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IOWA ORTHOPAEDIC JOURNAL

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Any article relevant to orthopaedic surgery, orthopaedic science and the teaching of either will be considered for publication. Articles will be enthusiastically received from alumni, visitors to the department, members of the Iowa Orthopaedic Society, residents and friends of the University of Iowa Department of Orthopaedics. We request that all illustrations be 5 x 7 inch black and white glossy prints for reproduction purposes. The journal will be published annually in April or May. The deadline for receipt of articles for the 1983 journal is February 1, 1983.

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The Iowa Orthopaedic Journal



This journal has as its primary purpose education. Those who participate in the production of each volume will undoubtedly learn the most. The challenges of such a task include in part, the critical and constructive review of articles, organization and editing of the journal, and the production and distribution of the "final product." The residents in the department have been given the opportunity and responsibility to participate in and accomplish these goals.

We intend to publish one volume annually and hope that this journal will reflect the activity of residents, alumni, visitors to our department, and, to some extent, the faculty. This journal should be the vehicle for the dissemination of thought. As such, we will include historical and "philosophic" articles as well as scientific and general review articles. This will provide a forum somewhat different from most periodicals now extant.

We thank the entire faculty for their help, and in particular, Drs. Pontarelli, Clark, and Cooper for providing the strong enthusiasm to initiate this endeavor. The clerical and secretarial staff have worked unselfishly to aid us and we thank them. We thank Mr. Dale Clark and Mrs. Sandra Bredman for contributing their administrative skills. We appreciate the cooperation of the authors and also the advertisers, who provided the necessary financial support. Our departmental creative ventures, such as this journal, are facilitated by outstanding administrative support from University Hospitals and Clinics, the College of Medicine, and the University of Iowa.

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

The editors

CARROLL B. LARSON A MAN FOR ALL PEOPLE

John J. Callaghan, M.D.*

"He was a quiet man with a sense of the personal dignity needed in the approach to problems not lending themselves to easy solutions. He listened; he constructively counseled without intrusion of his own concepts on those who sought his counsel or assistance. Perhaps this is the greatest gift that a man can give to his patients, his friends, his students, and his family—to present help in a manner which is acceptable to them. This he could do without rancor, without dominating, and without demeaning an idea no matter how frivolous it might have been. He gave assistance willingly and worried lest the recipient feel beholden to him. He appreciated and acknowledged success in others and worked so that many of his students and his colleagues might receive recognition for their efforts."

Reginald Cooper and Michael Bonfiglio
J.B.J.S., Vol. 61, Jan., 1979.

In publishing the second Iowa Orthopaedic Journal, we honor Carroll B. Larson. Only such a man could fill the shoes of his predecessor, Dr. Arthur Steindler. As the second chairman of the Department of Orthopaedics at the University of Iowa, he took a nationally and internationally recognized department and directed its growth into a teaching, research and service facility which was unsurpassed in this country. He helped train no less than six future chairmen of medical college orthopaedic departments (Cooper, Kettelkamp, Laros, Jacobs, McBeath and Murray) and countless other private and academic practitioners of orthopaedic medicine. He performed administrative tasks for the Department, the American Academy of Orthopaedic Surgeons, the Shriners Hospitals, and the community at large. He established a stable, renowned faculty, including Bonfiglio, Cooper, Ponseti, and Flatt. During his tenure, the Department produced three Kappa Delta Award winners and prepared the foundation for two future recipients. He developed the Department into an exemplary teaching and research model.

Carroll B. Larson was born September 10, 1909 in Council Bluffs, Iowa. His father, Charles Bernard, and



Dr. Larson in later years.

mother, Ida Caroline, owned a hardware store in the small town of Kiron. During his high school days, he pursued athletic as well as scholarly endeavors, earned awards in pole vaulting as well as in academics. He attended the University of Iowa from 1927 to 1933, obtaining his B.S. in 1931 and his M.D. in 1933. As an undergraduate, in addition to his studies, he joined the ROTC program and one year became the outstanding cadet in the Pershing Rifles (the ROTC honor fraternity). He was active in the Phi Beta Pi medical fraternity, an organization he supported even in later years.

From Iowa, he ventured to San Jose, California where he was an intern and resident in surgery at Santa Clara County Hospital between 1933 and 1936. Here he met Nadine West Townsend, a native midwesterner (via Missouri and Illinois), and married her on November 17, 1934. During the 1936-1937 academic year, Dr. Larson divided his time between Army duty in

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Duluth, Minnesota and working locum tenens for physicians in Indianola and Ida Grove. Next he moved to Boston where he did an Orthopaedic Residency at the Harvard Post-Graduate School from 1937 to 1939. He trained at both the Boston Children's Hospital and at the Massachusetts General Hospital.



Figure 2. Massachusetts General Hospital in the 1940's.

It was here that he met Marius Nygaard Smith-Peterson, a fellow Scandanavian by ancestry, a man he tried to emulate. The Harvard Orthopaedic program was well established in 1939 (Figure 2). In 1917 as an intern at the Massachusetts General Hospital, "Smith-Pete" had conceived the anterior supra-articular subperiosteal approach to the hip, being disturbed by the frequent shock occurring after hip surgery when he used other approaches. In 1931, Smith-Peterson introduced the three flanged nail for internal fixation of femoral neck fractures after observing the poor results of external fixation. Between 1937 and 1939, after working on the concept for twenty years, Smith-Peterson and Nathaniel Allison developed the vitallium cup arthroplasty. During these years and the decade to

follow, Dr. Smith-Pete and his two new assistants in private practice, Carroll Larson and Otto Aufranc, designed the instruments and techniques to perfect this operation. A quote referring to Smith-Peterson could very well have been applied to his assistant, Carroll Larson: "Uppermost in my mind is the personal magnetism that emanated from the grand old man. This magnetism had far-reaching effects, even down to influencing the results of his arthroplasties and to making those people around him work out their heart and soul for him without any direct demand on his part. This quality, it seems to me, is one he may have been born with, perhaps, but nonetheless possessed, and had no small part in his ultimate greatness."

Dr. Larson remained an associate of Dr. Smith-Peterson from 1939 to 1950. He was certified by the American Board of Orthopaedic Surgery in 1942 and became a member of the Academy in 1943. During World War II he was assigned by the Office of Procurement and Assignment as a full time teacher in the Department of Orthopaedic Surgery, Harvard Medical School. He supervised undergraduate and graduate teaching of orthopaedic surgery at Massachusetts General during those four years and directed a continuing Trauma Course for Armed Forces Medical Officers. In 1948, after assisting Smith-Peterson in the back surgery of Princess Martha of Oslo, Norway, he received the title of Royal Commander of the Order of St. Olaf, an honor he often mentioned (Figure 3). A year earlier, he and Smith-Peterson traveled to Norway to

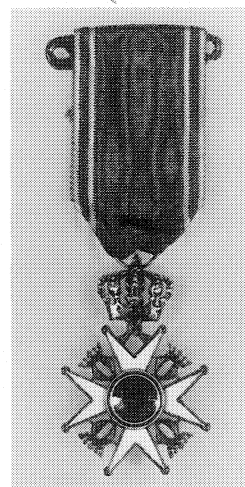


Figure 3. Royal Commander Order of St. Olaf of Norway Medallion.

perform cup arthroplasties on some pre-selected difficult hip problems. Also in 1948, the American Orthopaedic Association selected Carroll Larson to be in the first group of American, British, and Canadian Traveling Fellows. This group included William Bickel, John Fahey, Verne Inman, Donald Blanche, Lee Ram-

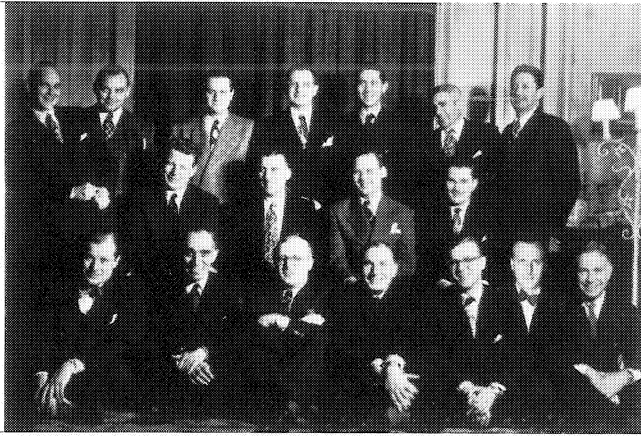


Figure 4. The first group of American, British, and Canadian Orthopaedic Association Traveling Fellows. Dr. Larson is in the top row third from the right.

say Straub, John Hamilton Allan, Hugh Smith, Benjamin Fowler and Benjamin Oblatz (Figure 4).

The ambition of his lifetime became a reality for Dr. Larson in 1950 when he became Chairman of the Department of Orthopaedics at his alma mater, the University of Iowa. Dr. Steindler had left a foundation for a strong orthopaedic department. Three energetic attending physicians, Dr. Ponseti, Dr. Bonfiglio, and Dr. Newman, constituted the faculty in 1950. Dr. Ponseti had started his biochemistry experiments and Dr. Bonfiglio had acquired the Pathology Laboratory and responsibilities from Dr. Ponseti. From this foundation, Dr. Larson, using his "democratic approach," developed a program that not only stayed abreast of the rapid growth of orthopaedic knowledge during the 1950's, 1960's and early 1970's, but one which also contributed to many of the advances. He introduced the cup arthroplasty to his fellow staff and residents and stressed the need for quantitation of results, particularly with respect to function. His visions for quantitating function were strengthened by the addition of the Upper Extremity Biomechanics Laboratory of Dr. Flatt in the 1950's and later the Lower Extremity Laboratory started by Drs. Johnston and Kettelkamp in the 1960's and continued today by Drs. Brand and Crowninshield. Dr. Larson encouraged Dr. Cooper in the pursuit of electron microscopy and helped arrange for him to spend a year at Johns Hopkins with Dr. Robert A. Robinson. He arranged a similar opportunity for Dr. Johnston to tour centers in Europe and America and learn current surgical techniques for the hip. During his tenure, the National Institutes of Health Research Training Award was obtained to encourage young researchers to study important musculoskeletal problems.

