or "idiopathic". For example, a diagnosis of "chronic patellar subluxation with secondary chondromalacia" is much more accurate and descriptive than "chondromalacia" alone. Actually it was Aleman[2] in 1928 who first used the term chondromalacia in the diagnosis of "chondromalacia post-traumatica patellae" to describe an articular lesion of the patella caused by prior trauma and found at surgery. Unfortunately, as the years went by the "post-traumatica" was dropped and the term chondromalacia was gradually equated with anterior knee pain. We are only now emerging from this confusion.

Following the use of accurate axial patellofemoral radiographs and the establishment of normal values for patellofemoral congruence it became apparent that a "normal" knee almost never suffers a dislocation of the patella. Rarely will a direct glancing blow to the medial edge of the patella cause a dislocation in an otherwise healthy knee. The increased valgus and external rotation deformity of the tibia associated with an acute ligament rupture of the knee infrequently can also rupture the vastus medialis obliquus and cause a patellar dislocation in a normal knee. Almost always the patient who suffers from patellar instability has an abnormal patellofemoral articulation or extensor mechanism to begin with. The only way to discover these abnormalities is by using a careful history and physical examination supplemented by accurate radiographs taken in the proper positions. A distorted x-ray will yield distorted information.

When assessing patellofemoral problems we must evaluate each of the factors known to influence patellar stability. The normal lateral vector imparted to the patella by the normal quadriceps angle (Q angle) is resisted by: 1) the depth of the femoral trochlea or sulcus and its larger lateral facet and 2) the vastus medialis obliquus (VMO) fibers which insert more distally and horizontally on the patella than those of the vastus lateralis. A deficiency of either the intercondylar sulcus or the VMO or both pre-

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Table I

PATELLOFEMORAL DISORDERS

I. TRAUMA (conditions caused by trauma in an otherwise normal knee)
  A. Isolated Trauma
    1. Fracture
    2. Dislocation (very rare in the normal knee)
    3. Contusion
      a. Anterior fat pad fibrosis
      b. Post-traumatic chondromalacia patellae
    4. Post-traumatic osteoarthrosis
    5. Reflex sympathetic dystrophy (includes surgical trauma)
  B. Repetitive Trauma (overuse syndromes)
    1. Patellar tendinitis ("Jumpers' knee")
    2. Quadriceps tendinitis
    3. Peri-patellar tendinitis (e.g. adolescent anterior knee pain due to hamstring contracture)
    4. Pre-patellar bursitis ("housemaid's knee")
    5. Osteochondritis
      a. Osgood-Schlatter's apophysitis
      b. Sinding-Larsen-Johanssen apophysitis

II. PATELLOFEMORAL DYSPLASIA
  A. Lateral patellar compression syndrome (LPCS)
  B. Chronic subluxation of the patella (CSP)
  C. Recurrent dislocation of the patella (RDP)
    1. Associated fractures
      a. Osteochondral (intra-articular)
      b. Avulsion (extraarticular and medial)
  D. Chronic dislocation of the patella
    1. Congenital (probably due to an abnormal external rotation of the entire extensor mechanism)
    2. Acquired (due to progressive fibrosis of the vastus lateralis from multiple injections)

III. IDIOPATHIC CHONDROMALACIA PATELLAE

IV. OSTEOCHONDRITIS DISSECANS
  A. Patellar
  B. Trochlear

V. SYNOVIAL PLICAE (a normal variant made symptomatic by isolated or repetitive trauma)
  A. Medial patellar ("shelf")
  B. Suprapatellar (frequent, but rarely symptomatic)
  C. Lateral patellar (infrequent)

disposes to patellar subluxation and dislocation. Any increase in the Q angle itself from any cause (external tibial torsion, genu valgus, etc.) increases the lateral vector on the patella. We must also remember that there is a dynamic increase in the Q angle when the foot is planted on the ground and the femur is internally rotated during the common maneuver of cutting or pushing off, predisposing to dislocation.

A high riding patella (patella alta) will also increase patellar instability since it articulates in the more shallow superior portion of the sulcus for any given degree of knee flexion compared to the normal. That is, the knee must be flexed more to bring a high riding patella safely within the deeper portion of the trochlea. The tight lateral tether of an hypertrophied lateral retinaculum can also increase the lateral patellar vector force.

Since so many of these abnormalities occur in combination to a greater or lesser degree in the same individual, it is apparent that there is an underlying genetic or developmental abnormality and the overall term of patellofemoral dysplasia seems appropriate. This can be thought of as analogous to congenital dysplasia of the hip. Embryologically the femoral trochlea develops early in utero (eight weeks) complete with the adult predominance of the lateral condyle even before articulation with the patella occurs. Some have postulated that the trochlea fails to develop due to a genetic defect. Others[7] feel that dysplasia of the quadriceps mechanism is primary, allowing patellar subluxation and leading to pressure inhibition of the lateral condyle. From a clinical viewpoint, we are not able to determine this point any more than we can answer the question: "Which came first, the chicken or the egg?"

In a paleontological study of the knee, Dye[4] has shown that the bilobed structure of the distal femur is one of the earliest and most consistent joint shapes through millions of years of phylogenetic development. However, the human asymmetric patellofemoral joint which developed in response to bipedal upright locomotion is relatively new. It should not be surprising that its genetic constancy is rather imperfect. I believe it is helpful to consider this group of patellofemoral disorders as a developmental dysplasia characterized by a continuum of anatomic deficiencies from mild to severe. Hopefully, this will tend to focus our attention on the search for the sometimes subtle abnormalities which explain each patient's symptoms and individualize our treatment to correct these deficiencies.

Having grouped these conditions together under the large category of patellofemoral dysplasia, it is also incumbent upon us to subdivide this classification. This will allow those patients with symptoms and signs in common to be assessed as a group and different treatment protocols be developed and compared. The most mild form of patellofemoral dysplasia would be the lateral patellar compression syndrome (LPCS) described by Ficat et al.[5] in 1975 ("Syndrome d'hyperpression externe de la rotule"). It is characterized by patellar pain while the patella remains stable within the sulcus without subluxation. The sine qua non is functional lateralization of the patella by increased lateral forces, decreased medial forces, or a combination of both.

Chronic subluxation of the patella (CSP) can be considered a moderate expression of patellofemoral dysplasia, in which the patella remains chronically displaced from its normal position during at least the first portion of its trochlear excursion. As in LPCS the presenting complaint is usually anterior knee pain aggravated by flexed knee activities. Since the displacement can only be a matter of degree, I would propose a somewhat arbitrary definition. Chronic patellar subluxation must be evident on an accurate axial radiograph with the knee flexed 30 degrees or more. Various measurements have been proposed to help quantify this subluxation[1,10,11] but their analysis is beyond the scope of this paper.

A more severe manifestation of patellofemoral dysplasia is recurrent dislocation of the patella (RDP) in which the patient suffers episodic patellar instability. Clinically one should be very careful to distinguish between the sudden feeling of weakness or release of the quadriceps which can be induced by sudden patellar pain and the true collapse of the knee as the patella dislocates. The patient will describe both of these as giving way or "going out". Unfortunately lateral releases and Hauser-type procedures have been performed on young ladies based only on such a history with no attempt to obtain an accurate axial radiograph or to try a reasonable nonoperative treatment program first. The rare young child whose patella dislocates almost every time the knee is flexed can still be classified as RDP and is the most severe form of this group.

A word should be said here about recurrent *subluxation* of the patella. I would agree with Brattstrom[3] that since the difference between a momentary subluxation versus a dislocation is one of degree only and cannot be quantified, only the term recurrent dislocation should be used as a diagnostic category.

Since these three diagnoses: LPCS, CSP, and RDP all have common features it should be apparent that any given patient could change from one diagnosis to the other with time, activity level or injury. For example, I have seen young patients under successful nonoperative management for LPCS who change sports and then experience their first patellar dislocation. This injury can stretch the medial retinaculum producing a chronic subluxation of the patella which was not present before.

The most severe form of dysplasia is the congenital chronic dislocation of the patella in which the patella never returns to the trochlea throughout the range of motion thus remaining permanently dislocated.

If the concept of patellofemoral dysplasia is accepted, then purely traumatic conditions of the patellofemoral joint are those that occur in an otherwise normal knee. Obviously direct trauma can also be superimposed on a dysplastic knee as well. Other conditions affecting the patellofemoral joint, such as osteochondritis dissecans and synovial plicae require separate categories.

In this proposed classification of patellofemoral disorders, the term chondromalacia patellae is omitted as a primary diagnosis. It resumes its proper meaning as a descriptive term for a secondary lesion of articular cartilage. For that steadily shrinking group of patients in whom a causative factor cannot be determined, the diagnosis of idiopathic chondromalacia patellae is used. Hopefully this classification will avoid confusion and encourage the clinician to seek the cause of the patient's complaints in order to develop and individualize a rational treatment protocol rather than focus mainly on symptoms.

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ACUTE COMPARTMENT SYNDROME: PRESSURE THRESHOLDS FOR FASCIOTOMY*

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Clinical criteria indicating the need for fasciotomy in acute compartment syndrome are well established. Numerous papers in the past two decades have demonstrated that tenseness of the involved compartment, pain with passive stretch of compartment muscles, along with sensory deficit and finally motor weakness, are important clinical indicators of failure of skeletal muscle compartment perfusion. It is likewise well recognized that certain patients cannot respond appropriately to provide the clincial indicators of pain and sensory change[1]. In particular, multiple trauma patients with associated head injury and unconsciousness, drug overdose patients, and occasionally young children are at risk because of masking of the principal clinical indicators of compartment syndrome. For this reason, the development of technology to facilitate the diagnosis of compartment pressure has received emphasis in the past decade[2,3].

There are presently several techniques available to the clinician to determine intracompartmental pressure. The needle injection technique[4] is simple, least expensive, and reliable in experienced hands but measurements by one physician or technician often differ from those of another by 20-30 mmHg when applied only occasionally. Similarly, noninvasive techniques[5] are similarly inaccurate and limited to only few compartments of the body. Furthermore, techniques that continuously monitor intracompartmental pressure accurately are preferable for following the clinical course of an acute compartment syndrome. These techniques include: 1) the continuous infusion method of Matsen and co-workers[6], 2) the wick catheter technique[7] (Intermedics Orthopaedics, Inc., 1300 East Anderson Lane, Austin, Texas 78752) and 3) the slit catheter technique[8] (Howmedica, Inc., 359 Veterans Blvd., Rutherford, New Jersey 07070). Typically, these three methods are within 2-3 mmHg of each other. These techniques permit the rapid and accurate evaluation of intracompartmental pressure and are very useful aids to the diagnosis of acute compartment syndrome.

Despite increasing clinical experience and an increasing base of scientific data however, there has arisen controversy about the "critical pressure" which indicates the need for fasciotomy. The purpose of this paper is to summarize the points of contention and recent research results which bear on this important question.

Recent Results Concerning Pressure Thresholds for Fasciotomy

Whitesides and co-workers[9] noted that in hypertensive patients, the tolerance for elevated compartment pressures increased. This observation was followed by confirmatory laboratory observations on infusion pressure[10,14].

"Box compression" of skeletal muscle in the rabbit hind limb indicates that capillary perfusion, and not arteriolar perfusion, is compromised in compartment syndromes[10]. In their box experiments, external compression is applied to skeletal muscle by enclosing the hind limb within a chamber in which pressure is elevated. By simultaneously increasing venous pressure and total tissue pressure, Reneman and colleagues determined a ΔP (mean arterial pressure outside the compression box minus box pressure) at which capillary flow stopped using intravital microscopic techniques. Total tissue pressure was measured by a technique similar to that of Whitesides and co-workers[4] and rose linearly with increased box pressure. Capillary blood flow stopped completely at a $\Delta P = 24 \pm 1.3$ mmHg during elevation of box pressure and was renewed when ΔP was lowered to 31 ± 1.6 mmHg. More recently, Slaaf and associates[11] observed that microcirculatory vasomotion disappeared during stepwise reduction of arterial pressure or elevation of total tissue pressure (box pressure). In these studies capillary flow stopped at $\Delta P = 25 \pm 5$ mmHg as box pressure was increased. Thus, these studies by Reneman and co-workers identify the site (capillary) and ΔP (about 25 to 30 mmHg) at which nutritional blood flow is occluded in a model compartment syndrome. Their experiments also emphasize the importance of blood pressures as well as tissue pressures in the pathophysiology of acute compartment syndrome.

As monitored by ^{31}P-NMR spectra techniques, Heppenstall and collaborators[12] also suggest that blood pres-

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sure plays an important role in determining the threshold intramuscular pressure at which ischemia occurs. Subsequently, these investigators also focussed on the additive effect of ischemia and local muscle trauma on the lowering of fasciotomy thresholds for acute compartment syndromes[13]. These studies indicate lower mean arterial pressures and local muscle trauma both make muscle more susceptible to necrosis associated with increased intracompartmental pressure. The studies of Heppenstall and Reneman and colleagues usually employ mean arterial pressure, calculated as diastolic pressure + ⅓ (systolic pressure minus diastolic pressure), as the arterial pressure part of their ΔP term. Furthermore, since mean arterial pressure is a calculated parameter, we have preferred use of diastolic blood pressure in our studies of ΔP thresholds for fasciotomy. Although mean arterial pressure or diastolic pressure may give some indication of perfusion pressure at the precapillary level, capillary pressures often do not correlate directly with arterial pressures and therefore, the concept of a ΔP (mean arterial pressure minus intramuscular pressure) may not always be valid.

Our recent experiments on animals and normal subjects provide further evidence to suggest that fasciotomy thresholds depend on conditions of blood pressure. Under conditions of hemorrhage hypotension in dogs (mean arterial pressure of 65 mmHg), significant muscle necrosis occurs after compartment pressures of 20 mmHg for six hours in the canine anterolateral compartment[14]. Employing a reliable technique for assessing long-term muscle function[15], a significant decrease in contractile properties occurs two days after maintaining intracompartmental pressure at 40 mmHg for eight hours in dogs (Figs. 1 and 2). However, in the subsequent period of seven to twenty-

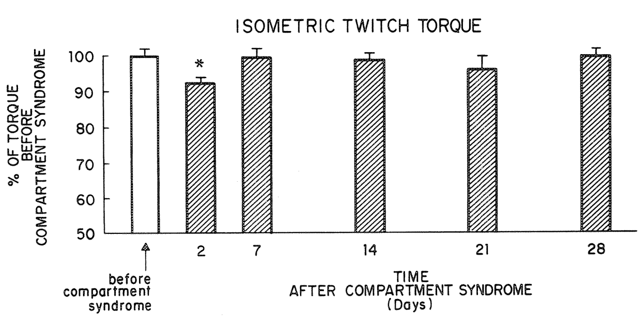

Figure 1

Isometric twitch torque decreases significantly (p <0.02) two days after compartment syndrome but returns and remains normal seven, fourteen, twenty-one and twenty-eight days after compartment syndrome at 40 mmHg for eight hours. From Mortensen et al. (1985).

eight days, isometric twitch torque and isometric tetanic torque return to their normal, pre-compartment syndrome values[16]. Using a recently-developed model for tissue (carpal canal) compression and evaluating median nerve

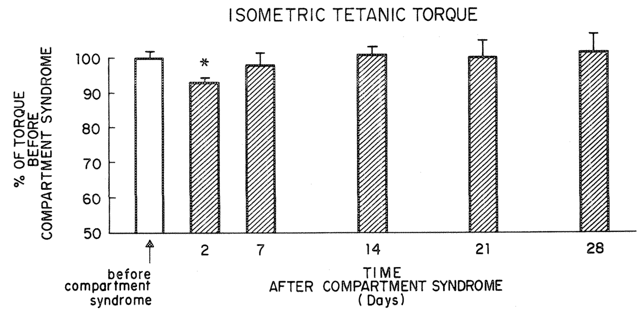

Figure 2

Isometric tetanic torque decreases significantly (p <0.02) two days after compartment syndrome but returns to normal seven, fourteen, twenty-one and twenty-eight days after compartment syndrome at 40 mmHg for eight hours. From Mortensen et al. (1985).

function, we determined that loss of sensory and motor activity occurs acutely between 40-50 mmHg in normotensive subjects (Fig. 3)[17]. This pressure threshold is raised to 60-70 mmHg in patients with hypertension (Figs. 4 and 5)[18]. In both groups of patients (normo- and hypertensive), compression thresholds for nerve dysfunction were consistently 30 mmHg below diastolic blood pres-

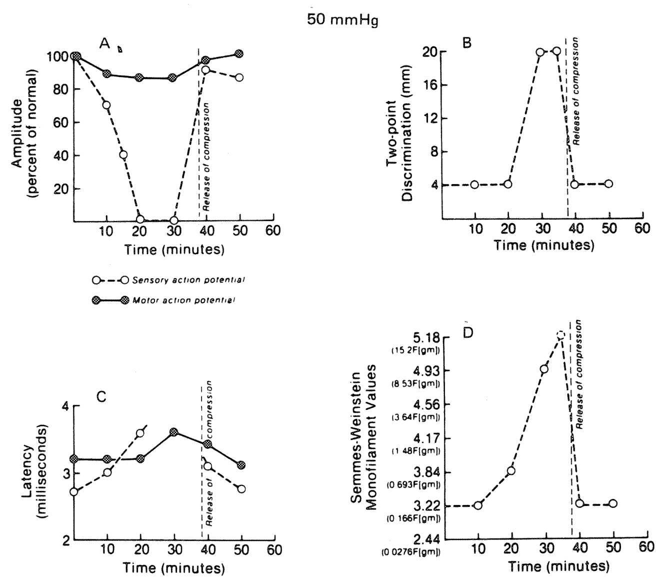

Figure 3

Sensory nerve conduction blocked by 20 min at a tissue fluid pressure of 50 mmHg in this representative subject (A,B). Clinical sensibility also disappeared at this pressure level (C,D.). A: Amplitudes are recorded in percentage of control baseline values. B: Motor (●) and sensory (O) latency in milliseconds. C: Two point discrimination is recorded in millimeters. D: Semmes-Weinstein monofilament values are recorded in both the manufacturer's numerical markings, log 10 (force in mg), and in grams of force (in parentheses). From Gelberman et al. (1983).

sure. However, external compression of the anterior compartment in thirty-three normal subjects produced significant neurologic dysfunction at intramuscular pressures 35-48 mmHg below diastolic pressures (Figs. 6 and 7)[19].

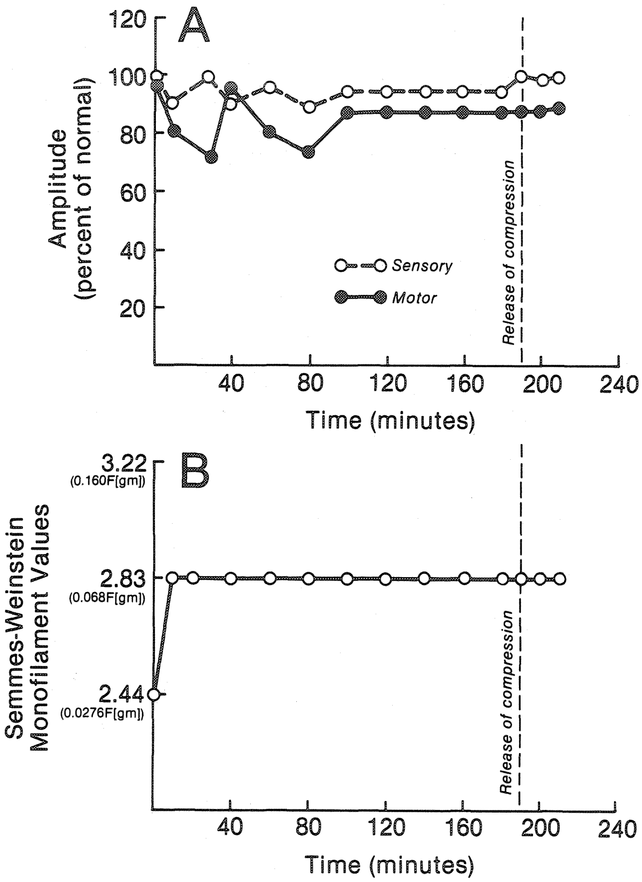

Figure 4

Hypertensive subject (BP 150/90), 60 mmHg compression. A: Amplitudes are recorded in percentage of control base-line values. Time is in minutes. B: Semmes-Weinstein monofilament values are recorded in both the manufacturer's numerical markings, log 10 (f mg), and in grams of force. From Szabo et al. (1983).

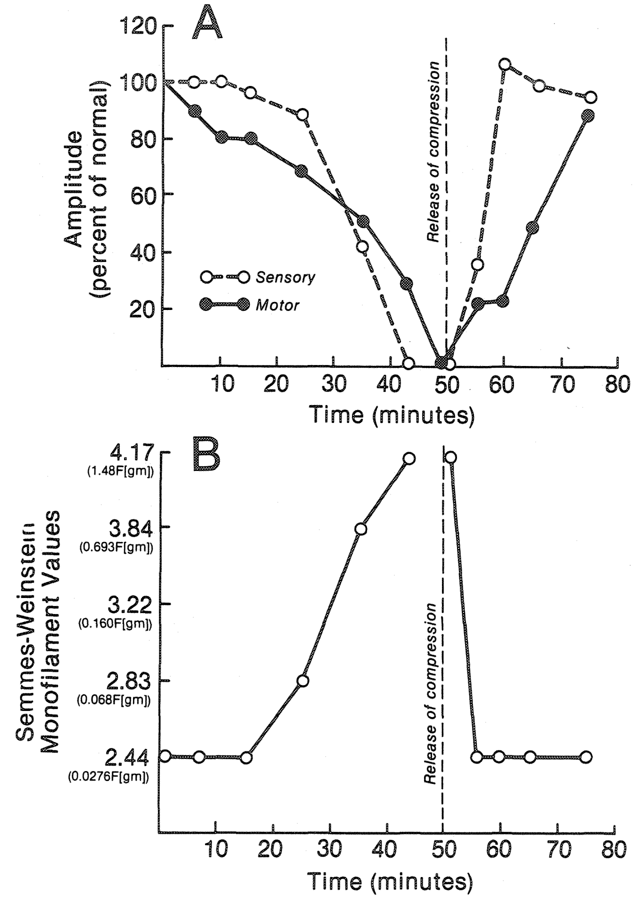

Figure 5

Hypertensive subject (BP 150/90) (same patient as illustrated in Fig. 4), 70 mmHg compression. A: Amplitudes are recorded in percentage of control baseline values. Time is in minutes. B: Semmes-Weinstein monofilament values are recorded in both the manufacturer's numerical markings, log 10 (f mg), and in grams of force. From Szabo et al. (1983).

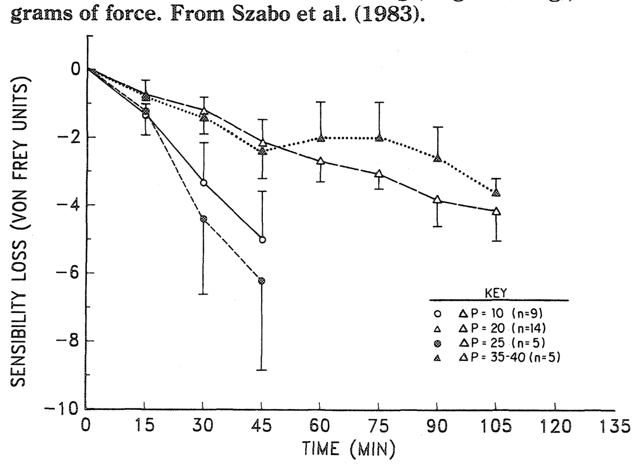

Figure 6

Significant losses of peroneal nerve sensibility occur with time at ΔPs of 10, 20, 25 and 35-40 mmHg. ΔP = diastolic blood pressure minus tissue fluid pressure near peroneal nerve. n = number of human subjects.

Other studies using hyperbaric oxygen (HBO) to treat impending compartment syndromes in dogs indicate that muscle necrosis and edema formation are significantly reduced following immediate[20,21] and two hour delayed[22] treatments of hyperbaric oxygen (Figs. 8 and 9, Table 1). Hyperbaric oxygen may play an adjunctive role in treating acute compartment syndromes by improving resorption of extravascular fluid via its vasoconstrictive effect and by promoting muscle viability via its hyperoxygenation effect. Clinically, however, HBO treatments are still experimental and their lack of universal availability does not alter fasciotomy threshold criteria at the present time.

Recent studies of perfusion by hypertonic solutions after muscle ischemia are interesting in terms of understanding the pathophysiology of compartment syndromes. However, as a treatment modality, hypertonic perfusion probably has limited if any use for decompression of acute compartment syndromes. Buchbinder and co-workers[23] found that hypertonic mannitol reversed tissue edema and ischemia associated with revascularization in isolated canine hind limbs. Of fifteen patients with acute leg ischemia,

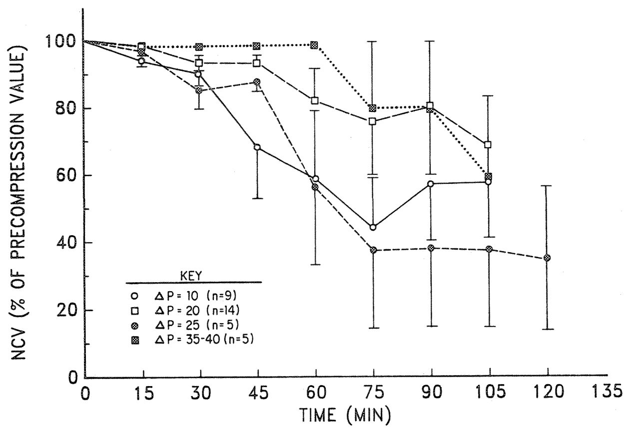

Figure 7

Decreased nerve conduction velocity (NCV) with time at ΔPs of 10, 20, 25 and 35-40 mmHg. ΔP = diastolic blood pressure minus tissue fluid pressure near peroneal nerve. n = number of human subjects.

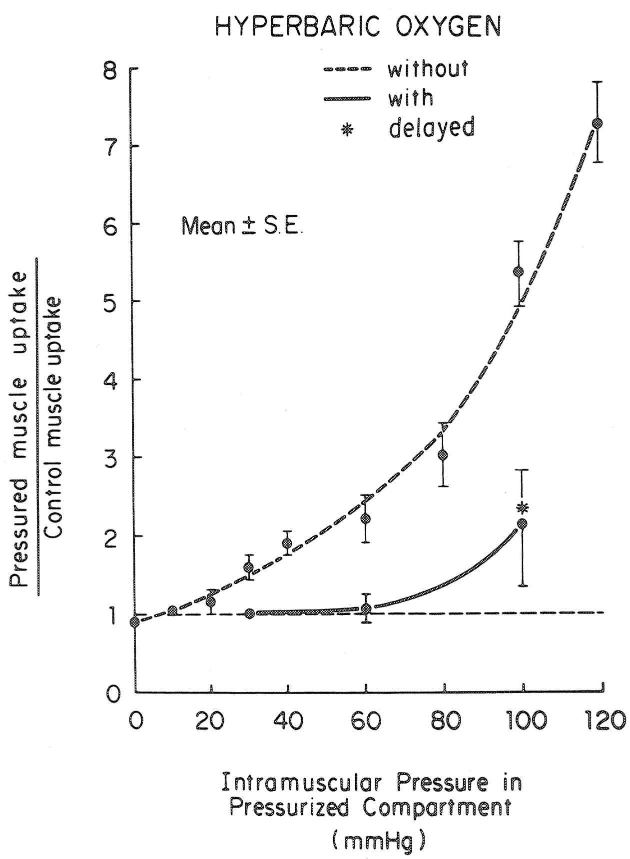

Figure 8

Ratios (pressurized/opposite control limb) of uptake of technetium99m-stannous pyrophosphate in muscles from animals receiving HBO (solid line) and from animals not receiving hyperbaric oxygen (broken line). The horizontal broken line represents a ratio of unity. At the pressurization levels of 60 and 100 mmHg the differences in muscle injury between untreated and HBO-treated dogs were significantly different ($p<0.02$ and $p<0.01$, respectively). Animals receiving two hour delayed HBO treatments are signified by a *.

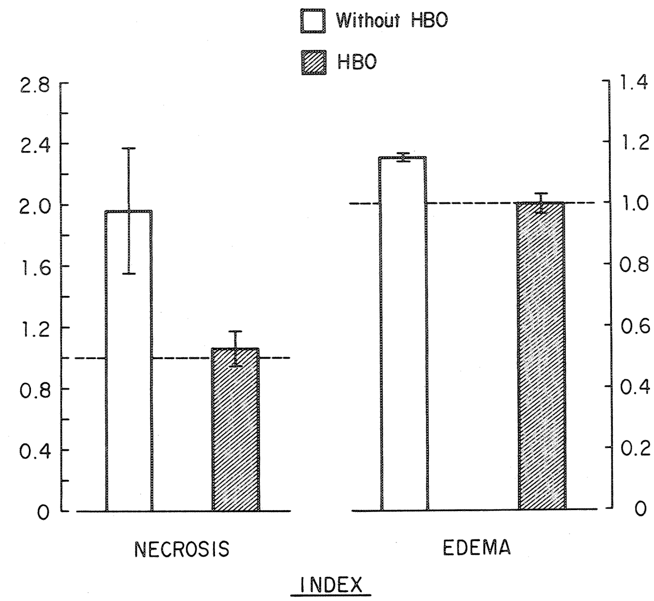

Figure 9

Reduction of necrosis and edema by immediate HBO treatment following compartment syndrome. Results are represented as ratios of ^{99m}Tc Sn-PYP and anterolateral compartment weight in pressurized muscle/contralateral control muscle. All values are expressed as means +/− S.E. with significant reductions for HBO-treated compared to untreated dogs ($p<0.05$). The broken lines represent ratios of unity at which uptake and weight are identical in experimental and control muscle compartments.

fourteen survived and had good results without thromboembolectomy[23]. In a later study, Hutton and associates[25] found that intramuscular pressure fell from 43 ± 5 mmHg to zero after twelve to fourteen hours of tourniquet ischemia and mannitol perfusion intravenously. Saline perfusion of similarly treated dogs increased intracompartmental pressures slightly (45 ± 7 mmHg). These studies suggest that much of the edema associated with post-ischemia swelling of skeletal muscle is localized to intracellular spaces.

The Clinical Application of Tissue Pressure Values in the Decision About Need for Fasciotomy

Our early studies utilizing a canine leg anterolateral muscle compartment model[25] used histological criteria and ^{99m}Tc-pyrophosphate uptake criteria to evaluate pressure-time relationships for muscle compartment necrosis. The pyrophosphate uptake in muscle is a sensitive indicator of early muscle damage[26,27]. The technique is dependent upon mitochondrial metabolic aberrations which occur during ischemia, and which increase Ca^{+2} accumulation in the mitochondria. The Ca^{+2} binder, the phosphate ion of the pyrophosphate, permits the investigator to detect muscle damage by the increase in gamma emissions from the tissue. The technique was first used to identify and quantitate muscle damage after myocardial infarction.

Our initial results indicated that muscle damage began to appear at an absolute tissue fluid pressure of 30 mmHg or at a ΔP of approximately 50 mmHg (diastolic blood pressure minus tissue pressure). We subsequently showed that the muscle damage at 30 and 40 mm tissue pressure was reversible if sustained for only eight hours and that muscle function subsequently returned in forty-eight hours. Nevertheless, we have used the 30 mmHg tissue pressure as an indication for fasciotomy in the clinical setting for several years for reasons which will be detailed below.

In brief, our reasoning takes into account the fact that 1) muscle damage has usually been sustained and 2) that periods of hypotension are commonly encountered in the multitrauma patient: both factors predisposing to muscle ischemia. Furthermore, since the large risk is on the side of ischemic contracture with its major long-term disability, we believe it is only prudent to state the criteria conservatively so that the error term favors too many fasciotomies rather than any ischemic necrosis.

It is possible, of course, for the experienced clinician to modify the fasciotomy criteria by special features of individual cases. In alert and cooperative patients, for example, clinical criteria outlined earlier should be present. Therefore, it is perfectly reasonable to observe a patient carefully over time in spite of elevated compartment pressures if perfusion is adequate for muscle and nerve viability. This usually means observation hourly in a hospital setting with continuous tissue pressure monitoring. Increasing pressure with time with the development of increased tenseness, pain and neurological deficits will, of course, mandate fasciotomy. Stable or declining pressures without those signs, indicates a favorable outcome without fasciotomy.

A patient with minor tissue damage localized to a single extremity, with no evidence of hypotension as well as being alert and cooperative, is obviously more likely to spontaneously resolve elevations in intracompartmental pressures without the need for fasciotomy than the multitrauma patient in shock with extensive tissue damage.

Therefore, the resolution of the question has no single answer. There is no "critical pressure" value correct for all cases. We continue to use 30 mmHg as our index tissue pressure value for fasciotomy in the high risk, unconscious, "shocking" multitrauma patient. We use clinical criteria in the alert, cooperative, localized-injury patient population. We supplement these observations with tissue pressure measurements but we delay fasciotomy until levels above 45 mmHg are attained when clear clinical signs are absent.

Finally, cases between these extremes will continue to challenge clinical judgment. It will be necessary for each clinician to call upon his best resources of experience and acumen to act appropriately. In this context it is always wise to bear the risk factors in mind: a fasciotomy means a scar, but ischemic necrosis means a limb.

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NONOPERATIVELY TREATED MAJOR TRAUMATIC PELVIC DISRUPTIONS: AN EVALUATION OF THE LONG-TERM RESULTS

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Much interest and controversy has arisen regarding the treatment and prognosis of major pelvic disruptions. For the discussion herein, only pelvic disruptions characterized by at least one vertical disruption through both the anterior and posterior portions of the pelvis and sparing of the acetabulum will be considered. As with most fractures, various forms of nonoperative treatment, external fixation devices, and internal fixation techniques have been reported for the management of these severe injuries. Nonoperative forms of treatment have generally been the most widely employed means of treating these fractures. Bedrest, postural reduction, closed manipulation, slings, casting techniques, turnbuckles, and traction apparatuses have all been described[2,6,7,8,13,14,16,29,38,40,43,44,47]. More recently, attention has been focussed on the operative management of pelvic disruptions using external and/or internal fixation. With these techniques, there exists in some cases the potential benefits of better reduction, more rapid mobilization, easier nursing care, increased patient comfort, diminished blood loss, and fewer complications such as pneumonia, decubitus ulcerations, and deep venous thrombosis[19,23,24,37,40,41,46].

The choice of treatment should, of course, be based to a large extent on the long-term outcome of a major pelvic disruption. Several studies have addressed to at least some extent the issue of long-term orthopaedic sequelae in operatively and/or nonoperatively treated patients[8,13,14,17,21,26,31,32,35,36,37,39,46]. Most of these reports, however, were not intended to be focussed specifically on the long-term sequelae and, therefore, are often somewhat incomplete in this regard. Some of these studies also included evaluations obtained less than two years after injury; likely of insufficient duration to truly assess the long-term outcome.

The purpose of this study is to critically examine the nonoperative treatment received by a series of patients with major pelvic disruptions and the long-term results of such treatment. An effort is made to identify critical factors which apparently relate to the long-term outcome.

MATERIALS AND METHODS

Thirty-seven adult patients who sustained major pelvic injuries with anterior and posterior disruptions not involving the acetabulum were retrospectively reviewed. Old radiographs obtained at the time of the injury, which were available in 70 per cent of the cases, and the hospital records were used to assess the initial injury and treatment. Follow-up evaluations five to fourteen years after injury (average 9.0 years) were obtained. All patients completed a detailed questionnaire. All but seven patients (19 per cent) returned for a physical examination as part of their evaluation. A standard supine AP pelvis radiograph was obtained at follow-up in all but two cases (5 per cent). For these two patients, old radiographs obtained at least six months after injury were available and felt to be adequate for determining the final position of the healed pelvis. There was a slight preponderance of men (57 per cent) and most patients (62 per cent) sustained their injury in a motor vehicle accident. Ages at the time of the accident ranged from eighteen to fifty-eight years, with an average of thirty years.

Displacement in a vertical direction of one hemipelvis relative to the other was determined from the AP radiographs as shown in Figure 1. A vertical midsagittal line was drawn through the lower lumbar/upper sacral area. Horizontal lines perpendicular to this center line were drawn across the superior most point of each iliac wing. The distance between these two horizontal lines was taken as the displacement of one hemipelvis in a vertical direction. This displacement was judged to be none, moderate (less than 1 cm) or severe (more than 1 cm).