Dr. Larson had three areas of particular clinical expertise; the hip, the back and the foot. He will be

remembered for his writings on the hip. During his twenty-three years as Chairman, he authored three classic papers which are frequently quoted and referenced. In the Iowa Orthopaedic Department tradition, he realized "that end-result evaluations are the only means available by which we can pinpoint the worth of any operative procedures and advance to refinements in our choice between procedures." With this in mind, he published his "Rating Scale for Hip Disabilities" (Clinical Orthopaedics, Vol. 31). He devised a 100 point system which included points for freedom from pain, function, gait, freedom from deformity, and motion. The scale, better known as the Iowa Hip Rating, remains a standard in evaluating hip procedure results. In his two clinical follow-up classics "Fracture Dislocations of the Hip" (Clinical Orthopaedics, Vol. 92) and "Results of Treatment of Hip Disorders with Cup Arthroplasty" (with Johnston, J.B.J.S., 51A, No. 8) he applied his critical evaluating skills. Dr. Larson's speed at performing the cup arthroplasty could not be surpassed. In his follow-up he reported doing one procedure in 30 minutes! It was a procedure always dear to him. Throughout his life, he wore a ring made of vitallium given to him by the company that manufactured "the cup."

Dr. Larson was interested in the back even before Smith-Peterson, Aufranc, and he wrote the classic paper "Osteotomy of the Spine for Correction of Flexion Deformity in Rheumatoid Arthritis" (J.B.J.S., Vol. 20, No. 1). However, because of the demands for cup arthroplasty, it was not until his return to Iowa that this became a major pursuit. Not only through the clinics and surgery, but also as Director of the Division of Rehabilitation (1955-1973) and Director of the School of Occupational Therapy, he studied the problems of back pain. A tribute to his interest and expertise in low back pain came in 1977 when the first major federally funded grant to study low back pain was awarded to Dr. Larson and Dr. Rim (Instructor in the Engineering College).

As Dr. Ponseti reiterated, Dr. Larson was "very concerned about the painful, severely deformed, degenerative and rheumatoid foot." I would imagine he had the same "hot line" to the brace shop and the prosthetics company to deal with these problems as do Dr. Ponseti and Dr. Cooper today.

In addition to his duties as Chairman at Iowa, he unselfishly served the American Academy of Orthopaedic Surgeons. He was Treasurer for five years, Chairman of the Committee on Teaching Aids, Chairman of the Committee on Graduate Education, member of the Executive Committee and in 1967 served as President of the Academy (Figure 5). He was instrumental in starting the "critical incidence study," which



Figure 5. Receiving Presidential medallion, American Academy of Orthopaedic Surgeons Meeting 1967.

established a professional definition for Academy members. In his presidential speech "The Big Look at Orthopaedic Surgery—1967," he expounded on the need for the orthopaedic teaching staff to "provide service, teaching and research in proper proportion." In the future when increased numbers of orthopaedic programs would be necessary to fill society's needs, he claimed it essential, for "the protection of the public against irresponsible and unqualified practitioners," that all members be concerned with the "academic" aspects of orthopaedic surgery.

Dr. Flatt recalls Dr. Larson's commitment to the examining process of the American Board of Orthopaedic Surgery. In the early 1960's when Dr. Flatt was establishing the Hand Service at the University into one of the most academic in the country, he was interested in certification by the American Board of Orthopaedic Surgeons. However, there was a clause in the charter that disallowed foreign-trained orthopaedists to sit for the examination. Every year before the Committee on Examinations would meet, Dr. Flatt would lobby, first for the Board to give him an honorary certification and second "if it must be," to take the test. Every year Dr. Larson would return from the meeting and tell Dr. Flatt that he voted against giving him the honorary certification. Standing by his principles, as always, he told Dr. Flatt he believed one must "earn" certification. Twelve years later, with help from Dr. Larson, the clause con-

cerning foreign trained orthopaedists was changed. Dr. Flatt, with much "grooming" by the Department in preparation, passed the exam.

Dr. Larson's deep concern for the patient was displayed by his commitment to the Shriners Hospitals (Figure 6). He was a member of the Shriners Medical Advisory Board from 1957 to 1966, Executive Medical



Figure 6. The Shriners Hospitals Dr. Larson served.

Advisor from 1966 to 1968 and Director of Medical Affairs from 1968 to 1976. In 1968 he was granted a one year leave of absence from the University to "direct a study of all 24 Shriners Hospitals in three nations and to recommend operational guidelines which would make the units more useful in the future." For his years of service, the Shriners funded a Lectureship in Dr. Larson's name. Already, two most eminent pediatric orthopaedists, Dr. Wood Lovell and Dr. Sherman Coleman, both chief surgeons of Shriners Hospitals, have been the honored lecturers. Another, Dr. Richard Cruess, will give the lecture this year. The words of Dr. Coleman surely proclaim the feelings of the entire organization. "He was an imaginative, trusted leader and organizer, always fair and always able to fill in the voids."

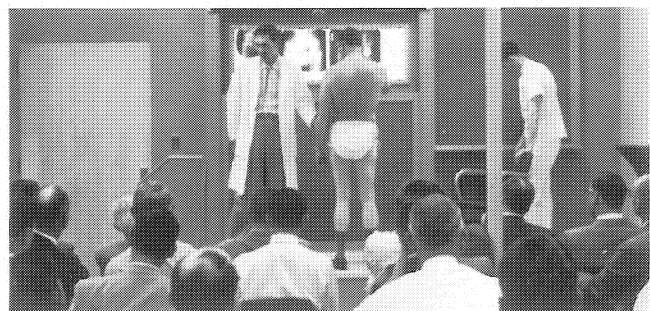


Figure 7. Presenting patients at Children's Hospital.

Dr. Larson had the same commitment to nursing as he did to the patient. He stated in his and Marjorie Gould's *Orthopaedic Nursing, 8th Edition* that "as orthopaedic surgery advances with new operative concepts, such as total joint replacement and new methodology in the study of bone metabolism, orthopaedic nurses must understand these concepts if they are to assume responsibility for patient nursing care and assist in the management of musculoskeletal problems." He and Marjorie Gould remained committed to the education of the orthopaedic nurse, constantly revising their book to keep the nurse practitioner current with the ever expanding field.



Figure 8. Discussing patients at the M.G.H. during his trip as Visiting Professor in 1968.

In addition to his other accomplishments, Dr. Larson served as an Associate Editor of the *New England Journal of Medicine*, as a member of the Editorial Board of *The Journal of Bone and Joint Surgery* and as a Trustee of the Journal. He was also on the Advisory Council of the Iowa State Industrial Commission. Dr. Larson was a member of the American Orthopaedic Association and was to give the Shands Lecture at the Association's Annual Meeting the year of his death.

Dr. Larson's life extended far beyond the hospital. He and Mrs. Larson raised three sons and one daughter. He was an excellent furniture maker. Along with two other physicians, he developed this skill at informal classes given by Mr. George West between the hours of 10 P.M. and 2 A.M. during his years in Boston. After moving to Iowa and establishing a homestead, at the time on the outskirts of town, his hobby was dabbling in farming. He was a member and then Chairman of the Board of Directors of Hawkeye State Bank and was also an active Rotarian.

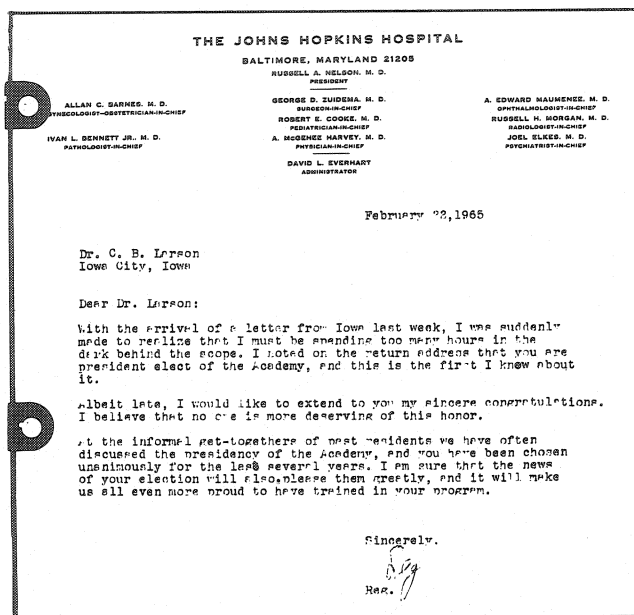


Figure 9. A congratulatory letter from a former resident upon his election as President of the American Academy of Orthopaedic Surgeons.

He influenced every resident he trained. He was always willing to listen, whether in the surgery lounge at Children's Hospital over a cup of coffee or at a field clinic or Christmas party over a martini. He expected all to be as sympathetic and empathetic to patients as he. He believed that he "could teach anyone to do surgery,

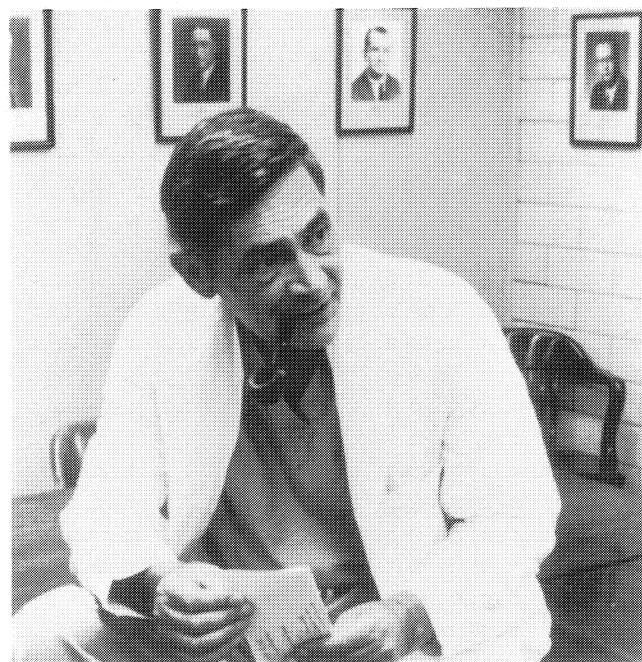


Figure 10. Dr. Larson taking a break between cases.



Figure 11. Dr. Larson at one of the resident and staff parties.

but that the important thing was to learn to deal with people." An endowment, in his memory along with that of Dr. Willis, will this year support a fellowship in the Department. This was always his wish.

Dr. Carroll Larson influenced his peers, students, nurses and patients. Every one of us can tell a story of a patient coming to clinic and expounding on an occasion when Dr. Larson treated him or her. Dr. David Boyer, in a 1978 letter, captured the feelings of Dr. Larson's students and peers. "While I was a resident at Iowa, you represented to me a calm and stable force with a maturity greater than seen in most men. I think you improved on a tradition of greatness at the Iowa program because of your confidence, ability, and a basic belief in yourself. This allowed you to be secure enough to let others beneath you grow. This quality which allowed the Iowa program to grow also touched many lives. Personally, in my growing relationships with my colleagues

and even more importantly with my family and children, I often search and hope for the maturity you displayed in dealing with other people. This was a strength about you that allowed those of us associated with you to grow to our greatest potentials. While all of our lives are finite, it is a rare individual like yourself that can have an impact on others to the point your values and strengths are perpetuated. For a portion of those strengths in my life, I am grateful to you and hope in turn I can pass them on to others." He always pushed for others to achieve and by doing so felt self achievement. He will always be remembered as a "gentle man," a man for all people.