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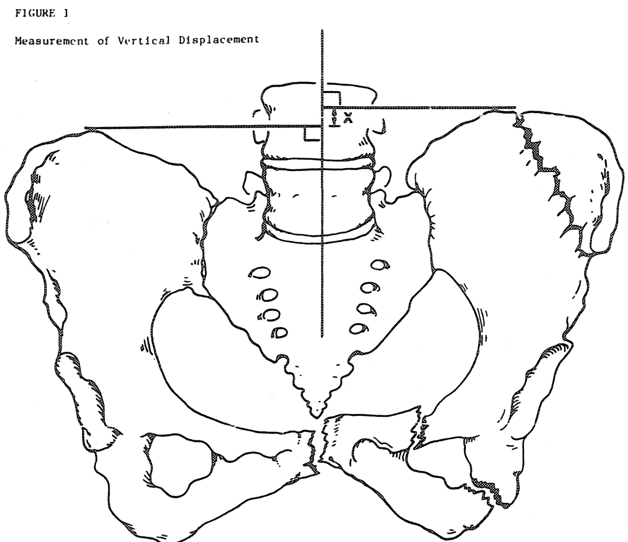

Figure 1
Measurement of Vertical Displacement

RESULTS

Initial Injury and Treatment

An indication of the severity of the trauma is given in Table I. A transient loss of consciousness and/or mental status changes lasting less than twenty-four hours were experienced by 32 per cent of the patients. An additional 19 per cent had mental status changes which persisted greater than twenty-four hours, but ultimately resolved. A skull, facial, and/or cervical spine fracture(s) was sustained by 30 per cent of the patients, and 49 per cent had a fracture(s) in the upper and/or lower extremities. Blood transfusions were received by 57 per cent of the patients, and in three cases over thirty units were given. Hematuria, either gross (27 per cent) or microscopic (54 per cent), was found in all but eight patients.

Table I

Associated Injuries

12 (32%)	mild cranial trauma
7 (19%)	moderate cranial trauma
11 (30%)	skull/facial/c-spine fracture(s)
18 (49%)	upper/lower extremity fracture(s)
21 (57%)	transfusions
20 (54%)	microscopic hematuria
10 (27%)	gross hematuria
4 (11%)	open pelvic fracture
19 (51%)	ileus requiring NG tube

The treatment methods employed for the management of the pelvic disruption are listed in Table II. Bedrest was the only form of treatment for 57 per cent of the patients. A pelvic sling, skeletal traction, a cast, or some combination of these, was used in sixteen cases (43 per cent) to treat the pelvic injury. None of the patients underwent operative reduction and/or fixation.

Table II

Treatment of Pelvic Disruptions

21 (57%)	bedrest only
12 (32%)	skeletal traction
6 (16%)	pelvic sling
3 (8%)	casting
0 (0%)	operative reduction/fixation

The length of time patients were kept in bed averaged thirty-four days. This was quite variable, ranging from one to 102 days. Once up to a chair, the patients usually soon started protected ambulation (average forty days after injury). Total hospitalization time averaged fifty-four days, but also varied greatly (five to 179 days). Injuries other than the pelvic disruption limited the rate at which patients could be mobilized in eleven cases. Omitting these patients, bedrest averaged twenty-seven days, ambulation started an average of thirty-one days after the injury, and total hospitalization averaged thirty-nine days (Table III).

As expected, treatment of the pelvic disruption depended to a great extent on the displacement. Only one of the thirteen patients with no residual vertical displacement was treated with anything other than bedrest. The exception had an "open-book" disruption without vertical displacement who was placed into a hip spica cast after two weeks of bedrest. Excluding two patients with other injuries which delayed their mobilization, patients without vertical displacement were kept at bedrest an average of only eleven days, started ambulation an average of fifteen days after injury, and were hospitalized an average of twenty-one days (Table III).

The pelvic disruption in the thirteen patients with moderate residual vertical displacement was treated more variably: eight patients (62 per cent) with bedrest alone, three patients (23 per cent) with a pelvic sling, and two patients (15 per cent) with skeletal traction (along with a sling in one case and followed by a hip spica cast in the other case). In eight cases, treatment of the pelvic injury (four bedrest, two sling, two traction) was the rate-limiting factor in mobilizing the patient (Table III).

Only one of the eleven patients with severe residual vertical displacement was not treated with skeletal traction. The exception was a patient who had perhaps the most severe injury, with multiple open pelvic wounds, multiple medical problems, extensive neurologic damage, and bilateral posterior disruptions. It had been elected not to treat the vertical displacement in her case. Three patients were also treated with a pelvic sling while in traction and another was placed into a hip spica cast after traction. Omitting four patients with other delaying injuries, the severely displaced group was at bedrest an average of forty-four days, began ambulating an average of forty-nine days after injury, and was hospitalized an average of fifty-nine days (Table III).

Table III

Average Mobilization Times and Displacement*

Residual Vertical Displacement	Bedrest	Ambulation	Hospitalization
None	11 days	15 days	21 days
	range 2-26	2-30	6-36
Moderate	34	36	47
	range 3-72	4-72	5-73
Severe	44	49	59
	range 34-72	40-72	44-83
All groups	27	31	39
	range 2-72	2-72	5-83

*Excludes those patients with injuries other than the pelvic disruption which delayed mobilization.

Skeletal traction in the twelve patients treated by this method was started during the first week after injury in ten cases, and two and four weeks after injury in the remaining two cases. On the average, traction was discontinued seven weeks after injury with a range from 3.5 to thirteen weeks.

Multiple complications were encountered during the hospitalization (Table IV). The high incidence of urinary tract infections is not surprising considering that all but two patients had a Foley or suprapubic catheter. In the absence of significant urologic injury, the patients did not become febrile as a result of the infection and it quickly cleared with antibiotics and/or removal of the catheter. Four patients developed pressure sores significant enough to require dressing changes. Three of the four patients with open pelvic fractures developed deep wound infections which required repeated surgical debridements. During their hospitalization, three patients developed depression significant enough to warrant psychiatric consultation. Two of these three patients had no history of psychiatric problems prior to their injury. Two patients were known to have developed lower extremity deep venous thrombosis, but clinically neither had a pulmonary embolus. Two patients developed acute tubular necrosis and required dialysis, but both ultimately regained independent renal function.

Table IV

Complications

17 (46%)	urinary tract infection
4 (11%)	decubitus ulcers
3 (8%)	pelvic wound infection
3 (8%)	depression
2 (5%)	deep venous thrombosis
2 (5%)	acute tubular necrosis
1 (3%)	"stress" gastritis
1 (3%)	fat embolism

Follow-up Examination

The residual vertical displacement as measured in the follow-up radiographs is shown in Table V. Roughly one-third of the patients fell into each displacement group. In the severely displaced group, the amount of displacement ranged from 1.2 to 4.5 cm and averaged 2.0 cm.

Low back pain was the most common complaint made at the time of follow-up; 86 per cent of the patients reported that they have had low back discomfort at some time since their accident. The patients were also asked to describe how often they have had low back pain, and as an indication of the severity of their symptoms, if they had ever sought medical attention or been hospitalized for their symptoms. The results are shown in Table VI. Only 30 per cent of the patients reported that they were rarely if ever troubled by low back discomfort and 49 per cent were having back pain on a frequent to daily basis. Thirteen patients (35 per cent) reported having seen a physician because of their back symptoms and five (14 per cent) had been hospitalized for the symptoms.

Table V

Residual Vertical Displacement

13 (35%)	none
13 (35%)	moderate ($<$ 1 cm)
11 (30%)	severe ($>$ 1 cm)

The results in Table VI can be compared to the results reported in two previous studies from the University of Iowa, each of which ask these same questions of one hundred normal controls[4,45]. Frequent or daily low back pain was reported by 25 per cent in both studies. Thirty-nine per cent and 30 per cent had seen a physician. Nine per cent and 16 per cent had been hospitalized. As a group, the patients who had sustained a pelvic disruption appear to have more frequent episodes of low back pain than "normal", but the problem would not appear to be particularly severe since they were no more likely than controls to have sought medical attention.

Table VI

Low Back Symptoms

11 (30%)	rarely (1-5 per lifetime) if ever
8 (22%)	occasionally (few per year)
18 (49%)	frequent (few per month) or daily
13 (35%)	seen by M.D. for symptoms
5 (14%)	hospitalized for symptoms

To gain further insight into the severity of the discomfort, the patients were asked about medication. Most patients (62 per cent) reported never taking any medication for their back. Another 24 per cent take only occasional aspirin or acetaminophen. Only 14 per cent reported taking medication (prescription non-steroidal anti-inflammatory drugs in most cases) on a regular basis.

The amount of vertical displacement correlated very well with the frequency of low back symptoms (Table VII). All eleven patients with residual vertical displacement greater than 1 cm were having frequent or daily episodes of low back pain as compared to only 15 per cent of those without displacement, and 38 per cent of those with displacement less than 1 cm (Table VIII).

Table VII

Vertical Displacement and the Frequency of Back Pain

Frequency of Low Back Symptoms	Residual Vertical Displacement None	Moderate	Severe
none/rarely	8 (62%)	3 (23%)	0 (0%)
occasionally	3 (23%)	5 (38%)	0 (0%)
frequent/daily	2 (15%)	5 (38%)	11 (100%)
totals	13 (100%)	13 (100%)	11 (100%)

Neurologic injury was manifested several ways. Objective motor weakness in the lower extremities was detected in five of the thirty patients examined (17 per cent) and eight patients (27 per cent) had an abnormal ankle and/or knee deep tendon reflex. In all cases, these findings were ipsilateral to a posterior pelvic disruption. Displacement was again important. Only one of the eight patients examined (13 per cent) without residual vertical displacement demonstrated any objective neurologic deficit. This compares with four of the twelve patients examined (33 per cent) with moderate displacement and five of the ten patients examined (50 per cent) with severe displacement who were found to have objective neurologic deficit(s) (Table VIII).

Table VIII

Long-Term Results and the Residual Vertical Displacement

Sequelae	Residual Vertical Displacement None	Moderate	Severe
Subjective			
frequent/daily LBP	15%	38%	100%
distal dysesthesias	15%	54%	91%
disability	8%	38%	91%
Objective			
neurologic deficit	13%	33%	50%
limp	13%	33%	80%

Subjectively, neurologic injury manifested as tingling, numbness, and/or burning sensations in a localized area of the lower extremities was described by nineteen (51 per cent) of the patients. In all but one case, these symptoms were ipsilateral to a posterior pelvic disruption. The presence of these dysesthesias correlated well with the vertical displacement. Only 15 per cent of the patients without displacement reported these sensations as compared to 54 per cent of the moderately displaced group and 91 per cent of the severely displaced group (Table VIII). Also, as a result of their accident, 24 per cent of the male patients were impotent.

Many patients reported that they had at least some degree of disability as a result of their accident. Patients rated their work capability as: 57 per cent no disability, 22 per cent able to work full-time, but at a lower level, and 11 per cent unable to work at all. However, only 14 per cent of the patients have actually changed occupations or are no longer working because of their pelvic injury. Disability correlated well with vertical displacement. Some degree of disability was reported by only 8 per cent of the patients without displacement as compared to 38 per cent with moderate displacement and 91 per cent with severe displacement (Table VIII).

Abnormalities of gait ranging from a subtle asymmetry to a shuffling gait requiring a cane and brace were observed in thirteen of the thirty patients examined (43 per cent). Only one of eight patients examined (13 per cent) in the group without residual vertical displacement had an asymmetric gait. This compares with 33 per cent of those examined with moderate displacement and 80 per cent of those with severe displacement who were found to have a limp (Table VIII). Pelvic obliquity was most commonly identified as a causative factor, but pain, weakness, and/or other injuries in the lower extremities were often implicated.

DISCUSSION

Although only patients with major anterior-posterior pelvic disruptions have been included in this study, selection bias towards the more severe injuries was unavoidably present due to the occult nature of many less severe posterior injuries. Also, a large number of patients with minor pelvic fractures are never admitted to a hospital and many other patients are not injured severely enough to warrant transfer to a major referral center. When all of these factors are taken into consideration, it becomes clear that the patients described herein are a small, select subset with far more severe injuries than the "average" pelvic fracture. Therefore, generalizations and prognostication for most patients with a pelvic fracture cannot reliably be made based on these results.

There is a large volume of literature devoted to the severe trauma associated with acute, major pelvic disruptions. The severity of the trauma involved in this series is clearly indicated by the high incidence of associated injuries and complications and substantiates the work of others[5,22,26,27,34]. The long-term sequelae of severe pelvic disruptions have not been so widely reviewed, however. Many aspects of this issue have been addressed in this study. Pelvic obliquity was present to some degree in twenty-four of the thirty-seven patients (65 per cent). Raf[32] identified pelvic obliquity in 38 per cent of his patients with anterior-posterior pelvic disruptions and Tile[39] reported 34 per cent with at least some inequality. The real clinical significance of this obliquity is not clear, however. Leg length inequality of as much as 1 cm is a common finding in many "normal" individuals who are asymptomatic and the role of obliquity in back pain is controversial[9,11].

As a result of their accident, 43 per cent of the patients when examined at follow-up had at least some asymmetry to their gait. In other reports, Raf[32] found 12 per cent with an impaired gait, Huittinen and Slatis[36] reported 32 per cent had impaired gait secondary to pelvic obliquity, and Semba, et al.[35] felt 31 per cent had a gait disturbance.

Neurologic injury was manifested several ways. Subjectively, 51 per cent described localized distal dysesthesias on the same side(s) as the posterior pelvic disruption(s). Objectively, 17 per cent of the patients examined had motor weakness and 27 per cent had abnormal deep tendon reflexes at the knees and/or ankles. Semba, et al.[35] and Huittinen and Slatis[17] reported that 37 per cent and 32 per cent of their patients, respectively, had lower extremity paresthesias. Raf[32] and Huittinen and Slatis[17] found abnormal deep tendon reflexes in 55 per cent and 25 per cent of their patients, respectively.

Low back pain is generally felt to be the most common long-term orthopaedic sequela of a major pelvic disruption. In other studies, the reported incidence of low back pain following a major pelvic disruption is 13-54 per cent[8,13,21,26,32,35,36,39]. In this series, 49 per cent reported frequent or daily episodes of low back pain. Terms such as "severe", "chronic", "disabling", "frequent", and "limiting" are used to qualify and define groups of patients with back pain. A major reason for the large differences between the various reported incidences of back pain is quite likely the difference in criteria used for a "reportable" level of back pain.

Data on back pain in patients who have sustained a pelvic injury must be viewed in proper perspective since low back pain is such an extremely common problem in the general population. Low back discomfort is experienced at some time by 50-80 per cent of the general population and 20-50 per cent suffer from pain that is severe, frequent, and/or causes them to seek medical attention[12,15,18,28]. Therefore, it is difficult to assess the causative role an old pelvic disruption may be playing in a given individual's low back symptoms. The problem is further confounded by the difficulty always encountered when trying to quantify the magnitude of any pain problem.

A clear shortcoming of this study is the lack of a controlled comparison group of normals evaluated in parallel with the patients who have had a pelvic disruption. It is reasonable, however, to make direct comparisons between our patients with a pelvic disruption and normal controls asked identical questions as a part of other studies[4,45]. The complaint of frequent or daily low back discomfort was more common in patients who have had a pelvic disruption than in normal controls (49 per cent versus 25 per cent). The severity of the back problem in the patient group as a whole would not appear to be particularly great, however, since the patients were no more likely to have visited a doctor or been hospitalized for low back symptoms than normal controls.

As clearly shown in Table VIII, residual vertical displacement appears to be an important factor in predicting the final outcome. Two other potentially important factors must also be considererd. Firstly, the initial displacement could be quite important in determining the outcome since this would correlate well with the amount of soft tissue injury which was incurred. Semba, et al.[35] noted that all their patients with less than 1 cm of combined anterior and posterior vertical displacement present at initial injury were asymptomatic at follow-up. In our series of patients, the displacement present on the initial radiographs (available in 70 per cent of the cases) was measured and compared to the displacement on the follow-up film. Only one patient was found to have been improved from one displacement group to another (severe to moderate displacement) by the treatment methods employed. Therefore, it is impossible to estimate the relative importance of the initial and final displacements from this series of patients. This is a critical question, however, since treatment can potentially affect one factor (final displacement), but not the other (initial displacement). Pelvic obliquity and gait asymmetry resulting from pelvic obliquity are undoubtedly functions of the residual displacement rather than the initial displacement. The objective neurologic sequelae of a major pelvic disruption and the subjective distal dysesthesias, however, are probably much more a function of the initial displacement than the residual displacement. The more common and complex long-term problem of back pain in these patients certainly could have components related to both the initial and residual displacements. This issue clearly warrants further investigation.

A second potentially important factor affecting outcome is involvement of the sacroiliac joint. In general, it is felt that intra-articular fractures are "less forgiving" than extraarticular fractures. Several authors have reported a higher incidence of symptoms in their patients with disruption of the sacroiliac joint than in those in whom the joint was spared[13,32,44]. However, none of these authors mentioned either the initial or residual displacement which potentially could have been the true underlying factor(s) affecting their results. In our series, frequent or daily low back pain was reported by 50 per cent of the patients who had involvement of a sacroiliac joint and by 47 per cent of those in whom the sacroiliac joints were apparently spared. It appears, therefore, that involvement of the sacroiliac joint was not a critical factor. Semba, et al.[35] likewise found back pain to be equally common in patients with disruption through the sacrum and those with disruption through the sacroiliac joint. This conclusion is drawn from our data with reservation, however, since it was often difficult to determine from a plain AP radiograph whether or not a sacral frature propagated into and involved the sacroiliac joint. The difficulty in recognizing and precisely defining the posterior component of a pelvic disruption is well recognized[1,3,20,30] and often a CT scan is required to clearly delineate the acute injury[10,33,42].

While some patients were improved to a slight extent by the treatment methods employed, in only one case was the improvement significant enough to change a patient from one displacement group to another. In view of the apparent importance of displacement, the old records and radiographs were reviewed in an attempt to ascertain why treatment was so ineffective at significantly reducing displacement. Factors such as the specific location of the disruption (e.g. sacrum, sacroiliac joint), presumed force vector involved (e.g. vertical shear, "open-book", lateral compression), delay in starting traction, and weight of traction were all considered. In this series of patients, no single factor could consistently be identified to account for the inability to obtain and maintain reduction. Malreductions are by no means limited to nonoperatively treated patients, however. With manipulation under anesthesia followed by external fixation, many patients are still left with residual vertical displacement[37,46]. This difficulty in obtaining anatomic reduction without direct operative intervention has been examined in cadavers[1].