(This review of Dr. Larson's life was made possible from the help of the following people: Mrs. Nadine Larson, Ignacio Ponseti, Sherman Coleman, Reginald Cooper, Richard Johnston, Adrian Flatt, and Richard Jacobs.)

“PHYSICIAN” OR “DOCTOR”: SOCIETY AND FAILED EXPECTATIONS

Richard A. Brand, M.D.*

The English word “physician” has its roots in the Greek word *φυσικός*—natural or pertaining to nature.³ (The term “physic,” in the sense of a drug, especially a laxative from herbs, derives from the same word.) The teaching of the healing arts in ancient Greece was carried out by the “natural” philosophers (*οι φυσικοί*) who speculated on the origin and existence of things, in contrast to other philosophers who speculated on moral or political questions. The word physician came into English usage through Old French and Middle English (*fisicien*).² Its use suggested one who practiced natural healing arts, i.e., with the use of herbs and natural substances.

The word “doctor” has its roots in the Latin verb “*docere*”—to teach (and its past participle “*doctus*”). (“*Doctrine*” is a related word since it was the thing that was taught.) The term “doctor” was applied by the Middle Ages universities to certain individuals who obtained an advanced degree (“*Masters*”) and who were teachers.³ Most European universities applied the term to teachers in many disciplines; although the English universities restricted the use to those in the faculties of law, medicine, and divinity. In the past few centuries the title doctor became commonly applied to those in the medical profession (whether they formally taught or not) but not to those in other disciplines. However, the degree continued to be conferred on those in other professions. The reasons for this are not entirely clear, but may be related to the fact that the medical “doctors” went out among the people (in contrast to academicians who remained relatively cloistered) and thus had public visibility.

Interestingly, the public primarily uses the word “doctor.” The medical profession, on the other hand, tends to refer to its members as physicians. (An unscientific survey of recent articles from the *Journal of the American Medical Association* and the *New England Journal of Medicine* demonstrated the use of the term physician two to three times more often than doctor.) The reasons for the differing preferences of the public and medical profession remain speculative.

The reason may simply be that the public uses the simpler (two-syllable) term, while the medical profession, selects the more difficult and “more professional” (three-syllable) term;¹ or perhaps those in the medical profession want to be distinguished from other doctors (e.g., PhDs). The question of differing usage may be of more than etymological significance. “Physicians” (practitioners of the healing arts) in our society do not generally consider themselves “doctors” (teachers).

In a past era of an illiterate, uneducated public, and a technologically unsophisticated healing arts profession, society probably expected relatively little of the healer. The healers offered more hope than realized expectations. The public is now educated and the medical profession is technically more sophisticated. Yet the gap between what society expects and what it gets increases. (One only need consider the dramatic rise in malpractice suits in recent years to document the increase in failed expectations). Who is responsible for the gap and what is to be done about it?

I submit that the “physician” (healers) must accept a fair share of responsibility for the gap. Physicians have abrogated their roles as “doctors” (teachers) and failed to educate patients (the public) about their problems, including the goals and likely outcome of treatment. To the extent that the individual physician fails to educate his or her patient, the patient may be dissatisfied or expect more benefit than is actually realized. (A physician seeing thirty or forty or more patients per day may not be spending much time in educating patients. The dissatisfaction or expectations will lead to more visits either with the initial physician or with a second or third. In the long run, physician time, patient time, and society’s resources will likely be conserved by spending time at the outset to educate the patient about his or her problem, including the likely outcome and the goals of treatment.

Some may argue that efficiency and the demands of many patient-requested visits precludes spending the time to educate the patient. I would argue that educated patients would request and need fewer visits, that patients would be more satisfied, and that physicians would ultimately save time. To the extent that physicians as a group do not educate the public about the

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capabilities *and* limitations of contemporary medicine, society will have unrealistic expectations of the health care system and will be dissatisfied with it. A combination of rapid, rather amazing technological advances in many areas and rapid dissemination of information (sometimes incorrect) about those advances creates an environment in which society's expectations are high, often unrealistically so. ("If we can send a man to the moon, why can't you cure my back pain?"). If "physicians" are not "doctors," both with individual patients and with society, the gap between expectations and services actually rendered will only increase.

It seems apparent to me that some of society's dissatisfactions with the health care system could be solved by changing the perception of those who provide that care: "physicians" should think of themselves as "doctors" and alter their approach to patients as these

words imply. The medical profession should increase its efforts to educate the public about the capabilities *and* limitations of modern medicine. A satisfied patient and a satisfied society along with maintenance of quality care should be our goal.

References

¹Crichton, Michael: Medical obfuscation: structure and function. *New England Journal of Medicine* 293:1257-1259, 1975.

²Oxford English Dictionary, Oxford University Press, New York, 1971.

³Skinner, Henry Alan: *The origin of medical terms*. Hafner Publishing Company, New York, 1970.

AN EARLY HISTORY OF LOWER LIMB AMPUTATIONS AND PROSTHESES

Kim R. Sellegren, M.D.*†

The first amputation was performed sometime far back in prehistory, likely by someone pressed into service before medicine was even an established craft. We have evidence of Neolithic amputations of fingers, indicated by outlines of hands drawn on cave walls in France and Spain. These have been dated to about 5000 B.C.⁴ Many of these amputations were probably ritualistic, but other possible reasons include trauma, frostbite, leprosy, and Raynaud's phenomenon. Many skeletal remains have been found in different areas of the world with amputated hands and arms. In the Middle East, the most common reason for amputation was punishment for crimes. Because of this, some patients refused amputation for medical reasons because it would identify them with criminals. Those who lost limbs to frostbite often carried certificates stating the reason for their loss of limb.⁴

Many early peoples did not practice amputation, even to save a life, because they believed that to amputate meant to deprive the person of the extremity both in this life and the next. Most preferred to die with the diseased limb intact, particularly the lower extremity. Amputations of hands were sometimes done as a means of verifying numbers of prisoners taken in battle.⁴ However, amputation of a foot or leg was less frequent since it rendered the captive unfit to work. Lower limb amputation remained a severe form of punishment, or for dire medical emergency.⁴ In Peru, amputated feet date from about 300 B.C. onward.⁴ Herodotus, in his *History*, written in 484 B.C., tells of a Persian soldier, Hegesistratus, captured by the enemy, imprisoned in the stocks, and encased by his foot. He escaped by cutting off part of his foot, and replaced it later with a wooden prosthesis.¹⁸ A mosaic from the Cathedral of Lescar, France, probably from the Gallo-Roman era, depicts an amputee supported by a wooden pylon (Figure 1). A fragment of an ancient vase unearthed near Paris in 1862 shows an amputee whose limb has been replaced by a pylon with a forked end (Figure 2).¹⁸ Peruvian figurines from the first and second centuries A.D. depict amputees, with



Figure 1. Mosaic from Gallo Roman era from Cathedral of Lescar, France. (Reprinted from Atlas of Limb Prosthetics, C.V. Mosby, 1980).

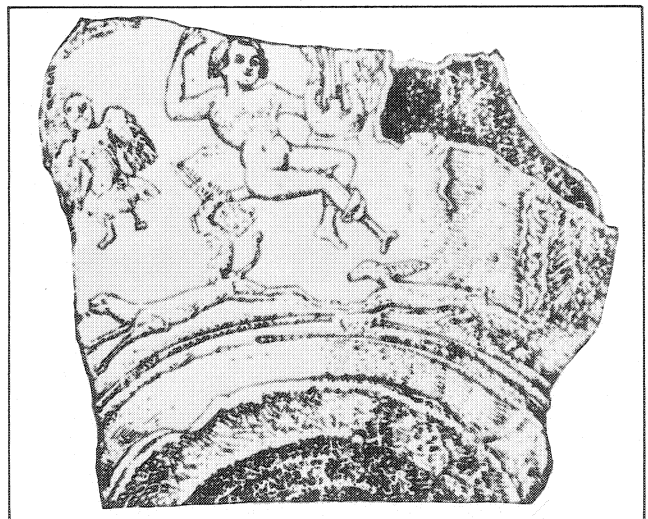


Figure 2. Fragment of vase showing amputee with pylon. (Reprinted from Atlas of Limb Prosthetics, C.V. Mosby, 1980).

one figure from about 50 B.C. showing the amputee placing a crude cup-like prosthesis on his stump (Figure 3).

The oldest recovered prosthesis, found in a tomb in Capua in 1858, dated from the Samnite wars in 300 B.C. It was made of copper and wood, and was unfor-

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Figure 3. Peruvian figurine depicting amputee with cup-like prosthesis. (Reprinted from Bulletin of Prosthetics Research, Spring, 1972).

tunately lost during World War II when an air attack destroyed the museum of the Royal College of Surgeons.¹⁸ In the middle ages, prostheses of iron were made by armorers for knights who had lost limbs in battle. Many knights refused to battle with these limbs, but the limbs were so heavy that they probably were of little use to someone not on horseback. An example of a sixteenth century lower limb prosthesis (Figure 4), was almost certainly not intended for walking because of the equinus of the foot, the short thigh



Figure 4. Sixteenth century lower limb prosthesis. (Reprinted from Historic Artificial Limbs, Paul B. Hoeber, Inc., 1930).

piece, and the two horizontal straps which would not have provided sufficient suspension. The knee does not extend fully, thus it was almost surely restricted to use while sitting in the saddle. Due to the fenestrations in the leg, this limb weighed only a little over three pounds.¹³ Another prosthesis, made in the seventeenth century, was probably made for a congenital deformity rather than an amputation (Figure 5). This is an Italian leg with a wooden foot and iron leg-pieces,

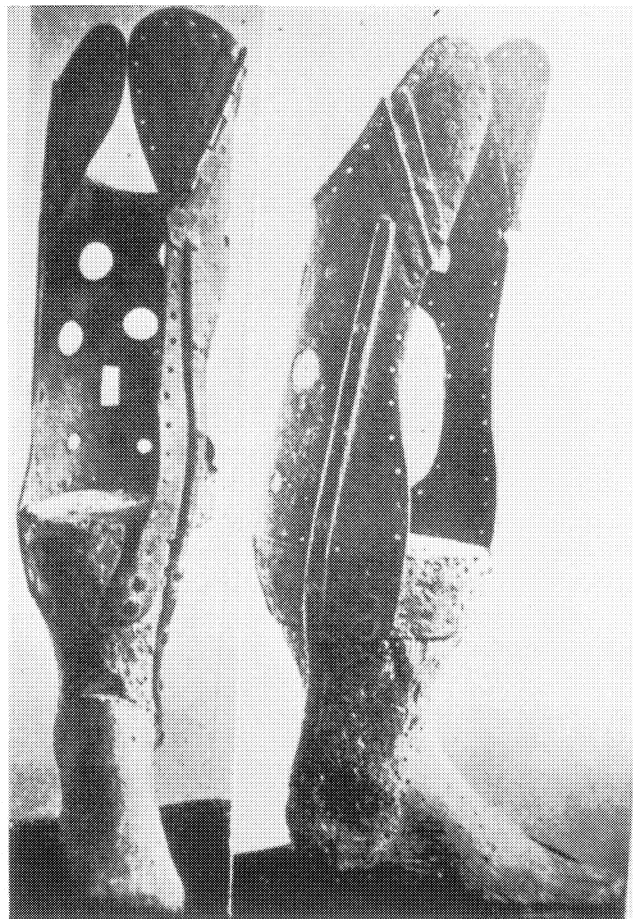


Figure 5. Seventeenth century lower limb prosthesis, probably made for a congenital deformity. (Reprinted from Historic Artificial Limbs, Paul B. Hoeber, Inc., 1930).

again perforated to save weight, and reinforced with two metal side-bars. The prosthesis, widest at its mid-point, contained a large oval opening at one side. Vittorio Putti, from whose 1930 book this photograph came, surmised that the prosthesis was most likely built for a man with a limb length inequality and a supinated, adducted foot, which could project through the medial hole.¹³ The nature of the amputation process itself constituted one of the major impediments to the development of a good walking prosthesis. The pro-

cedure was usually done without anesthesia or control of bleeding. In Europe, anesthetic techniques included alcohol or opium, and the natives of South America chewed cocoa leaves and alkali, releasing cocaine.⁴ Even so, the procedure had to be done quickly, and almost always by guillotine fashion, as described by surgeons from Hippocrates onward. Hippocrates described the use of ligatures, but this practice disappeared, and surgeons throughout the Dark Ages stopped bleeding by boiling oil or by crushing the stump. Obviously none of these techniques left the ideal stump for a prosthesis. The “styptics” used to control bleeding included vitriol, alum, and turpentine. Most surgeons now feel that these agents only stop bleeding from small vessels which would seal spontaneously, but the use of styptics remained common until 200 years ago. In the 1670’s, vitriol was allegedly used to stop bleeding in all amputations at the Hotel-Dieu, the oldest and largest hospital in Paris, although some surgeons preferred the ligature of Pare.¹⁷ One surgeon of the day, Rabel, so strongly believed in a special styptic, “vulnerary water,” that he claimed it could prevent any wounded soldier from bleeding to death. He finally persuaded Louis XIV’s minister of war to allow him to do a public demonstration. Before an assembled throng of physicians and surgeons at the Hôtel des Invalides, he amputated through the thigh of a soldier (presumably one who needed an amputation, although this is not specifically stated). Despite Rabel’s frantic, repeated applications of his styptic and fresh bandages, the soldier bled to death in full view of the crowd. In the late eighteenth century, John Hunter of England still called oil of turpentine “the best, if not the only true styptic.” Richard Wiseman, another British military surgeon of the seventeenth century also used oil of turpentine, but stated that the army surgeon “in the heat of the fight” would find cautery more effective.¹⁷

The use of cautery, a term used to describe any red-hot metal instrument, dates from the beginnings of surgery and continued well into the twentieth century. An ancient medical saying proclaimed: “Those diseases which medicine does not cure, iron cures; those which iron does not cure, fire cures; those which fire cannot cure are to be reckoned incurable.”¹⁷ Figure 6 shows several shapes of cauteries from the sixteenth century, along with a burner for heating them. Cautery was used as a hemostatic and anti-putrefactive agent, or a sort of early form of debridement. Paul of Aegina in the seventh century, the Arab physicians Albucasis in the tenth century and Avicenna in the eleventh century advocated cautery. In his book, “On Surgery and Instruments,” Albucasis praised the use of the “actual” cautery, meaning a red hot iron, as opposed to “poten-

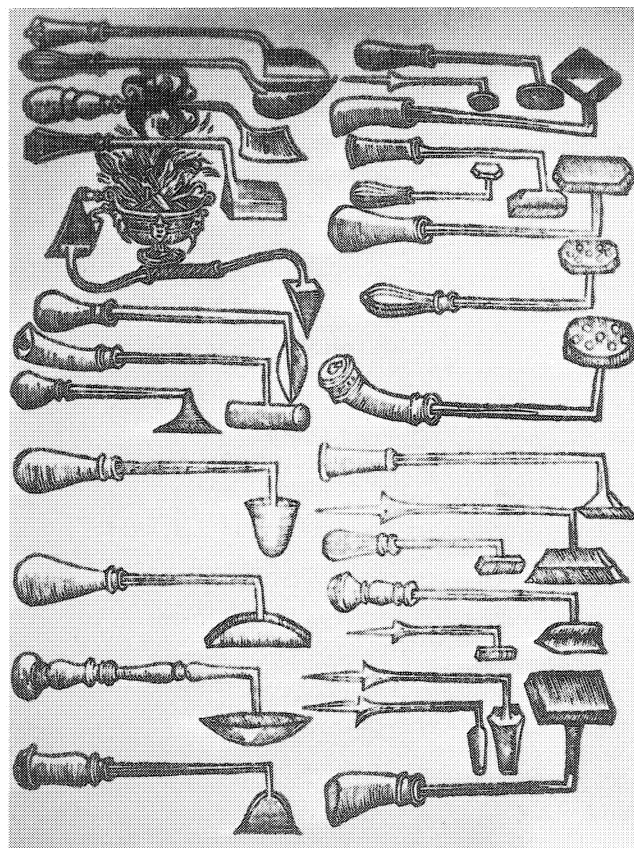


Figure 6. Cauteries and burner for heating. (Reprinted from Ambroise Paré and His Times, The Knickerbocker Press, 1897).

tial” cauteries, such as caustics. Caustics could spread beyond the desired area, whereas, “fire, on account of the nobility of its nature, has no such effect unless it is overdone.”¹⁷ Albucasis used cautery for debridement of infection as well as for hemostasis in fresh wounds. He preferred an iron cautery, although gold, bronze, and other metals were also in use. In 1600, a German surgeon, Fabricius Hildanus, recommended a heavy, red

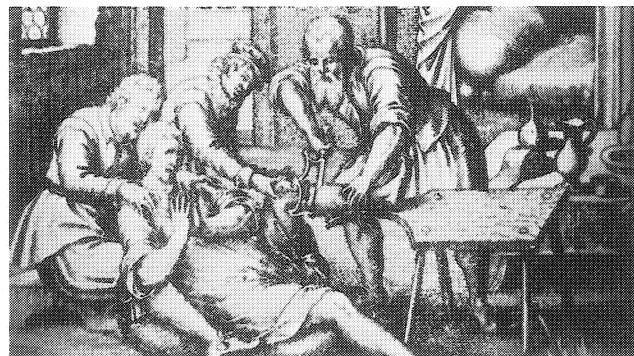


Figure 7. The German surgeon, Fabricius Hildanus, completing an amputation. (Reprinted from The Rise of Surgery: From Empiric Craft to Scientific Discipline, University of Minnesota Press, 1978).

hot knife to sever the soft tissues in amputations, thereby controlling all bleeding immediately.¹⁷ Figure 7 shows him completing an amputation. Note the firepot for heating the cautery.

This was the situation at the beginning of the career of Ambroise Paré (Figure 8). Paré, born in 1510, became one of the most renowned military surgeons of all time, and surgeon-in-chief to all the monarchs of France during the period. At least two major advancements in surgery are credited to Paré, the first being his renouncement of the use of boiling oil to treat fresh wounds. This occurred in 1537 during a campaign with the army in Turin. This passage from his "Journeys in Diverse Places," as quoted by Stephen Paget, tells of his discovery:



Figure 8. Ambroise Paré. (Reprinted from *Ambroise Paré, Surgeon of the Renaissance*, Warren H. Green, Inc., 1967).

"Now I was at this time a fresh-water soldier; I had not yet seen wounds made by gunshot at the first dressing. It is true I had read in John de Vigo, first book, *Of Wounds in General*, eighth chapter, that wounds made by firearms partake of venosity, by reason of the powder; and for their cure he bids you cauterize them with oil of elders scalding hot, mixed with a little treacle. And to make

no mistake, before I would use the said oil, knowing this was to bring great pain to the patient, I asked first before I applied it, what the other surgeons did for the first dressing; which was to put the said oil, boiling well, into the wounds, with tents and setons; wherefore I took courage to do as they did.* At last my oil ran short, and I was forced instead thereof to apply a digestive made of the yolks of eggs, oil of roses, and turpentine. In the night I would not sleep in quiet, fearing some default in not cauterising, that I should find the wounded to whom I had not used the said oil dead from the poison of their wounds; which made me rise very early to visit them, where beyond my expectation I found that those to whom I had applied my digestive medicament had but little pain, and their wounds without inflammation or swelling, having rested fairly well that night; the others to whom the boiling oil was used, I found feverish, with great pain and swelling about the edges of their wounds. Then I resolved never more to burn thus cruelly poor men with gunshot wounds.

While I was in Turin, I found a surgeon famed above all others for this treatment of gunshot wounds; into whose favour I found means to insinuate myself, to have the recipe of his balm, as he called it, wherewith he dressed gunshot wounds. And he made me pay my court to him for two years, before I could possibly draw the recipe from him. In the end, thanks to my gifts and presents, he gave it to me; which was to boil in oil of lilies, young whelps just born, and earth-worms prepared with Venetian turpentine. Then I was joyful, and my heart made glad, that I had understood his remedy, which was like that which I had obtained by chance.