Our results clearly indicate the critical importance of displacement in the long-term results of a major pelvic disruption. Any discussion of major pelvic disruptions would, therefore, be most meaningful if the amount of initial and final vertical displacement are included. These critical factors must be considered in a quantitative fashion to help guide the choice of treatment options, to determine prognosis for a given patient, and to fully interpret the quality of the result.

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THE ROLE OF ARTHROSCOPY IN THE TREATMENT OF TIBIAL PLATEAU FRACTURES

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The knee is a complex joint requiring strength of the supporting muscles, integrity of the ligamentous system, and a smooth aligned articular surface for optimal function. A displaced intra-articular fracture of the proximal tibia will throw this complex out of alignment, causing a visible deformity (Fig. 1) and in the long run may lead to premature degenerative arthritic changes (Fig. 2). It is important, therefore, to restore articular congruency, stability, and alignment to ensure satisfactory knee function.

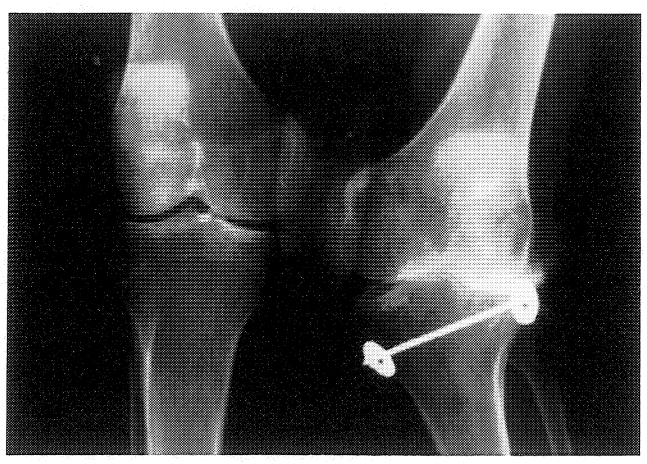

Figure 1
Malunion with valgus deformity due to loss of lateral tibial condyle elevation.

Figure 2
Valgus deformity and degenerative arthritic changes following inadequate lateral tibial plateau restoration.

Tibial plateau fractures are relatively common, and a number of residual structural problems may contribute to a poor outcome. These include angular deformity, ligament laxity, tearing of the meniscus, and irregularity of the articular surface. In the long term results of treatment of these injuries, experts have agreed that radiographic appearance usually does not reflect the final clinical result,

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and the prognosis has been shown to be most closely related to the residual displacement of the articular surface and the angular deformity[1-19]. When malalignment or degenerative arthritis develops, surgical intervention including joint debridement, osteotomy, allografting, prosthetic replacement (Fig. 3) or arthrodesis are advocated.

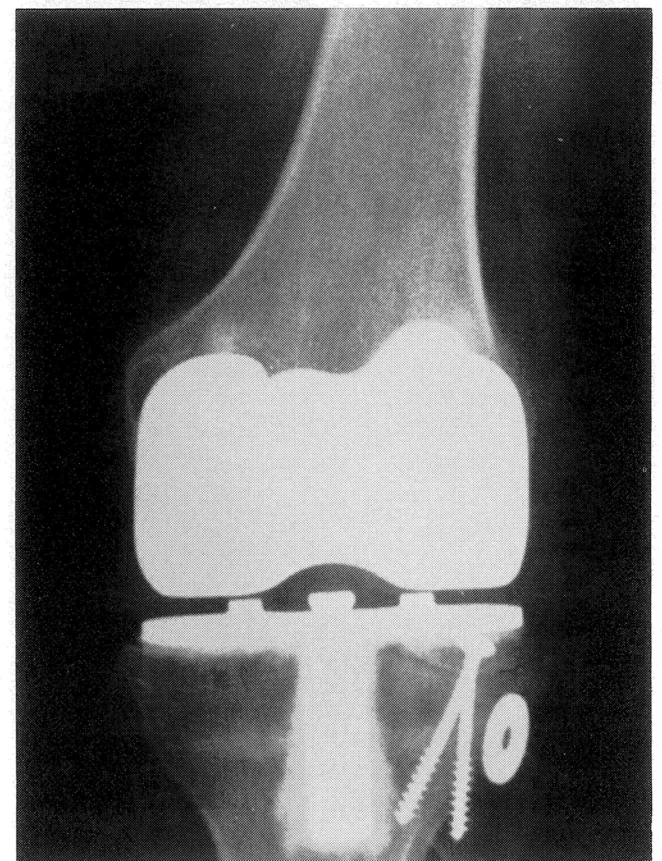

Figure 3
Total knee replacement with autograft to lateral tibial plateau (preoperative x-ray shown in Figure 1).

Recent articles have documented the high incidence of associated soft tissue injury including ligament tears and meniscal injury[14,15,20-31]. There has been a trend toward aggressive restoration of the normal articular surface with bone grafting and stable internal fixation, allowing early range of motion[9,12,32-25]. Numerous new surgical approaches have subsequently been developed including improved exposure of the articular surface by detaching the meniscus[36], followed by windowing the tibia and elevating the depressed fragment. Bone grafts are advocated with both cancellous and cortical bone, and intraoperative x-rays are used to assure reduction[37-42]. More conservative treatment options should remain in the orthopaedist's armamentarium and should include closed reduction with casting, traction, external fixation and the use of cast bracing with early motion[1,3,5,43,44].

Arthroscopy has been recently shown to have a place in the treatment of tibial plateau fractures[25-27]. The following is a retrospective analysis of our management of tibial plateau fractures from 1979 to 1984.

Classification

Articular fractures of the proximal tibia are classified to aid the clinician in thinking about the therapeutic problems peculiar to a particular fracture configuration. Most published classifications recognize split (or wedge), compression, split-compression, total condylar depression, and bicondylar types (Fig. 4). Several authors have included other types on the basis of their own observations of the behavior of different fracture lines (Fig. 5). Some have attempted to subclassify those fractures that are stable—thus minor and imposing no treatment problems—or unstable—thus major and requiring sophisticated knowledge and judgement.

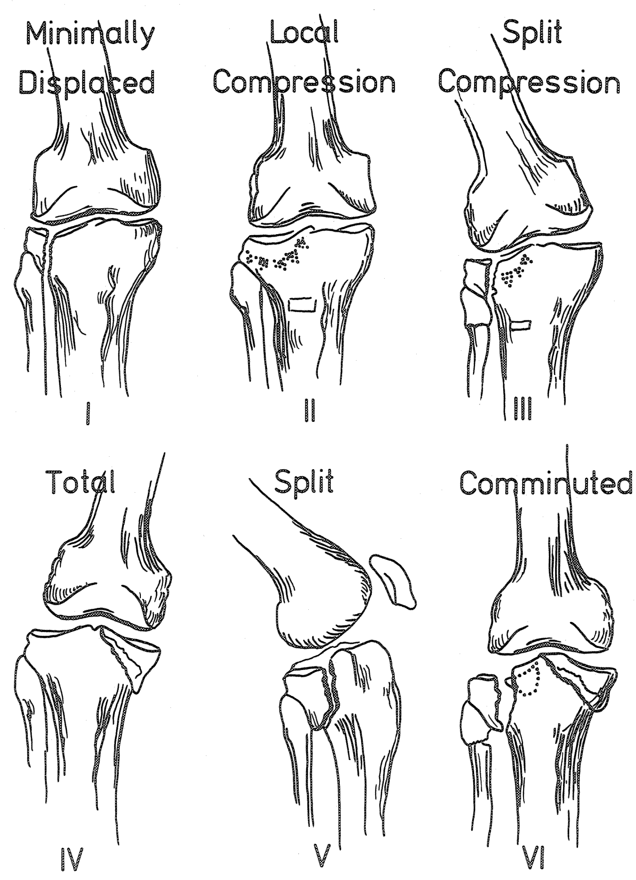

Figure 4
Classification of plateau fractures (Hohl, M.: Tibial Condylar Fractures, J. Bone Joint Surg. 49A:1456, 1967).

Diagnostic Techniques

Decision-making regarding the particular treatment for a given fracture is aided by radiographic techniques and careful clinical evaluation.

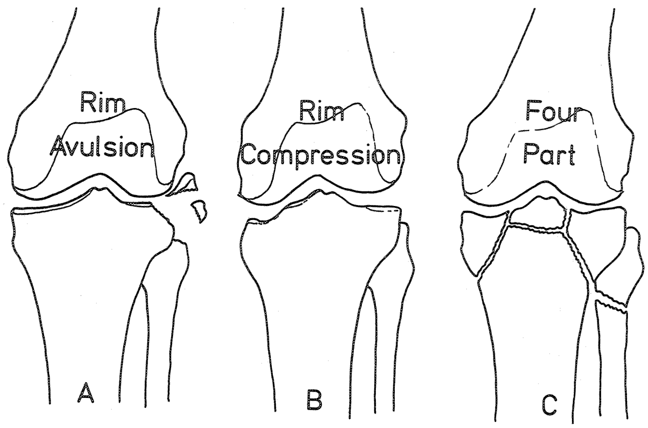

Figure 5
Other fracture types associated with fracture-dislocations of the knee. (redrawn from Hohl, M. and Moore, J.M.: Articular Fractures of the Proximal Tibia. In Evarts, C.M. (ed.): Surg. of the Musculoskeletal System. New York, Churchill Livingston, 1983).

Roentgenographic examination using anteroposterior and lateral projections usually reveals the fracture but often leaves considerable doubt as to the degree of depression or displacement of the fracture configuration[45]. In order to make the best treatment decisions, especially in the event that surgery is contemplated, the surgeon should document the fracture completely and clearly. The oblique view helps to determine the anteroposterior location of the fracture. The 10 degree caudal plateau view gives an accurate determination of depth of depression[46]. Polytomography also helps to delineate articular depression and degree of displacement[47-49].

The diagnosis of associated ligament injuries is suggested in routine x-ray views by widening of the cartilage space on the side opposite the fracture or avulsion fractures of the femur, tibia, fibula, or intercondylar region[50,51]. Most authors advocate stress testing under anesthesia to determine the clinical stability of the knee[22]. Instability however, may result from the fracture, ligament injury, or both. Arthrography also has been advocated to help delineate traumatic capsular and ligamentous defects[52].

Indications for Arthroscopy

Arthroscopy allows accurate definition of the fracture and also assessment of the concomitant soft tissue injury. In addition, the hemarthrosis and osteochondral debris is removed from the knee at the time of examination. Finally, utilizing arthroscopic visualization, more accurate articular restoration and stabilization of selected fractures can be accomplished percutaneously or with a limited incision. This eliminates the need of an open arthrotomy with detachment of the meniscus for adequate exposure of the articular surface. Arthroscopy also obviates the need for intraoperative roentgenograms to assure articular congruency.

Operative Techniques

The technique utilized for diagnostic arthroscopy in the setting of a tibial plateau fracture is similar to that utilized for an acute hemarthrosis secondary to other causes. Under general or spinal anesthesia the knee is examined, appropriate ligamentous stressing is performed, and stress x-rays obtained if indicated. A tourniquet is used and an appropriate leg holder is applied higher than usual to allow for adequate access of arthroscopic operative instruments, possible arthrotomy, and ligament repairs if required. A sterile video system is used in order to minimize the risks of contamination. A large bore inflow cannula is required as well as large volume bags (3 liters) of irrigation solution (of sterile saline or Lactated Ringer's) to provide adequate visualization. The arthroscope is introduced either via the transpatellar approach or via a portal opposite the side of the fracture. All debris and coagulated blood are removed and a thorough arthroscopic examination carried out. Careful attention is paid to the soft tissue injuries including the collateral ligaments, cruciate ligaments and menisci as well as the articular surfaces.

Reduction of selected tibial plateau fractures can be accomplished under arthroscopic control. Both split and split-compression fractures may be reduced by making a small transverse incision below the flare of the tibia and indirectly reducing the tibial articular surface from below. If the articular surface remains depressed (most often with central compression fractures) drill holes are placed through the anterior cortex and either an osteotome or an offset punch is driven under the fracture to elevate the various fragments. This technique has been termed "indirect triangulation" (Fig. 6). It is helpful to over-elevate the fragments; then place the knee through a range of motion. The femoral condyle tends to mold the surface of the tibial plateau back to its anatomical configuration. Bone graft may be placed under the fracture via the window in the anterior cortex. The stability of each fragment is assessed with a hook probe, placed through a separate portal.

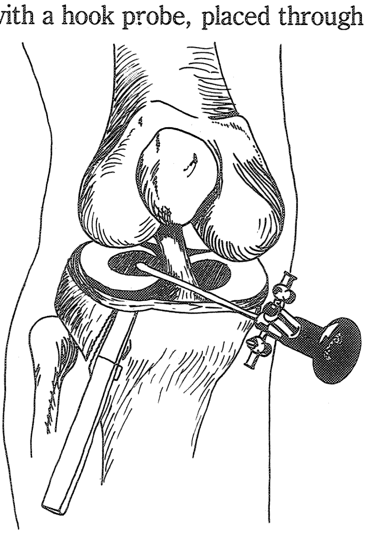

Figure 6
"Indirect triangulation."

After reduction of the fracture, internal fixation may be accomplished by percutaneous or open technique (Fig. 7). Guide pins for temporary fixation and cannulated screws are helpful. Maximum interfragmentary compression can be achieved for simple split fractures using a lag screw. Washers are suggested in the soft metaphyseal region. Buttress plates may be required for severely comminuted fractures.

Figure 7a
Example of split compression fracture.

Meniscal tears and ligamentous injuries can be taken care of appropriately. The fracture is then checked to determine the stability of the fixation and whether early range of motion may be initiated. We advocate early mobilization of tibial plateau fractures which are uncomplicated by associated injuries.

MATERIALS AND METHODS

From 1979 to 1984, thirty tibial plateau fractures were treated in twenty-nine patients (one person having sustained bilateral fractures in a motor vehicle accident). There were thirteen females and sixteen males, with an age range of fourteen to eighty-five years. Five patients were treated nonoperatively: in two cases, because the fractures were undisplaced, and in three cases because general health and/or other injuries made the risks of anesthesia

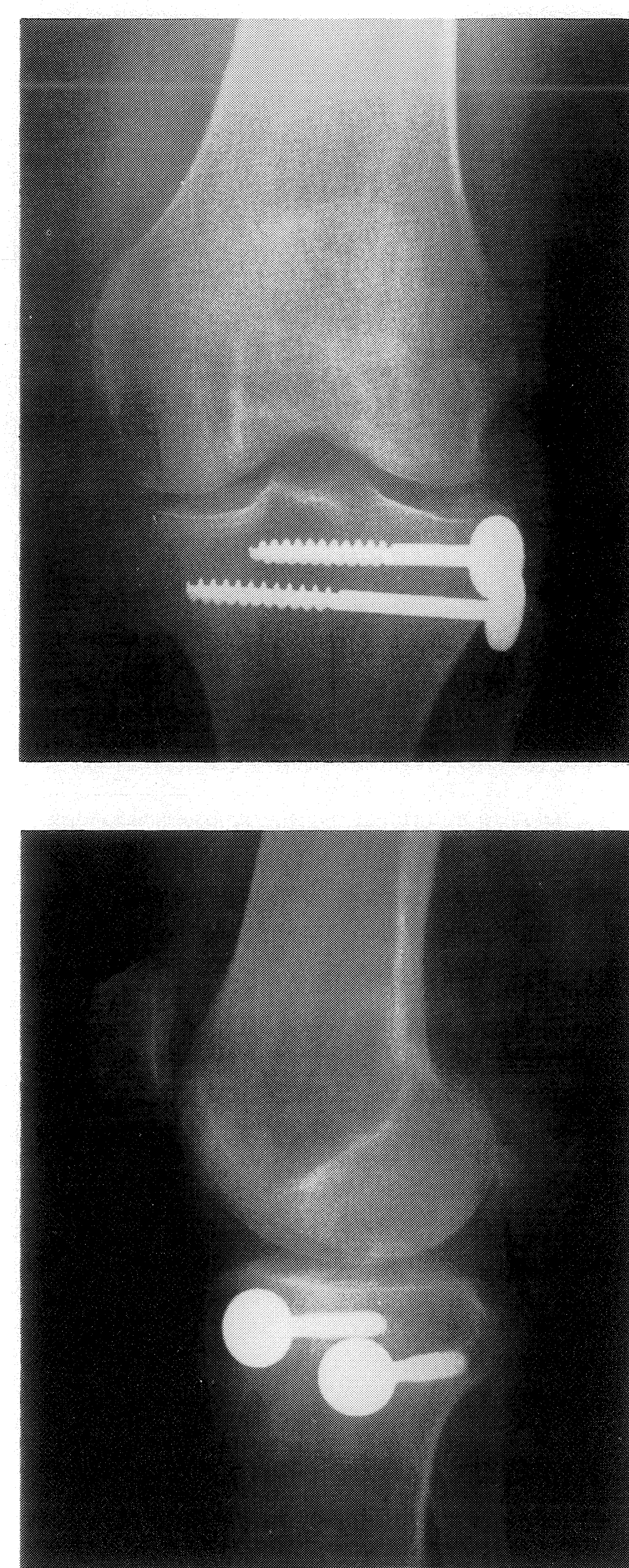

Figure 7b
Reduction and internal fixation accomplished by percutaneous technique. Arthroscopic visualization and "indirect triangulation" were used for anatomic restoration of articular surface.

or surgery untenable. Twenty-four patients had operative procedures. Four patients had an arthrotomy alone, seventeen patients were treated only by arthroscopy, while three patients had arthroscopy and arthrotomy.

Arthroscopic procedures included six purely diagnostic exams, three debridements of bony fragments, two partial meniscectomies, one closed reduction, and fourteen cases requiring reduction, internal fixation and/or bone grafting. Included in these fourteen were two reductions with bone grafting and no internal fixation, eight reductions with internal fixation, and three reductions with bone grafting and internal fixation. One patient with widely metastatic lung cancer and limited life expectancy had the fracture buttressed with methylmethacrylate instead of autogenous bone graft.

RESULTS

According to Hohl's classification (Fig. 4) there were ten Type I, one Type II, eight Type III, three Type IV, one Type V, and seven Type VI injuries (Table 1). Of the twenty-nine patients treated for tibial plateau fractures, twenty had arthroscopic procedures. In fifteen cases, it was possible to achieve an adequate reduction and stabilization of the fracture with arthroscopic techniques.