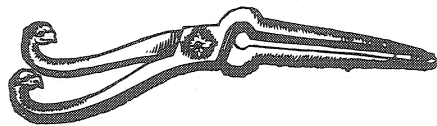
See how I learned to treat gunshot wounds; not by books."¹¹

He never again used boiling oil, but his balm included turpentine, and he continued to use both "actual" and "potential" cautery, for several more years. About fifteen years later, however, he made his second and most famous contribution, the use of the ligature for hemostasis in amputations. Ligatures were known before Paré. They had been described by Hippocrates, Celsus, Avicenna, Guy de Chauliac, de Vigo, Vesalius, Tagault, and Croce, and in Paré's time the use of the ligature in fresh wounds was not uncommon.¹⁷ Friedmann feels that the ligature was probably used by early Civilizations in South America.⁴ Certainly in Paré's hands the use of the ligature on major vessels in amputation surgery was, if not pioneered, at least championed and

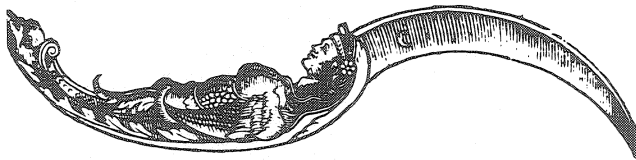
made widespread, Quoting from Paré's "Opera Omnia," as given in Paget:

"Here I confess freely and with deep regret that formerly I practised not this method but another. Remember, I had seen it done by those to whom these operations were entrusted. So soon as the limb was removed, they would use many cauteries, both actual and potential, to stop the flow of blood, a thing very horrible and cruel in the mere telling . . . And truly of six thus cruelly treated scarce two ever escaped, and even these were long ill, and the wounds thus burned were slow to heal, because the burning caused such vehement pains that they fell into fever, convulsions, and other mortal accidents; in most of them moreover, when the scar fell off, there came fresh bleeding which must again be staunched with the cauteries, which thus repeated, consumed a great quantity of flesh and other nervous parts. By which loss the bones remained long afterward bare and exposed so that, for many, healing was impossible and they had an ulcer there to the end of their lives, which prevented them from having an artificial limb. Therefore I counsel the young surgeon to leave such cruelty and inhumanity and follow my method of practice, which it pleased God to teach me, without I had ever seen it done in any case, nor read of it."

He retained the cautery in his first few amputations in case the ligatures should fail, but they did not, and he eventually gave up cautery entirely. He ligated major vessels in continuity before severing them. He would pull smaller vessels away from the wound with his Crowe's beake, the forerunner of our hemostat, and



212 Paré's crowes beake



213 Paré's ornate amputation knife

Figure 9. Surgical instruments used by Paré. (Reprinted from *The Rise of Surgery: From Empiric Craft to Scientific Discipline*, University of Minnesota Press, 1978).

then ligate them (Figure 9). Some have called Paré's contribution "the greatest improvement that has ever been made in operative surgery." Stephen Paget, one of

his biographers, said in his 1896 edition, "Prometheus, who brought fire to suffering mortals, is not to be compared with this good surgeon, who took it away from them."¹⁰ Paré's own comments on the case, however, were more modest: "I returned to Paris, with my gentleman whose leg I had cut off: I dressed him, and God cured him. I sent him home happy with a wooden leg, and he was well satisfied, saying that he had got off cheap." This was sometime between 1552, when he published a book advocating cautery, and 1564, when his next book retracted this and advised the reader never to use cautery for amputations. Paré's rediscovery of ligatures came in about 1560. The next comment on ligatures came in 1597, when Peter Lowe of Scotland said, "Where there is putrefaction, stay the flux of blood by Cauters actuals, and where there is no putrefaction, use the ligator."¹⁷ The Paris surgeon Pierre Dionis, in 1673, preferred ligatures but noted that he resorted to buttons of vitriol when ligatures failed. By 1707, Dionis declared that surgeons no longer used actual cauteries, and said that he displayed such instruments to his students "rather to excite horror with regard to their cruelty than to advise their use."¹⁷ However, fifty years later, a Montpellier surgeon claimed that surgical operations were not usually undertaken until the cautery was prepared, and in a 1754 essay for the French Royal Academy of Surgery, Guillaume Louis concluded that "Fire will always be a means of stopping hemorrhage in very urgent situations."¹⁷ Albrecht Middeldorpf in 1854 introduced a galvanocautery, and C. Pacquelin in 1876 invented an electrocautery. In 1928, Harvey Cushing and W. T. Bovie produced the surgical diathermy unit, with cutting and coagulating currents, which we call the Bovie today.¹⁷

Some have puzzled over the slow acceptance of what seems to us an obvious surgical breakthrough. However, we must remember how much slower the use of the ligature was, at a time when anesthesia and skilled help were almost non-existent. A German study in 1890 found that in above-knee amputations without cautery an average of 53 ligatures was needed.¹⁷ Many of these were on small vessels which previously would have been cauterized. Even in above-knee amputations for arteriosclerosis, the average was 25 ligatures. Furthermore, the surgeon of those years usually operated alone, with only servants to restrain the patient. Woodall used five assistants for amputating through live tissue; Dionis used six. The French military surgeon Hughes Ravaton (1768) had four aides: two to hold the patient, one to offer the patient cordials, and the fourth to pass instruments and help with the dressing.¹⁷ Skilled help to tie ligatures or hold the Crowes

beake was not easy to find. Even Jacques Guillemeau, Paré's favorite pupil, gave up the use of the ligature after Paré's death. In his book, Guillemeau states: "The leg now being extirpated . . . we must as then stoppe, and restrain the bleeding, which we must do through the imposition of the fingers on the mouths, or apertios, of the veins, which we must either bind or else cauterize, the one or the other according as the same shall be needful and requisite . . . Supposing to hold on the veins with the Crowesbill, and so to bind them, do most commonly chance to break between the Crowesbill . . . we are in the end constrained to use the actual cautery." Guillemeau also stated that if the limb to be amputated was gangrenous, hemorrhage was "far more stopped through the applications of glowing cauteries than by ligation."¹⁷ Paré did not abandon the use of cautery for debridement of dead tissue in gangrenous wounds, including the use of caustics. He seared the end of a bone following a forearm amputation "to dry up the perpetual flow of corrupt matter," and he added that the patient "was wondrously delighted by the application of such actual cauteries, a certain tickling running the whole length of the arm by reason of a gentle diffusion of the heat by applying the caustic."¹⁷

Hippocrates and Celsus advocated this, and when Leonides in the first century A.D. amputated a breast for cancer, he used the cautery for hemostasis and to dessicate all visible traces of the tumor. In the fourteenth century the French surgeons Guy de Chauliac and Henri de Mondeville used cautery to combat would sepsis, and this practice lasted well into the twentieth century. One of the scourges of the pre-antibiotic era was hospital-acquired gangrene. John Bell said in 1830 "When hospital gangrene rages in a great hospital it is like the plague. No operation dare be performed, every cure stands still, every wound becomes a sore, and every sore is apt to run into gangrene."¹⁷

Woodall, in the early 1600's, often used cautery to sear dead tissue in amputations, occasionally at the first dressing change postoperatively, and frequently at the second dressing change. He said that it was safe for patients, but because of the public's hatred of cautery, he added "I advise it to be privately absconded for the reputation's sake."¹⁷

In 1783, Ponteau of Lyons said that the best therapy for hospital gangrene was the destruction of the part "by fire," and he used the actual cautery, but he added that boiling oil or a caustic could be used, if, as he put it, "the cowardliness of the patient, or perhaps of the surgeon, prevent it."¹⁷ In 1813, when up to 500 wounded per day poured into Montpellier from Napoleon's Peninsular War, hospital gangrene became rampant. Delpech, of the surgical clinic at the University, sug-

gested that as an experiment the students should try cautery on all wounds in 150 men with infected bullet wounds from the siege at Pampeluna. To everyone's surprise, almost all the patients recovered, and Delpech eventually concluded in his monograph that no treatment had the "speed and constancy" of the cautery. Berkely Moynihan, of the Leeds school of surgeons, writing on wounds of the knee joint in World War I, said that "a preliminary sterilization of the tract with the actual cautery is an undoubted advantage." Even as late as 1935, August Bier used electrical cautery in Berlin hospitals to control infections of the hand in 230 patients.¹⁷

The use of cautery was very slow to die, even though ligatures had been proven effective, because cautery gave so much faster control of bleeding. The tourniquet represented a great boon to the use of the ligature. This certainly existed at the time of Paré. Guy de Chauliac used a tight band above and below the site of amputation to reduce pain and minimize bleeding by compressing the soft tissues against the bone. In the sixteenth century Leonardo Botallo used three bands and operated between the lower two. Fabricius tightened a band above the site of surgery by twisting it with a stick, and Johannes Scultetus of Ulm invented a screw compressor in the 1600's. In 1718, J. L. Petit devised the most



Figure 10. Tourniquet designed by J.L. Petit (Reprinted from *The Rise of Surgery*, University of Minnesota Press, 1978).

effective tourniquet (Figure 10). This instrument, tied to the abdomen, could not slip, and it put direct pressure on the major artery of the limb to be amputated, giving good hemostasis.¹⁷ This certainly made the use of ligatures much simpler.

Another important consideration to be resolved was the level of amputation. Hippocrates in his writings taught amputation through devitalized tissue rather than living to avoid the risk of hemorrhage. Celsus taught to operate above the dead tissue, and Paré revived this: "As to that which is necessary (say you), to use fire after amputations of the members, in order to consume and check the putrefaction of which is common to gangrene and to mortifications, that in truth hath no place here because the practice is to amputate always the part above that portion which is mortified and corrupted, as wrote and recommended Celsus, to perform the amputation on that which is healthy, rather than to leave any of the putrefied."⁹ Paré's teachings again were slow to be adopted. In 1639 the British surgeon John Woodall recommended operating through the upper level of dead tissue; he reasoned that this was painless for the patient, and after the amputation the surgeon could gradually whittle away at the dead tissue until it was gone.¹⁷

Another major controversy, still existent is the open versus closed treatment of amputations. Hippocrates, since he amputated through the dead tissue, left his amputation stumps open, to heal by granulation. This left a projecting segment of bone which later had to be removed by saw or rongeurs, which many of us have experienced. Hugh of Lucca, in the thirteenth century, (who founded the Bologna school), his pupil Theodoric, and Henri de Mondeville felt that all wounds, even contaminated ones, had to be closed. It was more common to close wounds than to leave them open, at least until the 1800's. French surgeons frequently closed wounds over small pieces of linen called charpies, until the advent of the antiseptic era. Dominique Larrey, Napoleon's military surgeon-in-chief of the late 1700's and early 1800's, learned in his early campaigns that primary closure of gunshot wounds produced a high complication rate, and in later years he advocated open treatment of all such wounds. Edward Alanson of Liverpool reported in 1782 a series of 35 major amputations without a death, an unusual success rate for that era. He approximated wound edges with adhesive tape, but did not close them.¹⁷ In the early 1800's, several surgeons, including Vincenz Kern in 1826 and Liston in 1841, advocated leaving a wound open for a few hours after surgery to allow it to develop a "glaze." Liston reported a mortality rate of 11.4 per cent for major amputations. This is quite good considering that in more

complicated cases, to save time (so that he could use both hands) he would hold the knife by its handle in his mouth.¹⁷

The official Union Army Manual of 1861 stated that "when the wound is extensive, as in cases of amputation, it is far preferable to leave the wound open, with a piece of wet lint, or a thin compress, interposed between the lips, for two or three hours, until the surface has become glazed." Eventually they recommended allowing the wounds to heal by granulation.¹⁷ Considering the slow acceptance of all these developments, (the use of the tourniquet, amputating through healthy tissue, the use of ligatures, and the use of delayed closure), the reader's attention is directed to a passage from Paré which is truly remarkable for its summary, in the mid 1500's, of much of what we use today:

"You shall certainly know that a Gangrene is turned into a Sphacell, or mortification, and that the part is wholly and thoroughly dead, if it looke of a blacke colour, and bee colder than stone to your touch, the cause of which coldnesse is not occasioned by the frigiditie of the aire; if there bee a great softnesse of the part, so that if you presse it with your finger it rises not againe, but retains the print of the impression. If the skinne come from the flesh lying under it; if so great and strong a smell exhale (especially in an ulcerated Sphacell) that the standers by cannot endure or suffer it; if a sanious moisture, viscide, greene or blackish flow from thense; if it bee quite destitute of sense and motion, whether it be pulled, beaten, crushed, pricked, burnt, or cut off. Here I must admonish the Young Chirurgion, that hee be not deceived concerning the losse or privation of the sense of the part.

For I know very many deceived as thus; the patients pricked on that part would say they felt much paine there. But that feeling is oft deceitfull, as that which proceeds rather from the strong apprehension of great paine which formerly reigned in the part, than from any facultie of feeling as yet remaining. A most cleare and manifest argument of this false and deceitful sense appears after the amputation of the member; for a long while after they will complaine of the part which is cut away.

Verily it is a thing wondrous, strange and prodigious, and which will scarce be credited, unlesse by such as have seene with their eyes, and heard with their eares the patients who have many moneths after the cutting away of the Legge, grievously complained that they yet felt exceeding

great paine of that Legge, so cut off. Wherefore have a special care least this hinder your intended amputation; a thing pittifull, yet absolutely necessary for to preserve the life of the patient and all the rest of his body, by cutting away of that member which hath all the signes of a Sphacell and perfect mortification; for otherwise the neglected fire will in a moment spread over all the body, and take away all hope of remedy; for thus Hippocrates wisheth; That Sections, Ustions, and Terebrations must be performed as soone as neede requires.

Where Amputation must be made.

It is not sufficient to know that Amputation is necessary; but also you must learne in what place of the dead part, it must bee done, and herein the wisdom and judgement of the Chirurgion is most apparent. Art bids to take hold of the quicke, and to cut off the member in the sound flesh; but the same art wisheth us, to preserve whole that which is sound, as much as in us lies. I will shew thee by a familiar example how thou maist carry thy selfe in these difficulties. Let us suppose that the foote is mortified even to the ankle; here you must attentively marke in what place you must cut it off. For unlesse you take hold of the quicke flesh in the amputation, or if you leave any putrefaction, you profit nothing by amputation, for it will creepe and spread over the rest of the body. It befits Physicke ordained for the preservation of mankind, to defend from the iron or instrument and all manner of injuries, that which enjoyes life and health. Wherefore you shall cut off as little of that which is sound as you possibly can; yet so that you rather cut away that which is quicke, than leave behind any thing that is perished, according to the advice of Celsus. Yet oft times the commodity of the action of the rest of the part, and as it were a certaine ornament thereof, changes this counsell. For it you take these two things into your consideration they will induce you in this propounded case and example, to cut off the Legge some five fingers breadth under the knee. For so the patient may more fitly use the rest of his Legge and with lesse trouble, that is, he may the better go on a wooden Legge; for otherwise, if according to the common rules of Art, you cut it off close to that which is perished the patient will be forced with trouble to use three Legges instead of two.

For I so knew Captaine Francis Clerke, when as his foote was stricken off with an iron bullet shot

forth of a man of warre, and afterwards recovered and healed up, hee was much troubled and wearied with the heavy and unprofitable burden of the rest of his Legge, wherefore though whole and sound he caused the rest thereof to bee cut off, some five fingers breadth below his knee; and verily hee useth it with much more ease and facility than before in performance of any motion. Wee must doe otherwise if any such thing happen in the Arme; that is, you must cut off as little of the sound part as you can. For the actions of the Legges much differ from these of the armes, and chiefly in this that the body rests not, neither is carried upon the armes, as it is upon the feete and Legges.

How the section or amputation must be performed.

The first care must be of the patient's strength, wherefore let him be nourished with meats of good nutriment, easie digestion, and such as generate many spirits; as with the yolkes of Egges, and bread tosted and dipped in Sacke or Muskedine. Then let him bee placed, as is fit, and drawing the muscles upwards toward the sound parts, let them be tyed with a straite ligature a little above that place of the member which is to be cut off, with a strong and broad fillet like that which women usually bind up their haire withall; This ligature hath a threefold use; the first is, that it hold the muscles drawne up together with the skin, so that retiring backe presently after the performance of the worke, they may cover the ends of the cut bones, and serve them in stead of bouldsters or pillowes when they are healed up, and so suffer with lesse paine the compression in sustaining the rest of the body; besides also by this meanes the wounds are the sooner healed and cicatrized; for by how much more flesh or skinne is left upon the ends of the bones, by so much they are sooner healed and cicatrized. The second is, for that it prohibites the fluxe of blood by pressing and shutting up the veines and arteries. The third is, for that it much dulls the sense of the part by stupefying it; the animall spirits by the straite compression being hindred from passing in by the Nerves: Wherefrom when you have made your ligature, cut the flesh even to the bone with a sharpe and well cutting incision knife or with a crooked knife, such as is here expressed.

Now you must note, that there usually lyes betweene the bones, a portion of certaine muscles, which you cannot easily cut with a large incision

or dismembering knife; wherefore you must carefully divide it and separate it wholly from the bone, with an instrument made neatly like a crooked incision knife. I thought good to advertise thee hereof; for if thou shouldst leave any thing besides the bone to be divided by the saw, you would put the patient to excessive paine in the performance thereof; for soft things as flesh tendons and membranes, cannot be easily cut with a saw. Therefore when you shall come to the bared bone, all the other parts being wholly cut asunder and divided, you shall nimbly divide it with a little saw about some foote and three inches long, and that as neare to the sound flesh as you can. And then you must smooth the front of the bone which the saw hath made rough.

How to stanch the bleeding when
the member is taken off.

When you have cut off and taken away the member, let it bleed a little according to the strength of the patient, that so the rest of the part may afterwards be lesse obnoxious to inflammation and other symptomes; Then let the Veines and Arteries be bound up as speedily and streightly as you can; that so the course of the flowing blood may be stopped and wholly stayed. Which may be done by taking hold of the vessells with your Crowes beake, whereof this is the figure. The ends of the vessells lying hid in the flesh, must be taken hold of and drawn with this instrument forth of the muscles whereinto they presently after the amputation withdrew themselves, as all parts are still used to withdraw themselves towards their originalls. In performance of this worke, you neede take no great care, if you together with the vessells comprehend some portion of the neighbouring parts, as of the flesh, for herof will ensue no harme; but the vessells will so be consolidated with the more ease, than if they being bloodlesse parts should grow together by themselves. To conclude, when you have so drawne them forth, binde them with a strong double thred.

How after the blood is stanchd, you must
dresse the wounded member.

When you have tyed the Vessells, loose your Ligature which you made above the place of amputation; then draw together the lippes of the wound with foure stitches made acrossed, having taken good hold of the flesh; for thus you shall

draw over the bones that part of the skinne and cut muscles drawne upwards before the amputation, and cover them as close as you can, that so the ayre may the lesse come at them, and that so the wound may be the more speedily agglutinated. But when wee say, draw together the lippes of the wound with foure stitches, you must not so understand it, as that you must endeavour, to draw them so close as to touch each other, for that is impossible; for the stitches would sooner breake out, and so the part would lye bare. Wherefore it will be sufficient to draw them indifferent close together, that so you may suffer the skinne and flesh thereunder to enjoy its former liberty which it possesest before the drawing up, and so in fine by natures assistance, the wound may be the more easily agglutinated.

How you must stoppe the bleeding, if any of the
bound vessels chance to get loose.

The business hitherto being performed as we said, if peradventure it happen that any bandage of any of the vessels be unloosed; then must you againe binde the member with that kinde of Ligature which you did before the amputation thereof. Or else, which is better, more easily and lesse painefull, let your servant taking hold of the member with both his hands, pressing his fingers strait, stoppe the passage of the loosed vessell, for so hee may stanch the bleeding. Then let the worke-master take a needle some foure fingers long, square, and having sharpe edges, drawing after it a three or foure doubled strong thred. With this let him binde the vessell after the following manner. Let him thrust his needle on the outside into the flesh, some halfe fingers breadth from the loosed vessell until he come to the end thereof, then let him put it about it, and bring it backe againe, but so that there be no more than the space of a fingers bredth betweene the going in, and comming forth of the needle. In this space let him put a linnen ragge three or foure times doubled, and thereupon bind somewhat strait the two ends of the thred together. For so he shall hinder the knot from hurting the flesh which lyes under it in the bindings, and also adde strength thereto. For so the bound up orifice of the vessell will in short space be agglutinated to the adjoining flesh, and that so firmly, that there hath never beene seene, any one drop of blood to have flowed from a vessell so bound up. But if the blood which flowes forth procede from any small vessell, you must not use this suture and ligature, nor

make any such great matter thereof; for it will quickly be stanch'd by the only application of Astringents presently to be mentioned."

In that one passage Paré described the following which seem so well known to us, but certainly were not in widespread use four hundred years ago: the principle of amputation through living tissue, the use of the tourniquet, the use of ligatures on major vessels, the hemostat, allowing small vessels to seal themselves, the standardized below-knee stump regardless of the level of gangrene, the preservation of length in forearm amputations, the phantom limb syndrome, retracting soft tissue before cutting the bone in order to get better stump coverage, delayed closure, and the use of a modified suture-ligature with bolsters for difficult bleeding. For any essay written in 1560, it is remarkable. Paré could probably enter a modern operating room and do an amputation which would be creditable by anyone's standards.