Table 1

Tibial Plateau Fractures Classified According to Hohl[6-10]

Fracture Type	Total Number	Arthroscopic Surgery	ARIF* and/or Graft
I	10	6	4
II	1	2	1
III	8	8	7
IV	3	1	1
V	1	1	—
VI	7	2	1
TOTAL	30	20	14

*ARIF—Arthroscopic reduction internal fixation

Soft tissue injuries occurred in seven of the fractures and included three meniscal tears, two medial and one lateral. The medial tears were managed by arthroscopic meniscectomy. A peripheral detachment of the lateral meniscus required a limited arthrotomy to affect a repair. A medial collateral ligament avulsion from the femur was repaired by standard techniques. A posterior cruciate ligament tear, not noted preoperatively, was suspected at the time of examination under anesthesia and confirmed by arthroscopy. An anterior cruciate ligament tear was noted in a patient who had delayed arthroscopy after open reduction at another hospital.

Length of hospitalization was roughly equivalent in all of the operative groups (ten to twelve days). Nonoperatively managed patients averaged twenty-seven days of hospitalization. Cast immobilization averaged five weeks in the non-operative group and four weeks in the groups treated by arthrotomy with or without arthroscopy. The average period of immobilization in the arthroscopy only group was ten days. Nine of this latter group were not immobilized and were started on immediate range of motion exercises as the fractures were noted to be stable after reduction and fixation.

Time required to achieve a functional range of motion (10 degrees to 100 degrees) was 4.3 months in the non-operative group and 3.0 months in the patients treated with arthrotomy with or without arthroscopy. A significant decrease, to 1.3 months, was noted in the group treated only with arthroscopy. Fracture healing assessed by clinical and radiographic examination occurred at four months in the non-operatively managed patients and those having arthrotomies, whereas fractures managed arthroscopically (without arthrotomy) showed an average healing time of 2.2 months. It should be kept in mind that these statistics are misleading in that some of the non-operatively treated fractures were those which were most comminuted and involved associated Grade III soft tissue injuries.

Complications in this series included three peroneal nerve injuries, one delayed union, and one suture abscess. Two peroneal nerve palsies were noted after arthroscopy. One resolved completely in ten weeks. The other was in a patient in whom the nerve was isolated and retracted during peripheral repair of the lateral meniscus. The third neuropraxia occurred in a multiply injured patient who was treated with closed reduction and casting alone and was probably related to the cast pressure or positioning in bed. The delayed union occurred following non-operative management in an osteoporotic female with a Type VI fracture who also had an associated proximal one-third transverse tibial shaft fracture. Finally, a stitch abscess was noted in the tibial incision in a patient treated with arthroscopic reduction and internal fixation and resolved without sequelae. There were no known deep infections, vascular injuries, deep vein thromboses or pulmonary emboli, or compartment syndromes from extravasation of fluid into the compartments of the lower leg.

DISCUSSION

Arthroscopic treatment of tibial plateau fractures requires a sterile video system and a full armamentarium of arthroscopic instruments. The operative technique requires an expertise in arthroscopy as well as an acquired "feel" for "indirect triangulation". Arthroscopy should not be used in the management of tibial plateau fractures that are open or are associated with skin abrasions.

With tibial plateau fractures there is injury to soft tissues, bone, and hyaline cartilage. There is a tremendous fibrous, cartilaginous, and osseous reaction in the healing period. Recent experimental work has stressed the disadvantages of immobilization and the functional and biologic advantages of early motion of the knee[10,53,54]. Arthroscopy allows direct visualization of the fracture to better determine articular congruency and fracture stability. If the fracture is stable, we advocate early range of motion. If the patient is reliable we send the patient home in a cast brace. Full weight bearing must await bony healing (two to four months). A prolonged, intensive, and carefully supervised exercise program is required if maximum function is to be reached.

CONCLUSION

The problem of accurate definition of tibial plateau fractures and associated soft tissue injuries is common for all orthopaedists who treat these fractures. Most of us are aware that these fractures are found to be more complicated at arthrotomy than was originally appreciated. Arthroscopy allows accurate diagnosis without obviating any means of treatment and permits the most appropriate treatment modality to be planned. Selected fractures may be treated by arthroscopic technique, apparently to good advantage in the immediate postoperative period. Arthroscopy confirms the accuracy and stability of fracture reduction, making extensive exposure of the joint unnecessary, and allowing immediate motion if the fracture fixation is stable. Removal of chondral, osteochondral, and meniscal debris reduces postoperative synovitis and joint degradation. No inference as to long term results of arthroscopic management can be made as follow up in this series is as yet too short.

Arthroscopy is of value in the management of tibial plateau fractures. Acute fractures and associated soft tissue injuries can be precisely defined allowing for timely management decisions. Based on direct arthroscopic observations, selected fractures can be reduced and stabilized and appropriate postoperative management determined.

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THE LONG-TERM FOLLOW-UP OF IPSILATERAL TIBIAL AND FEMORAL DIAPHYSEAL FRACTURES

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High energy trauma has become increasingly prevalent in the United States. In 1981 it resulted in an overall rate of hospitalization of approximately 1/100 people[34]. It is the most common cause of mortality and morbidity for persons between the ages of one to forty-four years[34]. Fractures are the most common of these injuries and are related to the high morbidity suffered by this population.

Ipsilateral femoral and tibial shaft fractures are an unusual combination in high-energy trauma. The combination of these two injuries in one limb leads to a prolonged rehabilitation and many poor functional results[7,9,11,14,17,20,25,30,38,41,51,53,57,58]. In spite of a large number of reports, controversy still exists regarding the choice of method and timing of treatment for these often polytraumatized patients. The choices for fracture treatment include combinations of skeletal traction, internal and external fixation of the femur and/or tibia depending on the patient's systemic condition, local soft tissue conditions, and available expertise and implants. As an example, most orthopaedists agree with Winquist, Hansen and Clawson that intramedullary nailing is the treatment of choice for closed femoral shaft fractures that are not comminuted[56]. Not all surgeons however, possess the expertise or willingness to nail a comminuted femoral fracture in a multiply injured patient emergently.

Recently, several studies have reported the risks and benefits of early operative stabilization of long bone fractures in multiply injured patients[1,13,14,23,32,42]. These authors have concluded that patients whose fractures were operatively stabilized, allowing early mobilization, had higher survival rates and lower rates of adult respiratory distress syndrome and other life threatening posttraumatic systemic complications.

If patients survive this early period, orthopaedic surgeons are then confronted with prevention of wound sepsis in open fractures, malunions, delayed or nonunions, and adjacent joint stiffness. Most recent reports of patients with ipsilateral femoral and tibial fractures indicate that these complications are much less frequent if both fractures are operatively stabilized[9,25,52]. Veith et al. and Karlstrom and Olerud reported rates of osteomyelitis among their patients treated operatively of 10 and 7 per cent respectively. In addition, among those patients treated operatively, greater than 80 per cent had good or excellent functional results at approximately three years after injury[25,52]. However, a large series reported by Fraser, et al. (N = 222) showed a 30 per cent incidence of osteomyelitis is cases where both fractures were either internally or externally fixed[9].

These results favor operative stabilization of fractures for preventing both early and later complications. However, not all patients or fractures are amenable to this therapy due to associated injuries (abdominal content rupture, pulmonary contusion, etc.), local soft tissue conditions, or comminution of the fractures. This was pointed out by DeLee in his report of treatment of patients with ipsilateral femoral and tibial fractures using traction and cast bracing[7]. The dilemma is further demonstrated in the three previously mentioned series[9,25,52] by the inclusion of a large number of patients that had either been treated without operative stabilization or required external immobilization to supplement fixation.

This study reports the longest follow-up of patients with this combination of injuries. The purposes include: 1) to collect and analyze data that would allow a correlation of fracture treatment with the incidence of early complications; 2) to correlate final alignment of the fractures at healing with the later condition of the adjacent joints, and 3) to correlate present functional status with treatment method, bony alignment and the condition of the adjacent joints.

MATERIALS AND METHODS

A computerized review of patients admitted to the University of Iowa Hospitals between July 1, 1966 and December 1, 1981 was done. During this time period 5,536 patients were admitted with multiple system trauma. Forty-five patients were identified with forty-six ipsilateral femoral and tibial shaft fractures. Patients were excluded if their fractures were proximal to the lesser trochanter or if they sustained an intraarticular knee or ankle fracture. These patients were not included, because the early operative fixation of these fractures has become well accepted[2,4,5,8,10,18,19,21,22,26,28,29,39,40,43,46-48,50,51,59]. Among the forty-five patients there were two early and two late deaths. Twenty-nine of the remaining patients were able to return for clinical exam and follow-up radiographs.

There was no significant difference between the group that returned and those who did not with respect to sex, age, soft tissue condition, or treatment. The male to female ratio was approximately 3:1 in both. The average age at time of injury was twenty-five and twenty-seven years respectively. The number of open vs closed fractures, method of treatment, and distribution of patients with accompanying injuries differ little. Approximately 75 per cent of the femurs in both groups were treated by traction and cast bracing as previously described[6,33,44,45]. Essentially, all the tibial fractures were treated by casting and early ambulation.[35] Sixty-two and 65 per cent of the two groups respectively experienced other injuries.

The follow-up exam included hip[27], knee, and ankle rating with attention to activities of daily living, pain, range of motion and knee stability. Radiographs included views of the entire involved lower extremity in two planes and standing AP views of both knees. From these, the final alignment of the femoral shaft and tibial articular surfaces were determined. The differences between knee cartilage shadows of the involved and uninvolved knees were measured.

RESULTS

Two major findings were noted: 1) early life threatening complications occurred more frequently among those with fractures treated for at least three weeks by closed methods, and 2) tibial malunion in recurvatum leads to loss of ankle motion and disability.

Among the forty-five patients with forty-six injured limbs, there were three treatment groups identified. Those included six limbs treated with primary IM nailing of the femur ($\leqslant$ three weeks), five treated with femoral IM nailing after malunion or nonunion had developed, and thirty-four limbs treated with traction and cast bracing. Early complications, excluding infections, occurred in ten patients. These included two deaths, five patients with pneumonia, two with thromboemboli and five with fat emboli. One death occurred during initial resuscitation and the other after two weeks of traction. Excluding the death during initial resuscitation, all the patients who experienced these early complications were among the group treated by traction and cast bracing. These patients had also experienced a proportionately higher number of pulmonary contusions and abdominal content ruptures. There were no early complications among those treated by primary femoral IM nailing.

Infection occurred infrequently. There was one femur and six tibiae that showed evidence of infection. None occurred after open treatment of a fracture; all occurred in patients with open fractures. All were treated successfully and united.

Overall, the twenty-nine patient's functional status with an average follow-up of 6.5 years (range two to fifteen years) after injury was good. The average hip, knee and ankle ratings were ninety-six, ninety-four and eighty-eight points respectively (Table 1). Seventy-nine per cent (twenty-three of twenty-nine) were working; forty-eight per cent were heavy laborers (e.g. farmers, meatcutters) and thirty-one per cent were sedentary (e.g. executives, teachers). Among the unemployed patients was one whose ratings were less than good at the hip and knee. He was a severely traumatized thirty-three year old male with a contralateral traumatic knee disarticulation, prolonged resuscitation, ipsilateral hip dislocation, subtrochanteric femoral fracture, and Grade III open tibia fracture. This lower limb injury was complicated by a femoral artery occlusion and subsequent compartment syndrome. In addition, he experienced a cardiac arrest during the primary surgical treatment, then acute tubular necrosis and pneumonia (Figs. 1, 2, 3). The remaining five unemployed patients were either retired, unskilled, or suffering the residuals of their closed cranial trauma.

FUNCTIONAL RESULTS
CLINICAL RATINGS

	HIP	KNEE	ANKLE
Average	96	94	88
Range	83 – 100	83 – 100	53 – 100

TOTAL MOTION

	Extension–flexion	Dorsi–plantar flexion	Eversion–inversion
Average	129	47	18
Range	90 – 150	0 – 90	0 – 15

Table 1
Our final clinical ratings for the hip, knee and ankle and total motion of the knees and ankles.

Seventeen patients were limited in sports activities. Two were over sixty years of age. Two had associated injuries that limited their sports activities, one a below knee amputation in the opposite extremity, and the other, closed cranial trauma. A twenty-two year old male decreased his sports activities but worked as a meatcutter moving greater than 70 kg carcasses repetitively. This man and twelve others related their sports limitations to complaints about the knee or loss of ankle range of motion.

The average knee rating was excellent. The average range of motion was 129 degrees. The knee range of motion averaged 135 degrees if the femur was internally fixed less than three weeks after the injury. The average was 132 degrees for the patients treated with traction and cast bracing. The range decreased to 113 degrees if the femur was internally fixed after the three week period, usually for impending malunion or nonunion.

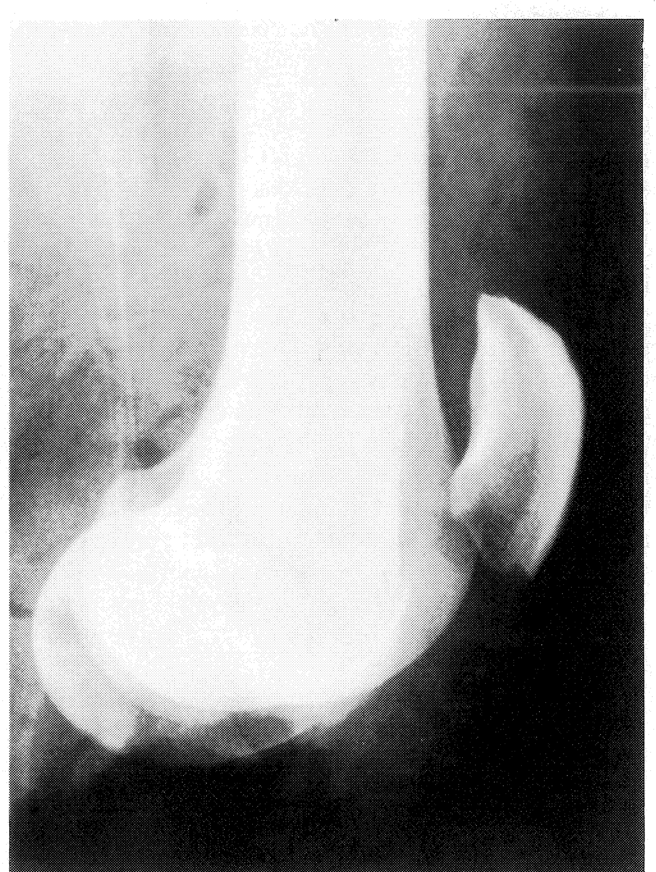

Figure 1

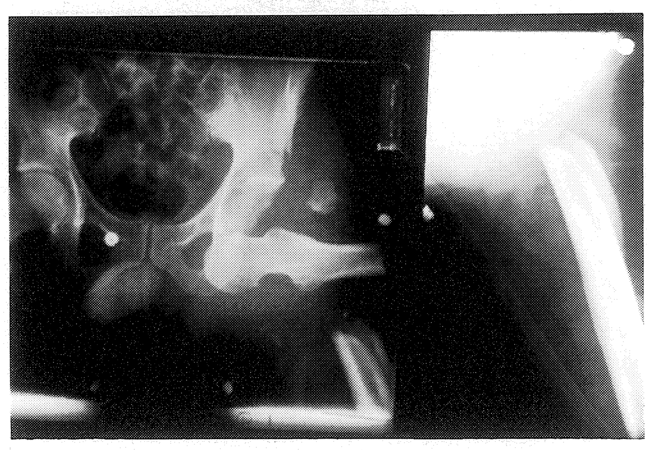

Figure 2

Figure 3

Figure 1, 2, 3: This series of x-rays shows the severe combination of injuries with which this patient presented. Figure 1 shows the radiographic appearance of the knee disarticulation, Figure 2 the hip dislocation above a subtrochanteric fracture and Figure 3 the ipsilateral open segmental fracture of the tibia.

Differences in thigh circumferences ranged from 1 to 5 cm with an average difference of 1.1 cm between injured and uninjured thighs. There was also a 21 per cent incidence of at least Grade II (in any plane) knee instability found at the time of follow-up.

Seventeen of twenty-nine patients had symmetric medial and lateral cartilage width. The average medial loss was 0.5 mm (range: 0-2 mm) and laterally, 0.3 mm (range: 0-5 mm). Overall, the difference in knee cartilage shadow width did not correlate with decrease in knee function, sports disability or increased pain.

The average ankle functional rating was only good and six of the twenty-nine patients had ratings less than eighty points. The greatest loss of points was due to decrease in range of motion of the tibiotalar and subtalar joints. Eleven of the seventeen patients who stated they had limited their sports activities had limited ankle range of motion. The average of the entire group was 47 degrees total dorsiflexion-plantar flexion and 18 degrees total inversion-eversion. Among the eleven who had limited their sports activities, the average were 32 and 11 degrees respectively. In addition, there is a statistically significant correlation ($P = 0.03$) between tibial malalignment in the sagittal plane and loss of range of motion. An increase of posterior angulation correlated with a decrease in ankle range of motion (Fig. 4). The x-rays in Figure 5 show tibial malalignment of one of these patients. His ankle range of motion was from 5 degrees of dorsiflexion to 50 degrees of plantar flexion. There was no subtalar motion.

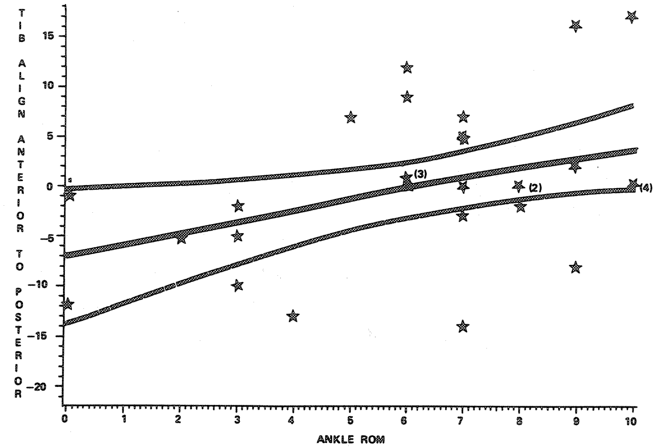

Figure 4
Relation between the alignment of the tibia following healing and the ankle motion of the same side. On the vertical scale, positive numbers are degrees of anterior angulation while negative numbers are degrees of posterior angulation. On the horizontal scale the numbers zero through ten are values assigned to ankle range of motion by our rating system, with zero meaning no motion and ten, full motion. The solid line is the line of best fit by regression analysis.