How, one may ask, did all of this lead to progress for the amputee? Among other things, surgeons armed with the new techniques of ligature and tourniquet began to grow more bold. Whereas formerly only lower leg amputation had been done successfully (due to the fact that it was almost impossible to stop blood flow in the major vessels of the thigh by cauterization), William Clowes in 1588 performed a successful above-knee amputation for gangrene, and another was reported by Fabricius in 1614. In 1781 John Warr successfully amputated through the shoulder, and by 1803, Larrey, the French military surgeon, successfully amputated several times at the shoulder, and also through the hip. In this country, Walter Brashear of Kentucky successfully amputated through the hip in 1806.² Nathan Smith, also in the United States, published the first report of a planned operation through the knee joint in 1825.² Billroth allegedly attempted a hindquarter amputation but Gordon-Taylor published the first successful series in 1940. Until the development of anesthesia, in all of these procedures, speed was of the essence. Jacques Lisfranc of Paris in the early 1800's used 1000 cadavers per year to teach operative surgery, and could amputate the thigh of a cadaver in ten seconds. He felt that a critical part of the technique was to avoid kneeling on the floor at any time, since one wasted too much time regaining the standing position.¹⁷ Benjamin Bell of Edinburgh divided all except the bone in a thigh amputation in six seconds; James Woods of New York did a thigh amputation in nine seconds. Dominique Larrey averaged three minutes, and could disarticulate a shoulder in seventeen seconds, not counting ligatures and dressings.¹⁷ Ferguson took from twelve to twenty seconds to amputate through the hip

joint. These techniques, of course, were not without their complications. A colleague of Liston in London amputated a thigh in a few seconds, but in his zeal he included two fingers of his assistant, and both testes of his patient.¹⁷ Larrey, in the Moscow campaign, did 200 amputations in the first 24 hours, or one every seven minutes, day and night.¹⁷

Most amputations done in this rapid fashion were relatively crude, guillotine operations, with bone and soft tissue cut at the same level. The "chop" amputation leaves an unsatisfactory result because of protruding bone. While most were concerned with speed, some were working on improved techniques to leave a better stump. Paré recommended retracting skin and muscle proximally before severing the bone, to leave more coverage for the bone. True flap amputations were first credited to James Younge of Plymouth in 1679.¹⁷ Verduin of Amsterdam, in 1696, and Revation and Vernal of France in the 1700's also designed simple flaps. In 1837 Robert Liston introduced a flap amputation like the one used today.² Gradually, as the flap amputation replaced the circular, knives changed from the curved of

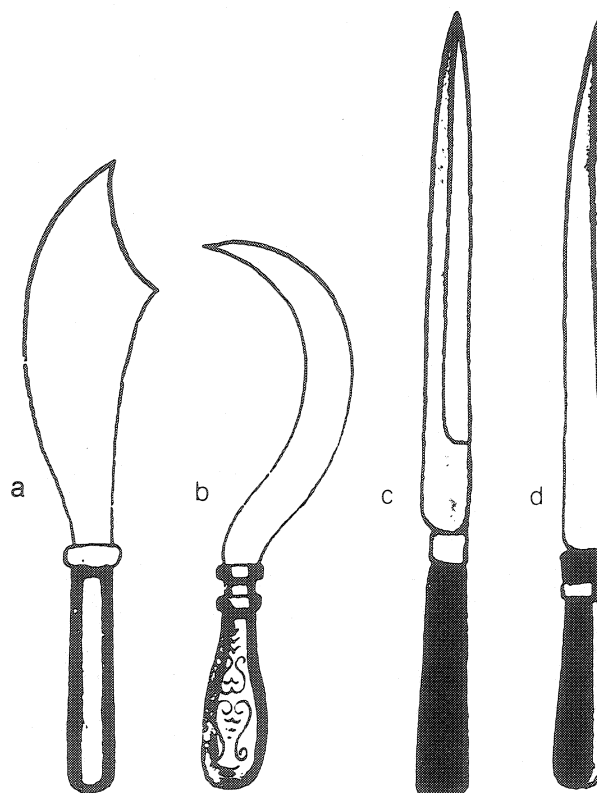


Figure 11. Amputation knives of the early 1800's. (Reprinted from *The Rise of Surgery*, University of Minnesota Press, 1978).

Fabricius to the straight of Liston (Figure 11).¹⁷ Malgaigne in Paris introduced a racquet type incision. In 1807, Charles Bell illustrated a well performed thigh

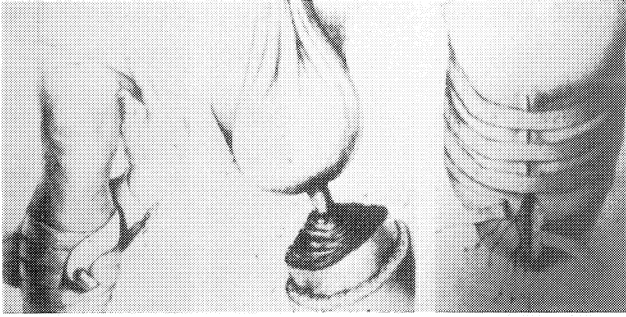


Figure 12. Use of muscle retraction in thigh amputation. (Reprinted from *The Rise of Surgery*, University of Minnesota Press, 1978).

amputation using the same principle of muscle retraction (Figure 12).¹⁷ Both flap and circular amputations have been used.

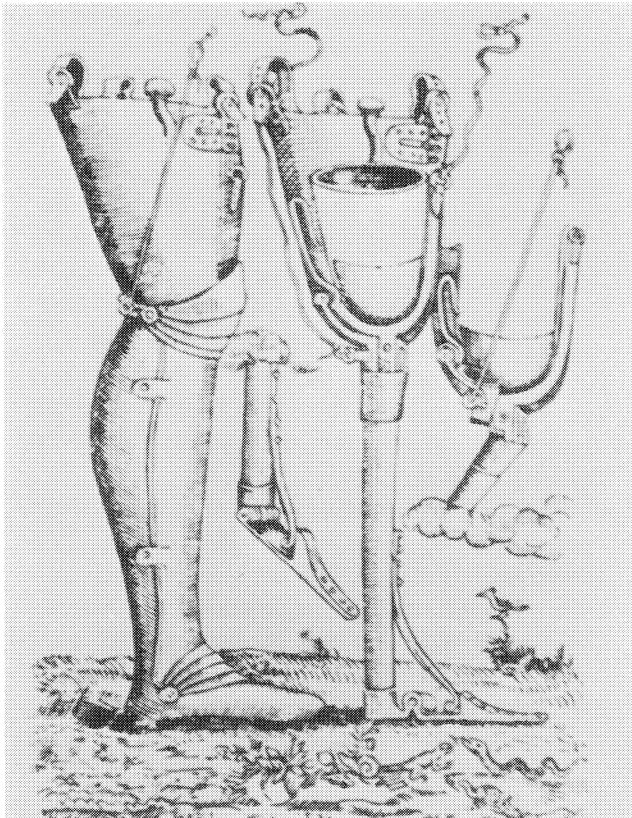


Figure 13. Paré's above knee prosthesis with articulated joints (Reprinted from *Limb Prosthetics—1972*, Robert E. Krieger Publishing Co., 1972).

As the amputation stump improved, surgeons began to design true walking prostheses. Paré designed the first known above-knee prosthesis with articulated joints (Figure 13). Verdun, one of the designers of the flap type amputation also produced the first limb which allowed knee motion for below-knee amputees. The foot was wooden, and the socket made of copper lined by leather (Figure 14). This resembled the thigh corset,

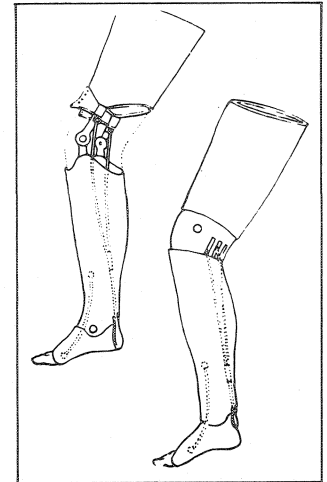


Figure 14. Verdun's innovation of a below knee prosthesis allowing knee motion (Reprinted from *Limb Prosthetics—1972*, Robert E. Krieger Publishing Co., 1972).

below-knee prostheses still in use today, but for some reason the design was lost until re-introduced by Serré in 1826.¹⁸ The next advance in the above-knee prosthesis after Paré was by James Potts of London in 1800. His prosthesis was lighter because it had a wooden socket and shank, unlike Paré's metal one. It had a steel

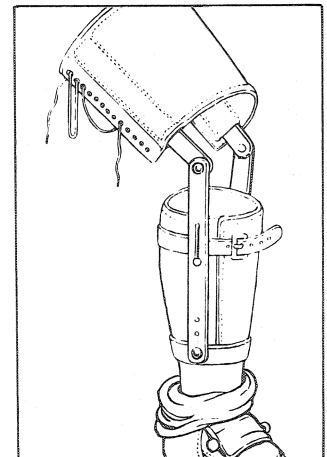


Figure 15. Prosthesis designed by James Potts of London in 1800 (Reprinted from *Limb Prosthetics—1972*, Robert E. Krieger Publishing Co., 1972).

knee joint, an articulated foot, and cords connecting the knee and ankle so that toe lift was coordinated with knee flexion. The Marquis of Anglesea used this after he lost a leg in the battle of Waterloo, and it became known as the Anglesea leg (Figure 15).¹⁸ This was introduced into the United States in 1839 and modifications were made, including a rubber plate in the ankle to reduce jarring and a rubber sole for grip. It eventually became known as "the American leg." In 1842, Martin placed the knee hinges more posteriorly to give a more stable knee. The foot had a spring-controlled joint within in. Bly in 1858 introduced an ivory and rubber ball and socket ankle joint with variable tension, and in 1860 Marks substituted a hard rubber foot for the wooden variety.¹ After the Civil War J.E. Hanger, one of the first on the Southern side to lose a limb, replaced

the cords of the Anglesea leg with rubber bumpers at the ankle which could vary plantarflexion and dorsiflexion, a design which remained almost universal until recently. A large prosthetics firm still bears his name.¹⁸ He also popularized the suction socket. A quotation from his patent states "The first part of this invention relates to the bucket or socket of artificial legs or arms intended to receive the stump, and it consists in the fastening of such bucket to the stump by means of atmospheric pressure in such a manner that the straps usually employed for this purpose can be dispensed with and at the same time a perfect fit of the bucket is obtained." His leg had adjustable springs for the toes so that the foot could adapt itself to the ground. For some reason it was only decades later that this prosthesis became the universally accepted limb which it is today.¹ The production of prostheses received a tremendous boost during the Civil War, with 30,000 amputations performed by the Union Army Medical Corps alone. Marks introduced the leather or parchment covering for the wooden socket, and Herrmann of Prague introduced aluminum moving parts to replace the steel. Limbs were produced during that period for \$75 to \$150 each.¹