The average alignment of the femur was 3 degrees varus and 5 degrees increased anterior bow. This ranged from 21 degrees varus to 13 degrees valgus and 26 degrees posterior to 46 degrees anterior angulation (Figure 6). No correlation was found between loss of knee "cartilage space" or knee function, and femur or tibia alignment at union.

Tibial alignment averaged 1 degree varus and 0 degrees in the sagittal plane. It ranged from 12 degrees varus to 15 degrees valgus and 14 degress posterior to 17 degrees anterior angulation (Figure 7).

There was an average shortening of the thigh of 1.1 cm (range: 0-6 cm) and leg of 0.7 cm (range: 0-2.5 cm). No significant correlation was found between functional status and shortening.

There were no nonunions at the time of follow-up. The average time to weight bearing without external support on the tibia was 11.8 months overall and 12.3 months for the open fractures. The same averages for femora were 7.2 and 7.0 months respectively. Six tibiae and five femora required bone grafting. Healing time for tibiae did not vary significantly among the treatment groups. The average times to full weight bearing on the tibia was 10.7 months if the femur was treated closed and 11.4 months if it was internally fixed with ranges of two to thirty and six to twenty-four months respectively.

DISCUSSION

Accumulating experience with this combination of injuries is a slow process due to its infrequent occurrence. The retrospective nature of a study of these patients with multiple injuries compounds the difficulties of separating variables and of drawing supportable conclusions. However,

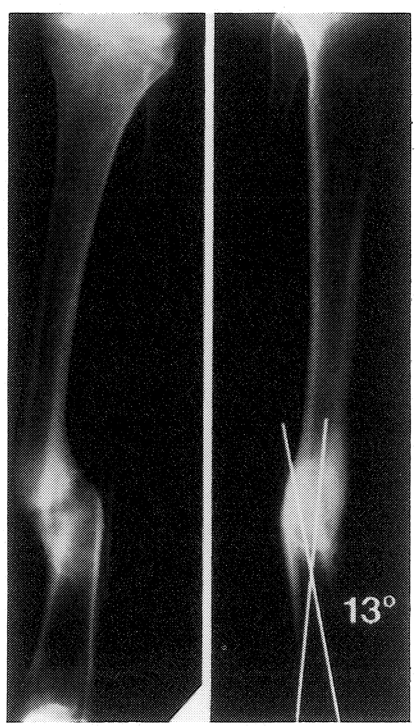

Figure 5
This is a radiographic example of one of our patients with union of his tibia in recurvatum. He also demonstrated a severe loss of ankle range of motion.

FRONTAL		FEMUR		SAGITTAL
	0	45–49	1	
	0	40–44	0	
	0	35–39	0	
	0	30–34	1	
	0	25–29	1	
VALGUS	0	20–24	3	ANTERIOR
	0	15–19	0	
	3	10–14	2	
	4	5– 9	2	
	2	1– 4	3	
	8	0	8	
	2	1– 4	2	
	4	5– 9	3	
	2	10–14	1	
	2	15–19	1	
VARUS	2	20–24	0	POSTERIOR
	0	25–29	1	
	0	30–34	0	
	0	35–39	0	
	0	40–44	0	
	0	45–49	0	

Figure 6
Range of femoral diaphyseal alignment.

FRONTAL		TIBIA		SAGITTAL
	0	45–49	0	
	0	40–44	0	
	0	35–39	0	
	0	30–34	0	
	0	25–29	0	
	0	20–24	0	
VALGUS	2	15–19	2	ANTERIOR
	0	10–14	1	
	5	5– 9	3	
	8	1– 4	2	
	4	0	10	
	5	1– 4	4	
	3	5– 9	3	
	2	10–14	4	
	0	15–19	0	
	0	20–24	0	
	0	25–29	0	
	0	30–34	0	
	0	35–39	0	POSTERIOR
VARUS	0	40–44	0	
	0	45–49	0	

Figure 7
Range of tibial diaphyseal alignment.

ever two findings were noted. First was the association between tibial malunion in recurvatum and loss of ankle range of motion. The second and more important, was the high rate of early morbidity and mortality due to fat embolism, thromboembolic phenomenon, or pneumonia.

No support was found for the hypothesis that an association exists between knee dysfunction and less than anatomic alignment at union of femoral or tibial diaphyseal fractures. Based on biomechanical studies of the knee, Hardy recommended accepting malalignment of the femur only when less than 5 degrees in the frontal plane[16]. Treating fractures of the tibia and femur with internal fixation has decreased the incidence of less than anatomic alignment at healing compared to traction and cast bracing[7,9,16,24,25,52,56]. However, there has been no long-term follow-up study that quantifies the acceptable amount of malalignment for femoral or tibial diaphyseal fractures based on functional outcome. Our patients' knee function and radiographic knee condition did not correlate with the malalignment of their tibiae or femora.

Ankle dysfunction was independent of femoral malalignment but did correlate with the presence of tibial recurvatum. The loss of ankle motion accompanying tibial diaphyseal malunion in recurvatum has not been reported before. Loss of ankle motion has been documented in several large series of tibial fractures but it most often was related by the authors to soft tissue conditions (open vs closed fractures)[24,25]. However, soft tissue conditions did not correlate with ankle motion among our twenty-nine patients. These patients appeared to have experienced an Achilles tenodesis from the combination of approximation of fracture callus and tendon and prolonged ankle immobilization. This loss of ankle motion was the physical finding most often related to sports disability.

Fraser et al. reported a 32 per cent incidence of decreased ankle motion greater than 20 degrees[9]. There were no patients reported in Veith's study[52] (in which all of the femora were internally fixed and half of the tibiae were internally or externally fixed) with this amount of ankle motion loss. But, 80 per cent of ankles in this series were immobilized for periods ranging from four weeks to three months. Karlstrom and Olerud reported that if both femur and tibia were rigidly fixed, no patients developed this amount of ankle motion loss. However, if only the femur or neither fracture was rigidly fixed, then their results were similar to ours in which fourteen per cent of the patients lost 20 degrees or more of the motion of their affected ankle[25]. DeLee reported only one of his fifteen patients had less than symmetric ankle motion in a series treated entirely by traction and cast bracing[7].

Other findings from this series that correlated with poor functional outcome coincided with previous observations made of isolated knee or femoral injuries. For example, knee instability accompanying a femur fracture was found in 21 per cent of our patients. Most of these ligament injuries were not diagnosed at first presentation, a fact previously reported[39,49,54,55]. Knee instability has also been reported in many series of ipsilateral femoral and tibial fractures[7,9,14,52]. DeLee and Grana et al. reported that this was the most common reason for their patients to have limited sports activities[7,14]. The patients seen in our study did not have either knee dysfunction or sports disability, unless the ligament instability was accompanied by thigh muscle atrophy. This has also been reported in isolated knee injuries.[3,12,31,36,37].

Overall, our patients were functioning well in activities of daily living. Only 21 per cent were unemployed and only two of those six were not working because of the affected limb. Sports disability occurred in approximately half. These were most often related to ankle motion loss, not pain, shortening, knee laxity or stiffness.

Using Karlstrom and Olerud's strict criteria for judging results, there were no excellent, five (17 per cent) good, eight (28 per cent) acceptable and sixteen (55 per cent) poor results in our series. These results are comparable to Karlstrom and Olerud's patients treated with traction and casting or nonrigid internal fixation, but much worse than those treated with rigid fixation of both fractures[25]. Veith et al. used these same criteria and found 92 per cent good or excellent results when at least the femur was internally fixed[52]. They frequently needed to use postoperative casting due to less than rigid fixation. These patients had minimal sports disability and far less residual deformity when compared to our twenty-nine patients.

The Seattle patients[52] were mobilized much earlier than the Iowa patients and the reported healing times were much shorter. Functionally (unsupported weight bearing) the patients were healed at an average of nineteen weeks. The patients whose femora were internally fixed in both studies (Iowa and Seattle), returned to usual activities more rapidly than patients in the Iowa group treated with traction and cast bracing.

The most important reason to choose an aggressive treatment combination is the accumulating evidence that the early survival of multiply injured patients with long bone fractures is higher and early complication rates are lower, if the patient's fractures are fixed adequately to allow mobilization from bed[1,3,15,23,32,42]. From our series, the lone early death in patients who survived past resuscitation occurred in a patient treated with traction and cast bracing. Karlstrom and Olerud reported a 6 per cent early mortality rate but did not state how the fractures were treated in those patients[25]. The series from Seattle in which all of the femoral fractures were stabilized, had no early deaths[52]. The rate of fat embolism and thromboemboli among the Iowa patients (11 and 4 per cent respectively) was similar to that reported by Veith et al. (13 and 6 per cent respectively), but one death was associated among the Iowa patients. This difference in survival related to fracture treatment following multiple trauma, has been confirmed in reports by Meek et al., Goris et al., and Border[1,13,15,32]. These authors showed that in groups with comparable injury severity, patients from whom long bone fractures were stabilized early experienced lower mortality rates. In a more recent report by Johnson, et al.[23] the incidence of adult respiratory distress syndrome was found to be significantly lower in those patients undergoing early operative stabilization of their fractures.

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REVISION TOTAL JOINT ARTHROPLASTY FACILITATED BY EXTRACORPOREAL SHOCK WAVE LITHOTRIPSY: A CASE REPORT

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Revision surgery for failed cemented total joint arthroplasty constitutes a major problem for today's orthopaedic surgeon[4,17]. Numerous techniques and various instruments, including fiberoptic lights, high speed drills, and special extraction tools have been developed to aid and assist the surgeon in performing this task[5,6,19]. All of these certainly help in making revision easier but do not eliminate all complications[7,13,14]. Adherence of cement at the bone-cement interface continues to impede adequate cement removal.

There remains an absolute need for better and more efficient means of extracting cement during revision surgery.

In this case report the extracorporeal shock wave lithotriptor* was used as an adjunct to facilitate the revision of the tibial component in a sixty-four year old female with a painful left total knee. The femoral component was not treated with the lithotriptor.

CASE REPORT

H.W. is a sixty-four year old female with rheumatoid arthritis who had undergone bilateral total knee arthroplasty in 1975. She had been doing extremely well until about September of 1984 when she developed progressive pain and varus deformity of her left knee. Over the next year her Iowa Knee Rating went from 75 to 54.

On physical exam, she had an antalgic gait and a 20 degree varus deformity of the left knee. Range of motion was 10 to 120 degrees of flexion. Medial pseudolaxity was severe. There was no swelling, warmth, or inflammation observed or palpated.

Her preoperative roentgenograms showed a radiolucent line around the tibial component and severe varus deformity (Fig. 1).

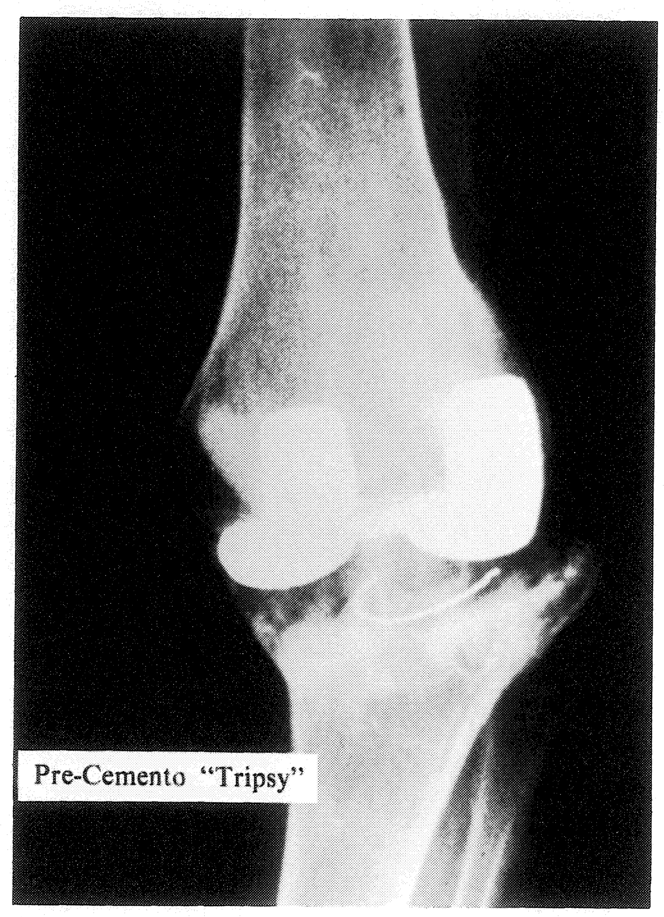

Figure 1
AP roentgenogram taken preoperatively demonstrating 20 degrees of varus and settling of the tibial component.

On September 1, 1985, the patient was admitted for revision surgery. Pertinent preadmission laboratory values were hemoglobin 10.2 gm/d1, WBC count 6,200 with normal differential count, creatinine clearance 15 ml/min, and ESR 100 mm/hour. Her RBC indices were consistent with anemia of chronic disease.

On the day of admission, the patient was brought to the lithotripsy suite in the Department of Urology where under epidural anesthesia she underwent extracorporeal shock-wave treatment. The beam was focused in two planes on the bone-cement interface around the tibial component

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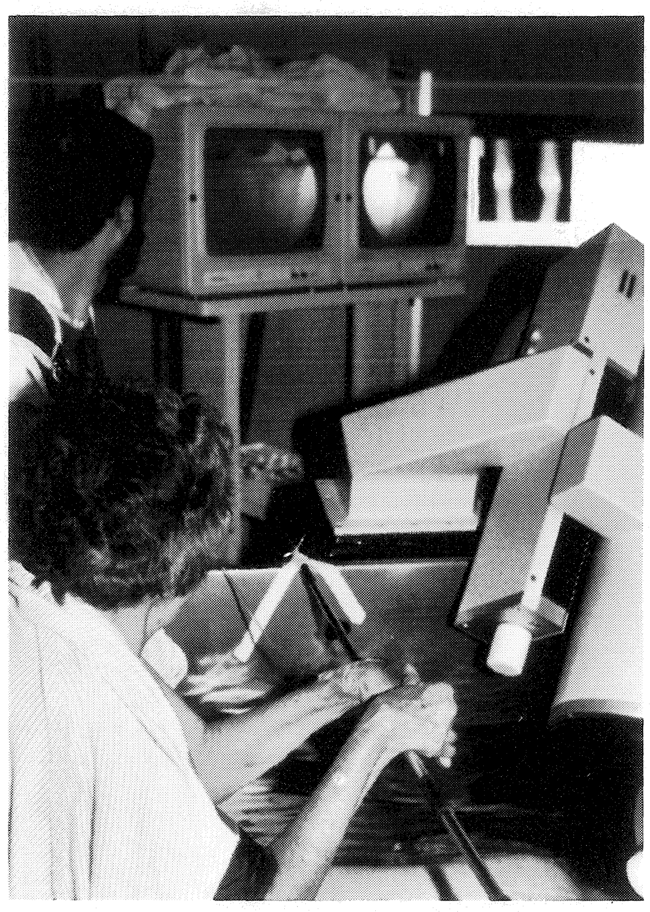

Figure 2
Patient in the lithotriptor bath with the x-ray beam being focussed in both the AP and lateral plane around the tibial component. 1,200 shocks of 20 kv each were given.

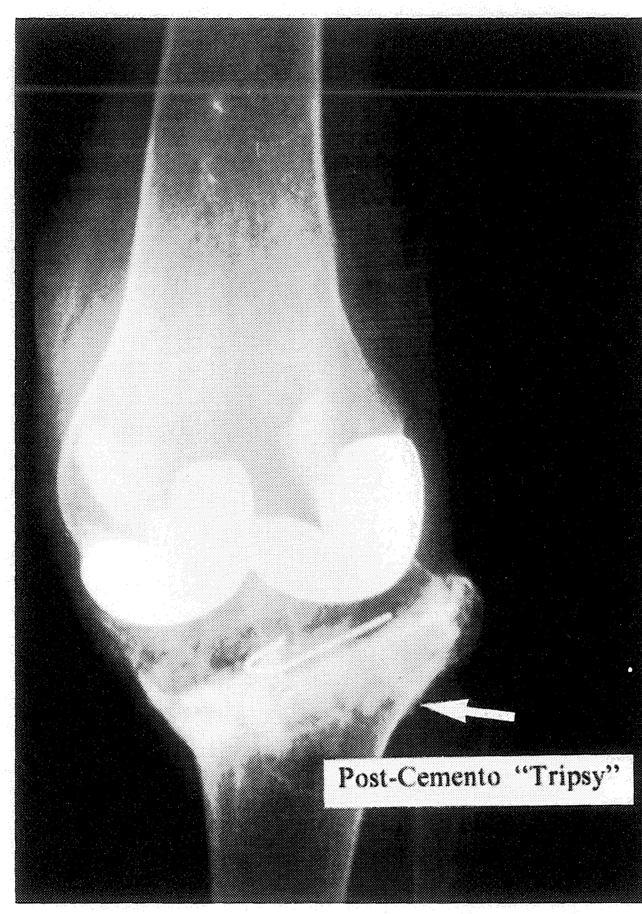

Figure 3
Post lithotripsy. AP roentgenogram demonstrating subtle widening of the tibial lucent line of the bone-cement interface as indicated by the arrow.

(Fig. 2). She received 1200 shocks of 20 kv each. Post-lithotripsy roentgenograms were obtained. These showed a subtle widening of the tibial lucent line at bone-cement interface (Fig. 3).

On the fifth day post-lithotripsy treatment, a one-stage exchange revision of the left total knee arthroplasty was performed without incident. The joint was exposed via the previous surgical incision, a median parapatellar approach. With the tibial component in view and the tibia subluxed anteriorly, the tibial component and all its cement were removed *en bloc* (Fig. 4). The femoral component was not loose and standard techniques were employed for its extraction. Intraoperative cultures were taken and remained negative at ten days.

The post-operative course was uneventful and the patient was discharged on the eleventh post-operative day. Range of motion on discharge was 5 to 95 degrees.

DISCUSSION

Modern surgery is enhanced by new technology. Surgeons today have the option of adjunct techniques which, in combination with standard procedures, increase the effectiveness of surgical intervention. Frequently, these adjuncts bring the additional advantage of lowered risks to patient health. Extracorporeal shock wave lithotripsy has been documented to be such a technique in the treatment of kidney stones[1,2,3]. Developed in Munich, Germany, this technique is now routinely used at the University of Iowa in the treatment of kidney stone disease. The use of shock-waves for destruction of kidney stones has been based on the following properties[1]:

1. Shock-waves generate mechanical stresses in brittle materials like kidney stones which exceed the strength limit of the stone.
2. Shock-waves can be transmitted freely and propagated through the body without energy loss if an appropriate transition medium, such as water, is used.
3. They do not cause damage in passing through body tissue.
4. In conjunction with suitable reflectors, shock-waves can be focused and thus brought to bear on specific areas.

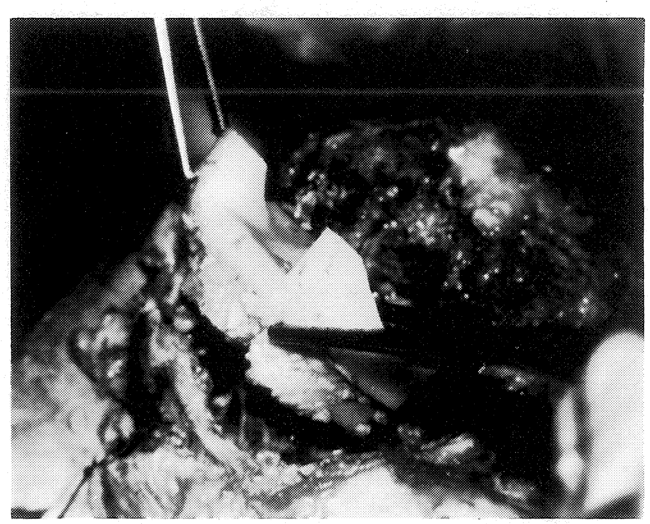

Figure 4
Tibial component removed en bloc with the cement intact.

Table I

Material (speed of sound m/s)	Acoustic Impedance (Kg/m^2s)
PMMA (1594.48)	1,881,486.4
UHMWPE (725.48)	689,206.0
Bone (365.15)	
Cortical (436.44)	6,062,175.0
Cancellous (femoral neck) (2865.23)	766,815.0
Ti_6Al_4V (4955.16)	22,248,585.0
Water/Soft Tissue (1437.00)	1,437,000.0

5. Shock-waves can be reproduced reliably for clinical use. The actual techniques of producing and focusing the shock-waves have been well established.

The impact force of a compression wave at the interface of two materials is directly proportional to the difference between the acoustic impedances of each material (acoustic impedance = density × speed of sound in the material of interest). When a shock wave reaches an interface between two materials with differing acoustic impedances, a high pressure load is established. Where the pressure amplitude exceeds the strength of the material, mechanical disruption occurs. Lithotripsy is based on this principle. The speed of sound in several of the materials of interest in total joint surgery were calculated [Speed of sound = (modulus of elasticity/density)$^{1/2}$]. These values were then used to calculate acoustic impedances (Table I)[8,9,11,12,15].

The acoustic impedance of soft tissue is close enough to that of water so that the soft tissue/water interface could be neglected. The difference in impedance across cancellous bone is about 2.45 times less than PMMA, while the impedance of cortical bone is 3.20 times greater than PMMA. It was reasoned that the significant differences in the acoustic impedances of bone and PMMA would allow for disruption of that interface.

Two significant theoretical questions immediately arose. The acoustic impedance of soft tissue and bone are significantly different, therefore what happens at this interface? Chaussy alludes to experiments done in which no damage was noted to "vital bone structure"[1]. Furthermore, no fractures (of ribs) or complications related to the skeletal system were reported in all of his animal or human investigations. We reasoned this technique could be applied safely in the region of the knee.

The second question concerns damping, or a decrease in amplitude of the pressure wave as it travels through cortical or cancellous bone. This attenuation of the pressure wave is more significant in cancellous bone than in cortical bone[8]. Fortunately, the amount of cancellous bone which must be traversed in the diaphysis of the femur or in the proximal tibia, as in this case, is limited. However, at the dominant frequency of the shock waves, the penetration depth in the radial direction in wet human cortical bone may be very limited (2-3 mm)[8,9,10]. Over such a distance, the wave intensity is reduced to approximately one-third its original value and exponentially decreases as the distance increases. In addition, this does not consider reflection of the waves from the bone surface. The attenuation of the shock wave in living bone is due to several properties: viscoelastic loss associated with the collagenous phase of bone, losses from fluid flow, and conversion of energy into slow wave motion. Theoretically, though, if only 10 per cent of the energy is transmitted it may be enough to disrupt the bone-cement interface in order to simplify the prosthetic extraction process. Thus, the conceptual framework was provided which prompted this clinical experiment.

In this case the tibial component was loose by roentgenographic criteria pre-lithotripsy. The extent of loosening was unknown. At surgery, as seen in Figure 4, the tibial prosthesis-cement composite was removed *en-bloc* without difficulty whereas the nontreated femoral component had to be removed in the routine fashion. It is certainly conceivable that the tibial component had completely loosened before the lithotripsy and we affected no change with the lithotriptor.

We are well aware that although the risks appear low and the benefits great, further experimental work needs to be done before clincial application can be justified. Several in-vitro experiments are in progress and early results are providing further encouragement to continue investigation of this potentially useful surgical adjunct. We must, however, proceed with caution in evaluating this technique.

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IMAGING TECHNIQUES FOR A SOFT TISSUE MASS IN THE EXTREMITY

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The evaluation and imaging of a *soft tissue* mass in the extremity often presents a diagnostic problem for the physician. The radiograph is accepted as the gross anatomy for bone tumors and usually delineates a lesion by virtue of increased or decreased mineralization. In fact, for bone lesions which have been well characterized relative to histology, the radiograph is frequently diagnostic. A soft tissue mass in the extremity, however, may be "invisible" or overlooked on the standard radiograph[1].

Because of the difficulty in defining a mass radiographically, the evaluating physician might elect to "observe" a lesion to determine its natural history or, conversely, proceed directly to a biopsy. Both options are potentially detrimental if a malignant lesion is allowed additional time to grow or, by contrast, is "shelled out" without proper surgical planning[2].

Two other aspects of clinical evaluation may mislead the physician regarding the seriousness of a given mass. One is the presence of a soft tissue mass observed for several years without appreciable change. A false sense of security may also be derived from the palpatory examination. Namely, a lesion which is small, superficial, mobile or cystic is often presumed benign, but in not infrequent instances is malignant.

Because of the inherent difficulties in defining a heterogenous group of soft tissue lesions in extremities, the author has developed an algorithm for their evaluation (Fig. 1).

The *history* related to the mass is recorded, including prior trauma, pain, and growth observed. A sizeable mass present only a few weeks or months is reviewed with extreme suspicion. Usually the patient presents for an evaluation because the lesion is growing, painful, or causing some limitation of extremity function.

The *physical examination* of the extremity should include observation for symmetry of parts, edema, deformity of normal contours, skin color changes, and presence of increased superficial veins. Ranges of motion of the joints

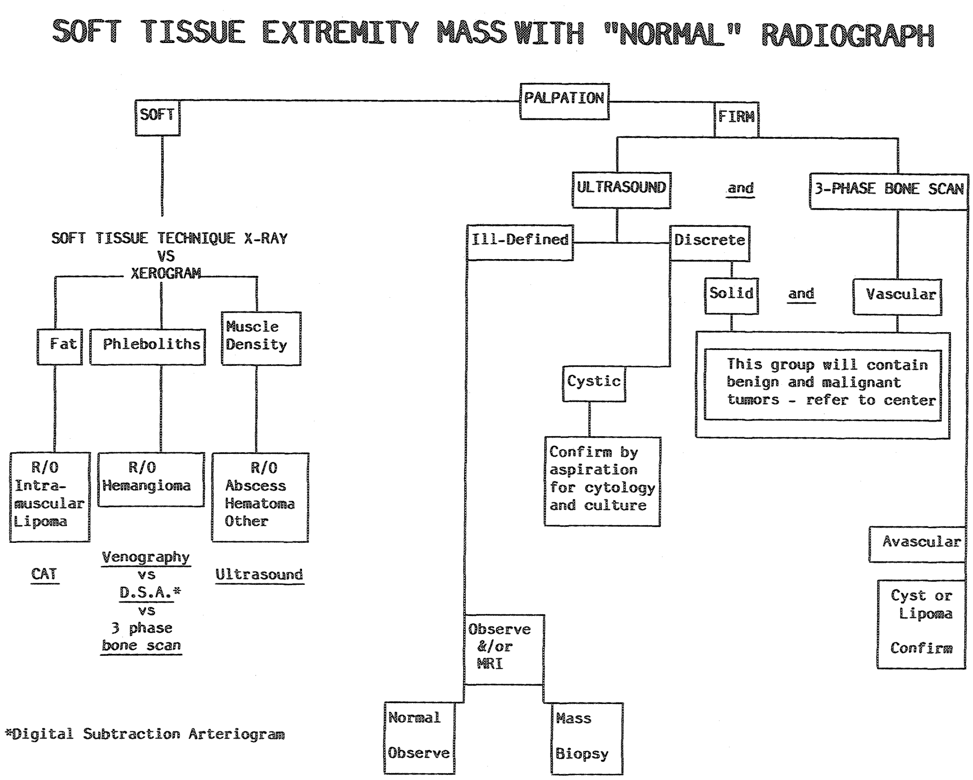

Figure 1
Algorithm for the evaluation of a soft tissue mass in the extremity.

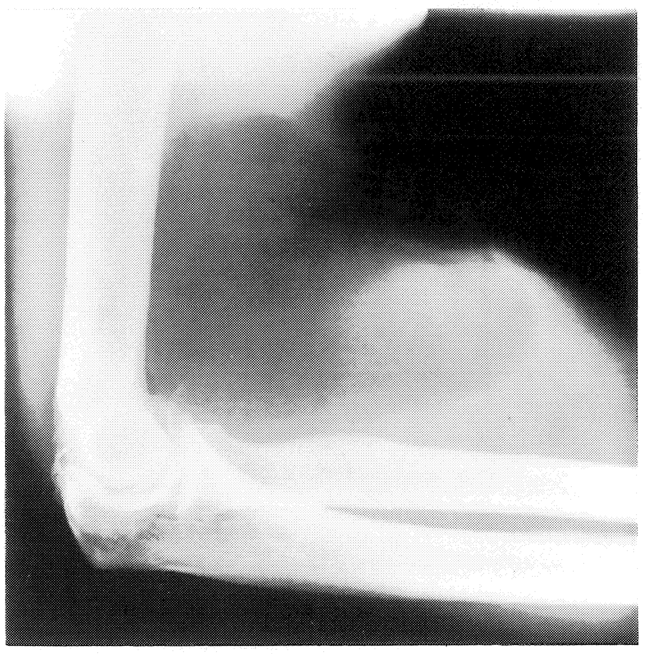

Figure 2a
Soft tissue technique radiograph of an intramuscular lipoma in the brachioradialis muscle.

Figure 2b
The bone scan flow study of the elbow region reveals a relatively hypovascular area corresponding to the soft tissue mass.

proximal and distal to the lesion are recorded. The physical examination then proceeds to include palpation of the soft tissue of the entire extremity, including compressibility and depth. I have found this tactile examination to be enhanced by the use of a lubricating jelly on the patient's skin. This "slippery skin" examination reduces friction between the examiner's fingers and the patient's skin and allows a much more accurate assessment of the mass, especially for size and boundaries. The palpatory exam usually determines the sequence of studies. For palpably large, deep but "soft" lesions such as intramuscular lipomas, a xerogram or soft tissue radiograph can be diagnostic (Fig. 2). The fat density tumor is outlined by muscle fibers and fascia. The contrasting tissue densities allow reasonable localization of these unique lesions by these techniques[3]. The CAT scan of a similar lesion (Fig. 3) is more exquisite in detail and contrast and is also helpful in the diagnosis of a benign intramuscular lipoma[4].

If on palpation, a ganglion or superficial cyst is suspected, it can be transilluminated and aspirated. The aspirate should be sent for cytology to rule out cystic degeneration of a malignancy. I have personally seen four cystic sarcomatous tumors inadvertently excised as benign cysts.

Most problem lesions are deep to muscle fascia, and are firm and relatively immobile. Unless a density different from muscle (such as fat or mineral) is present, it will not be seen radiographically except for distortion of soft tissue planes. In this instance my first choice of study following the radiograph is ultrasound. In a group of fifty previously unbiopsied patients reported on at the 1985 Iowa Orthopaedic Alumni Meeting, ultrasound was used as the primary screening study. All lesions were subsequently biopsied to allow correlation between ultrasound results and diagnostic category of benign or malignant. One major finding was that of fifteen lesions which could not be localized or

Figure 3
CAT scan of a thigh with an intramuscular lipoma within the adductor compartment. The lesion density is identical to subcutaneous tissue. A thin line of muscle fascia defines the lesion.

"found" by ultrasound, all were benign conditions such as hematoma, intramuscular hemangioma or lipoma. Within the group of thirty-five lesions which were clearly defined or demarcated by ultrasound, all fourteen malignant tumors were identified. This would suggest that "discrete" lesions by ultrasound demand further study and biopsy (Fig. 4).

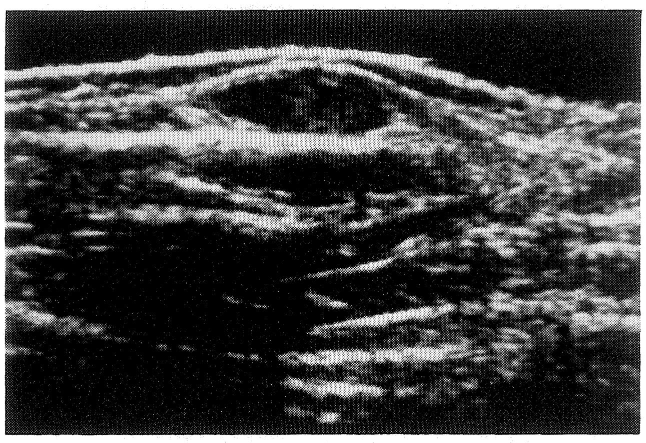

Figure 4
Ultrasound of a rhabdomyosarcoma, labeled "T" (tumor), in the anterior compartment of a three year old child. The lesion is deep to the muscle fascia and superficial to the underlying bone cortex.

Although ultrasound would hopefully distinguish between cystic and solid tumor masses consistently, this can be confused in the case of cyst containing floating debris. This may occur in an abscess with thick proteinaceous pus or a complex Baker's cyst with rice bodies. Because of the internal echoes, the lesion appears solid. Although we biopsied fourteen fluid-filled lesions, only seven were correctly identified by the radiologist as cystic because the others had internal echoes present. This does not detract from the value of ultrasound as a screening study for discrete tumors since cystic lesions may also be malignant, especially about the knee[5].

The additional advantages of ultrasound need to be stated. It is inexpensive and available in most community hospitals. Besides placing the lesion in question into one of the major groups (discrete vs. ill-defined), ultrasound gives information about size and depth relative to tissue planes[6,7]. Not the least important is the psychologic advantage to having an image of the lesion. The physician can now "see" it. It is no longer just a palpable entity but an "image".

A readily available noninvasive companion study which can yield a great deal of helpful data is the Tc99m MDP bone scan. In order to maximize information obtained after the radionuclide injection, three phases are recorded: 1) immediate images of the lesion or region of interest containing the suspect mass at five second intervals, the flow study; 2) early images at one to five minutes post injection, the blood pool image; and 3) the standard two to four hour delayed views of the bone. In some special cases increased radionuclide activity within the soft tissue mass itself may be seen, such as myositis ossificans, extraskeletal osteosarcoma, synovioma with calcification, and myxoid liposarcoma[8]. Most solid lesions with the frequent exception of lipomas will have some increased vascularity seen on either the "flow study" or early "blood pool" image. I consider these early vascular phases to be an important addition to standard delayed "skeletal" images. The information from radionuclide studies supplements the ultrasound by providing a biologic perspective, namely the vascularity of a mass in question.

If a lesion is avascular or "cold" on the flow and blood pool images but discrete on ultrasound, a cyst or ganglion could be the explanation. On the other hand, a relatively vascular lesion by radionuclide techniques which is not seen or ill-defined by ultrasound may represent an intramuscular hemangioma.

The important skeletal phase of the bone scan requires emphasis. The physical relationship of bone to an overlying soft tissue tumor (important in surgical planning) can be assessed by bone scan[9,10]. This information should be considered as biologic activity since the scan reflects the bone's response to the tumor.

By the time these screening studies are completed, one should have a fairly strong sense of whether an extremity lesion is potentially malignant. Any solid or "discrete" mass which is vascular on Tc99m Methylene Diphosphonate flow study must be considered potentially malignant and optimally would be referred to a center with a surgeon or oncologist experienced at further evaluation of tumors.

If the lesion is suspected of being malignant, the biopsy is performed so as not to jeopardize the opportunity to do a radical resection later. A fine needle biopsy with a TruCut (Travenol) disposable needle has not detracted from subsequent localizing studies such as CAT scan, MRI or arteriograms. If a needle biopsy is done, the biopsy tract is placed in a site that will not compromise the intended resection and which can be included in the specimen for the pathologist.

The biopsy, based on pre-op studies, becomes the key to successfully planned surgery rather than the lock which closes the door on limb salvage surgery. Open biopsy incisions can indeed be treacherous[11]. When possible, they should be longitudinal and at the distal pole of the lesion. Hemostasis and wound drainage will minimize hematoma contamination of tissue planes by tumor cells. Accepted techniques in tumor surgery, along with preoperative adjuvant therapies, allow limb salvage in well over 50 per cent of the patients seen with malignant soft tissue neoplasms[12]. Poorly planned biopsy sites, attempted debulking of large lesions, and large postoperative hematomas are all detrimental to the best possible care for patients with extremity sarcomas. Frozen sections are routinely done in our institution to be certain that fresh viable tumor tissue and not reactive muscle or necrotic tumor are available for study. If EM or cultures are indicated based on the frozen section, they can be obtained as well.

In summary, although frustrating to image by plain radiographs, soft tissue lesions can be adequately evaluated by commonly available techniques such as ultrasound and triple phase bone scan. This noninvasive work-up on an outpatient basis can quickly determine the urgency of biopsy and definitive care.

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PIGMENTED VILLONODULAR SYNOVITIS INVOLVING THE WRIST
A CASE REPORT

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Pigmented villonodular synovitis is a benign lesion which may be located in joints, tendon sheaths, or bursae. The most common sites are the knee and fingers. These account for about 75 percent of cases. Other joints of the extremities have been reported, but with a lower incidence. A review of the medical literature reveals that pigmented villonodular synovitis of the wrist with involvement of the carpal bones is rare[8].

The purpose of this report is to describe a case of this unusual entity, comment on the surgical approach and provide a review of the literature.

CASE REPORT

A forty-two year old right hand dominant female presented with a four year history of a lobulated dorsal left wrist mass. She underwent an excisional biopsy and limited dorsal synovectomy two years prior to presentation. A diagnosis of pigmented villonodular synovitis of the wrist was confirmed histologically. One year later, she had recrudescence of the pigmented villonodular synovitis and presented with vague wrist discomfort primarily with the extremes of wrist flexion and extension. Decreased left wrist motion began to interfere with her daily activities.

Physical examination revealed a prominent, firm, nontender, nodular 3 cm x 3 cm soft tissue mass on the dorsal aspect of the left wrist (Fig. 1). Local inflammation and fluctuance were absent. Fullness was noted on the volar aspect of the wrist, particularly on the radial side. Phalen's test and Tinel's sign were negative. Wrist motion was: 45 degrees dorsiflexion, 40 degrees palmer flexion, 25 degrees ulnar deviation, and 20 degrees radial deviation. Forearm pronation and supination were both 80 degrees. Extrinsic and intrinsic function were normal. Allen's test was negative but with slow radial artery refill; ulnar artery refill was brisk and complete. Two point discrimination was 4 mm in all digits.

Figure 1
Preoperative photograph demonstrating the nodular soft tissue mass on the dorsal aspect of the left wrist.

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Left wrist roentgenographs revealed marked soft tissue swelling on the dorsal aspect in the area of the ulnar and radial styloid processes. Erosion and cystic rarefaction of the scaphoid, trapezium, and capitate were present. The radiocarpal and intercarpal joint spaces were not narrowed. Normal mineralization was present in the carpal bones (Fig. 2).

Figure 2
Anterior-posterior roentgenogram of the left wrist with marked soft tissue swelling in the area of the ulnar and radial styloid processes, normal mineralization, and normal joint spaces.

Computerized tomography demonstrated multiple soft tissue masses involving the radiocarpal joint with dorsal and volar extension. The carpal bones were slightly indistinct with osteolytic changes in the dorsal aspect of the scaphoid, trapezium, trapezoid, and capitate (Fig. 3).

A dorsal and volar approach to the wrist was utilized attempting to incorporate the previous curved incisions.

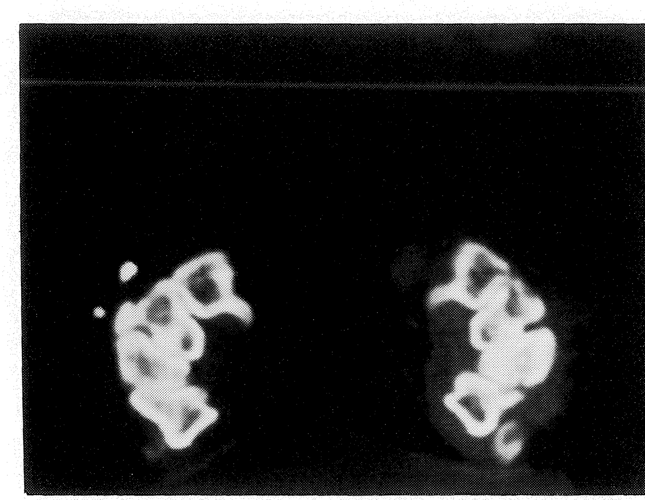

Figure 3
CT scan of the left wrist with the soft tissue mass surrounding the carpal bones and osteolytic changes in the scaphoid, trapezium, trapezoid and capitate.

A brownish-yellow, firm, solid, nodular, encapsulated, villous mass was encountered at the level of the extensor retinaculum with extension approximately 2 cm beyond the palpable margins of the tumor (Fig. 4). The extensor tendons were not involved. With further dissection through

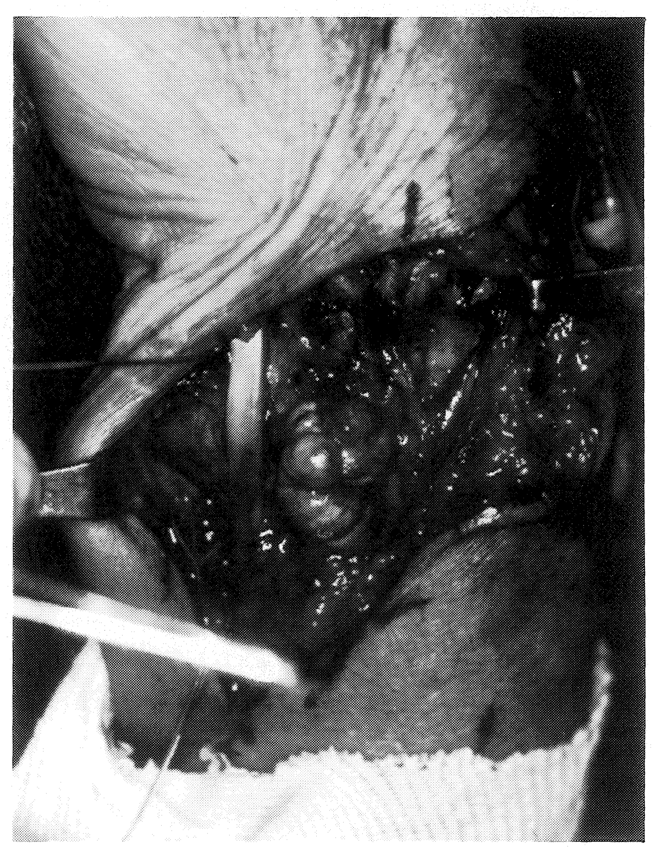

Figure 4
Dorsal surface of the left wrist depicting the nodularity of the pigmented villonodular synovitis originating from the wrist joint.

the dorsal wrist capsule, the lesions were noted to originate from the wrist joint. As the mass was followed, a lobular tumefaction was found surrounding the carpus and penetrating into the scaphoid, trapezium, trapezoid, and capitate from which it was curetted (Fig. 5). No evidence of extension into the carpal canal was noted. Histologic examination demonstrated a villous proliferation of synovial cells premeated by cleft-like spaces (Fig. 6A), lipid-laden histocytes, hemosiderin pigment (Fig. 6b), and multinucleated giant cells (Fig. 6c).

Figure 5
Dorsal surface of the left wrist after the mass was removed from the intercarpal joints.

DISCUSSION

Jaffe, Lichtenstein, and Sutro coined the term pigmented villonodular synovitis in 1941[3,6]. They identified its characteristics and relationship to other pathologic states. The synovial or diffuse form is most commonly located in the knee with a slightly smaller incidence in other joints of the lower extremity. Rarely is the upper limb involved. The tenosynovial or nodular form is very common in the hand.

Pigmented villonodular synovitis involving the wrist joint is an unusual lesion. Eighteen cases have been reported

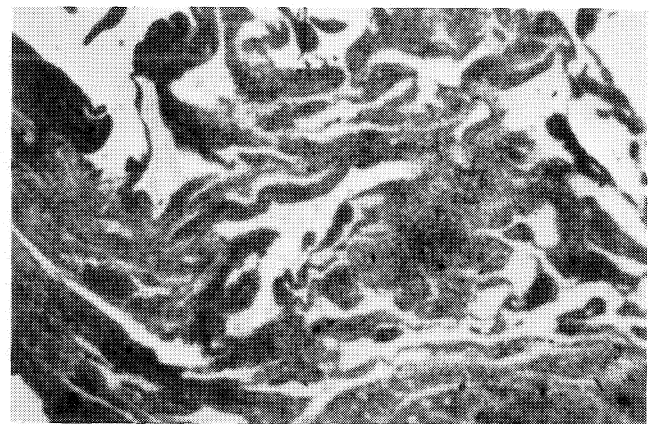

Figure 6a
Photomicrograph demonstrating a villous proliferation of synovial cells permeated by cleft-like spaces.

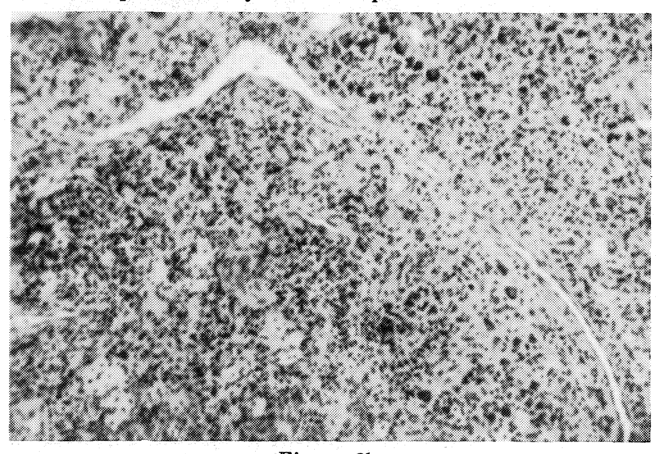

Figure 6b
Photomicrograph demonstrating an abundance of hemosiderin pigment.

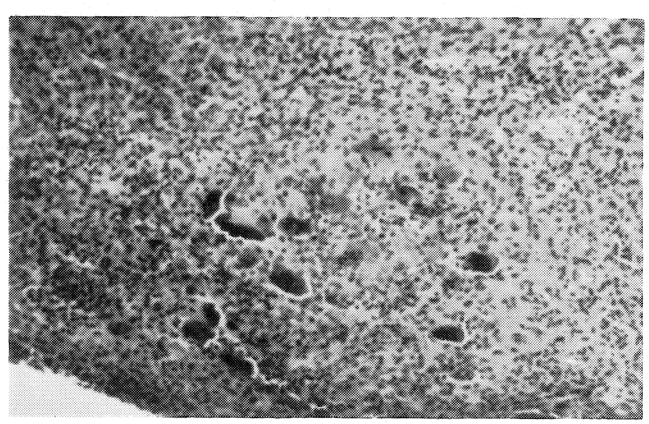

Figure 6c
Photomicrograph depicting the multinucleated giant cells.

in the English literature. Lewis[9], Patel and Zinberg[8], Schajowicz and Blumenfeld[9], Moynagh[5], Breimer and Freiberger [1] and Pandey[7] each described one case. In a series of 118 cases reviewed by Jones, Soule, and Coventry[4], four were located in the wrist. Nilsonne and Moberger[6], reported two cases involving the carpus in a series of twenty-nine lesions. Smith and Pugh[10] discussed four cases while Byers, et al.[2], reported two involved the carpus.

Invasion and erosion of bone in the nodular form is common in circumscribed lesions involving the tendon sheaths. In the diffuse form, bone and intra-articular involvement is much less common [1,9]. Intra-osseous extension of the articular form occurs through the articular cartilage and cortex at the chondro-osseous junction[5,7]. Excessive pressure from the synovial overgrowth may be responsible for the bony lesions with articular cartilage and cortical bone erosion as well as cystic degeneration in the cancellous bone. These osseous changes are reflected in a characteristic radiographic appearance [1,2,10]: 1) well-circumscribed cortical erosions with sclerotic margins and irregular articular surfaces, 2) cystic changes in the carpus, 3) lobular tumefaction surrounding the carpal bones, 4) normal mineralization despite extensive wrist involvement, and 5) absence of calcification in the synovial swelling.

The incidence of pigmented villonodular synovitis involving joints other than the knee and hip is too small to indicate specific principles of clinical diagnosis[6]. Therefore, the diagnosis is usually made at surgical exploration.

Most authorities agree that nodular lesions of the upper extremity should be treated by local excision, despite the reported recurrence rate of 8 per cent of 48 per cent [2]. Radiotherapy has been utilized both alone and in combination with synovectomy. Satisfactory long term results have been reported even if the disease has not been completely eradicated[2]. The incidence of recurrence may be decreased if a complete dorsal and volar wrist synovectomy is performed at the initial surgical procedure, which may have been beneficial in our patient.

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COMPLICATIONS IN BUNION SURGERY

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Some common and routine orthopaedic procedures can end with major complications. This paper will present two such complications of bunion surgery.

Case #1

A twenty-five year old female had a seven year history of right foot pain because of hallux valgus deformity and difficulty in shoeing. A corrective metatarsal osteotomy was performed. Postoperatively the patient experienced great pain, swelling and erythema. Because of continued pain she eventually sought another opinion. On physical examination she had full plantar flexion at the first MP joint of the great toe, but had no dorsiflexion with marked pain on any range of motion. She appeared to have good circulation and had no sensory deficit in the toe. X-rays of the foot (Fig. 1) showed that the osteotomy had healed well but there had been secondary aseptic necrosis with collapse and deformity of the first metatarsal head. A Keller bunionectomy was done to decompress the deformed joint. This gave her excellent relief of the pain in the first MP joint and did relieve the deformity. She eventually developed pain beneath the second metatarsal head, for which she uses insoles.

Case #2

A fifty-two year old female had a Silver type bunionectomy of the right foot in November 1975. Because of failure to correct deformity and continuation of symptoms, in February 1976, she had an osteotomy of the first metatarsal with pin fixation. The pin was removed two months later. She had continuing pain in the medial side of her right foot and over the first metatarsophalangeal joint. After several years of impaired function and continued pain she sought a second opinion. There was marked point

Figure 1
Avascular necrosis with collapse and deformity of metatarsal head-osteotomy healed.

tenderness in the region of the first MP joint of the right foot and over the distal metatarsal shaft. The operative incision was well healed and there was no evidence of infection. The great toe was in varus and there was an increased space between the first and second toes. The foot was neurologically intact. Varus and valgus stress x-rays showed nonunion of the metatarsal osteotomy (Fig. 2,3). There was little or no motion in the MP joint itself, with all of the apparent motion of the great toe at the osteotomy site. As a salvage procedure a Mayo type bunionectomy was done with removal of the head and neck of the first metatarsal. This restored full range of motion to the first MP joint and put her toe in a position of anatomic alignment. She did have pain beneath the second and third metatarsal heads which was treated successfully with extra-depth shoes and a metatarsal wedge.

DISCUSSION

Dr. Arthur Steindler recognized early that simple surgical procedures have the greatest chance of success and the least complications[5]. Over one hundred variations of

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Figure 2
Nonunion metatarsal osteotomy — 62 degree deformity with valgus stress.

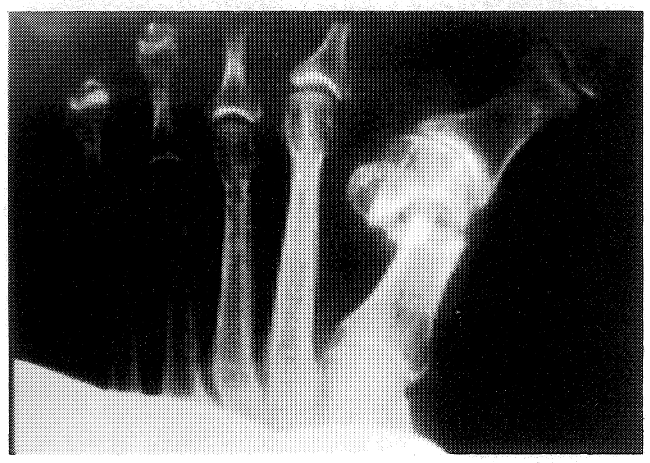

Figure 3
Nonunion metatarsal osteotomy — 17 degree deformity with varus stress.

surgical procedures have been described for correction of hallux valgus and bunions. Dr. Steindler relied on three different procedures. The first is a Silver procedure. This involves excision of the median eminence and reefing of the medial soft tissues. The second is the McBride procedure which does the same things but adds release of the adductor brevis from the base of the proximal phalanx and implantation of this tendon into the neck of the first metatarsal. The third is a Keller procedure which is a combination of the Silver procedure plus excision of the base of the proximal phalanx of the great toe. Generations of Iowa residents have learned and applied these techniques.

Metatarsal osteotomy in its various forms is another technique that has been tried. This procedure is based on the premise that metatarsus primus varus is the underlying pathology of bunions and that this must be corrected to prevent recurrence. Osteotomy can indeed give very satisfying cosmetic and functional results as shown by Mitchell[3], Carr[1], and Shapiro and Heller[4], but it does introduce multiple further possible complications. Among these are nonunion, malunion and aseptic necrosis. This paper presents two such complications. In his original paper, Mitchell had a 3 per cent incidence of avascular necrosis and 1 per cent incidence of nonunion in a series of 100 patients[3]. Jahss has reported up to 17 per cent incidence of avascular necrosis when lateral capsular release is performed at the time of bunionectomy[2]. Malunion or dorsal displacement of the distal fragment can lead to metatarsalgia laterally secondary to abnormal weight distribution. The Mitchell osteotomy can cause the same results because of actual shortening of the first metatarsal. A remedy for this is, of course, to cause some plantar angulation of the distal fragment during healing but this is not always accomplished.

Jahss suggests modifying Mitchell's original operation in four major ways to reduce the complications.

1. In order to avoid excessive shortening of the first metatarsal a biplane osteotomy without actual removal of bone can be done.
2. Crossed wire fixation is used for six weeks postoperatively in order to give the necessary stability while bony healing occurs.
3. The displacement of the distal fragment of the metatarsal at time of osteotomy should be less than one-third the diameter of the shaft to help insure healing and give the maximum stability.
4. *Do not* perform an adductor release — this further soft tissue stripping of the metatarsal head and neck may be sufficient to devascularize it.

With the above modifications in the proper hands, good and excellent results have been reported with metatarsal osteotomy. To the inexperienced operator any of these complications can be devastating and may necessitate later salvage operations which may still leave marked impairment of function.

CONCLUSIONS

The very fact that there are over 100 described operations for bunions is a good indication that there is no one procedure that is satisfactory for all problems. Many of these described operations are variations on one another and don't deserve mention beyond that.

Metatarsal osteotomy, while it appears to be an attractive procedure, does have a higher incidence of complications than do other types of bunion procedures. In Dr. Steindler's practice the emphasis was always on getting the best possible results with the least complications. His often quoted maxim that, "operative interference is but one event in the care of an orthopaedic problem", remains true today.

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