Also, new techniques of amputation were introduced, most of them representing attempts to produce end-bearing stumps. Most amputations were devised after the introduction of ether for anesthesia at Massachusetts General Hospital in 1846. Before then, few surgeons wanted anything but the quickest possible amputation. One of the first new amputations was introduced by Frances Chopart in 1792. He proposed a disarticulation through the talonavicular and calcaneocuboid joints. This was for a time, a popular amputation. There was a marked tendency for the hindfoot to go into equinus and varus, due to unbalanced muscle pull. Furthermore, the normal upward inclination of the plantar surface of the calcaneus was no longer supported by the rest of the arch. The plantar surface naturally came to rest flat on the ground, forcing the calcaneus into equinus. The weight bearing forces on the talus were thus directed somewhat forward as well as straight down, and it would almost invariably slide anteriorly and medially to the calcaneus, resulting in subtalar joint pain, and revision of the amputation.¹⁴ Lisfranc described his metatarsal-tarsal disarticulation in 1815. This operation, although relatively quick, requires a long plantar flap to cover the bones of the tarsus, and since it is often the sole of the foot which is most destroyed, this amputation has found relatively little use. Also the Lisfranc amputation removes the tibialis anterior and the peronei, and tends to destroy the arch of the foot.¹⁵ Nicolai Pirogoff introduced his amputation

in 1854; this removes all of the foot and tarsal bones except the posterior half of the calcaneus. The distal tibia and fibula are cut through, and the posterior half of the os calcis is rotated ninety degrees and allowed to rest against the cut surface of the tibia. It is difficult to keep the calcaneal fragment properly located, the rehabilitation is slowed while waiting for bony union,¹⁴ and weight bearing is on the skin of the posterior, not the plantar, aspect of the calcaneus, which remains less than ideal.

James Syme in 1843 introduced extirpation of the entire foot, leaving only the heel pad. The distal ends of the tibia and fibula are removed with a saw, and the heel pad is swung up to cover the cut surface of the tibia, again giving an end-bearing stump. This has the advantage of requiring no bony healing. The procedure has remained popular through the years, more so in Canada than in the United States,⁶ although the bulbous stump is somewhat difficult to fit with a prosthesis, and the prosthesis is not cosmetic. Syme initially introduced the procedure mainly because of a lower mortality rate than the standard below-knee amputation, presumably

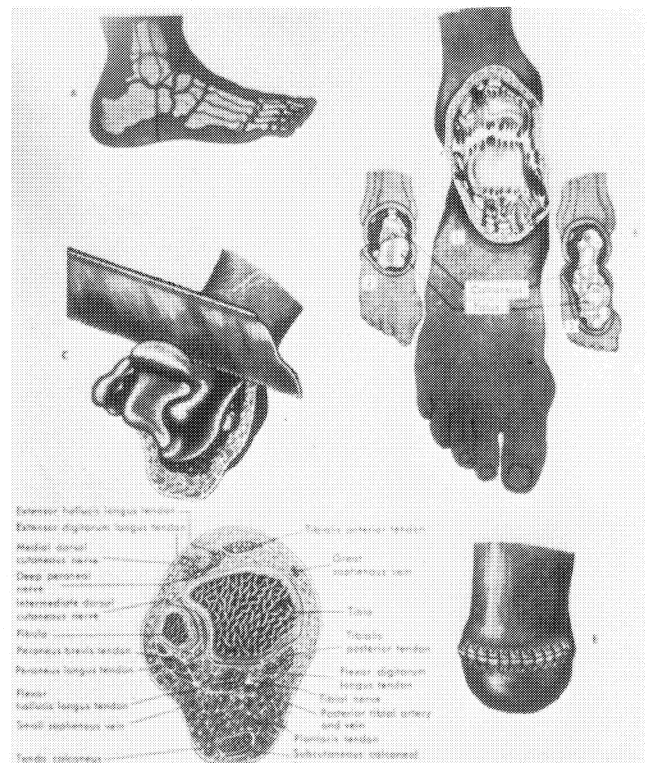


Figure 16. Method of Syme amputation (Reprinted from *An Atlas of Amputations*, C.V. Mosby, 1949).

due to less exposure of tissues and a lower infection rate. Today its main advantage is to provide a stump on which the amputee can walk for short distances without crutches or prosthesis. Figure 16 shows the technique of the Syme operation. Gritti in 1857 introduced an

operation designed to give an end-bearing above-knee amputation stump. He did a supracondylar osteotomy of the femur, removed the cartilage from the patella (leaving the quadriceps mechanism attached), and fixed the patella to the cut surface of the femur. This operation, modified slightly by Stokes in 1870, has since been known as the Gritti-Stokes procedure.¹⁵ Like similar procedures in the foot, it has proven difficult to hold the cut patella in place, particularly since the quadriceps constantly tends to pull it up. The time required for bony healing delays rehabilitation and if healing is successful, late osseous changes often make the stump unuseable.¹⁵

What new developments have occurred in amputations and prostheses since 1900? Refinements in detail have occurred, but the basic principles have changed little. The circular amputation has not been abandoned, and in fact, the Surgeon General in World War II required that all amputations in forward areas be done in circular fashion, as distal as possible, and that the

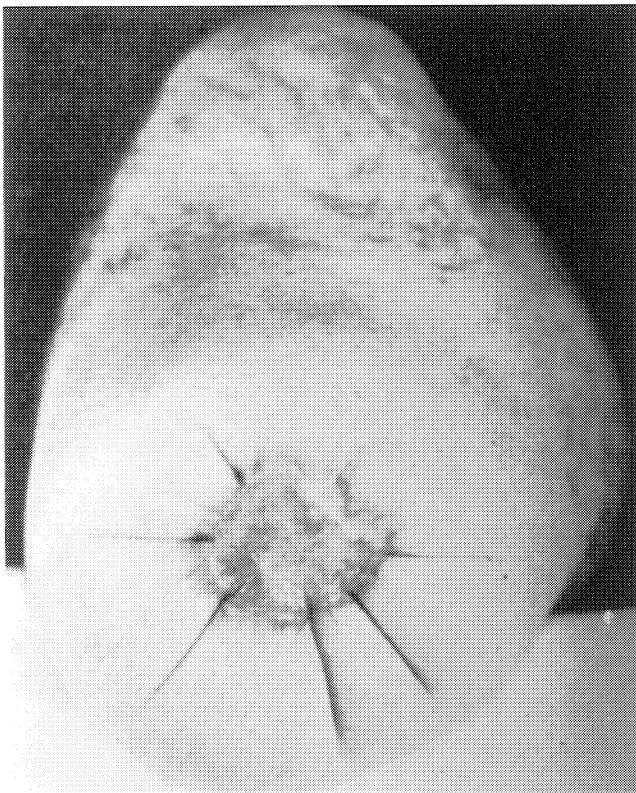


Figure 17. End result of circular amputation stump treated with postoperative skin traction (Reprinted from *An Atlas of Amputations*, C.V. Mosby, 1949).

wounds be left open with traction on the skin edges.¹² The ideal end result for the stump is seen in Figure 17. Occasionally this stump requires excision of the distal scar, but in cases where the scar is this small, thanks to

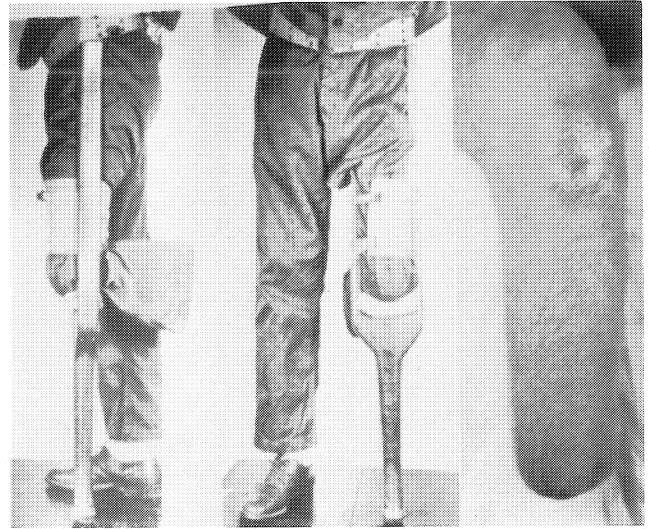


Figure 18. Peg leg type prosthesis on below knee amputee (Reprinted from *An Atlas of Amputations*, C.V. Mosby, 1949).

carefully applied traction, scar removal is a minimal procedure. World War II resulted in some interesting homemade prostheses, many made from scrap materials in prisoner-of-war camps. Figure 18 shows the classic Long John Silver peg leg, with the patient kneeling in the prosthesis. Until recently, some loggers used

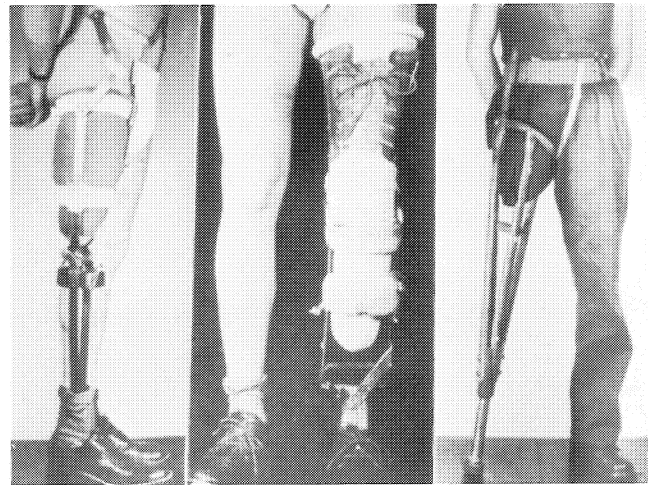


Figure 19. Homemade prostheses from World War II (Reprinted from *An Atlas of Amputations*, C.V. Mosby, 1949).

this type of prosthesis because the foot of a regular below-knee prosthesis caught in the bushes.¹⁴ The prosthesis on the right in Figure 19 was made in a Philippine prison camp from bailing wire, a crutch, a rubber hose, and a sink pipe. The two prostheses on the left were made in German prisoner-of-war camps from scrap metal.¹⁴

One amputation has been introduced recently. In 1939 Boyd described a modification of the Ricard am-

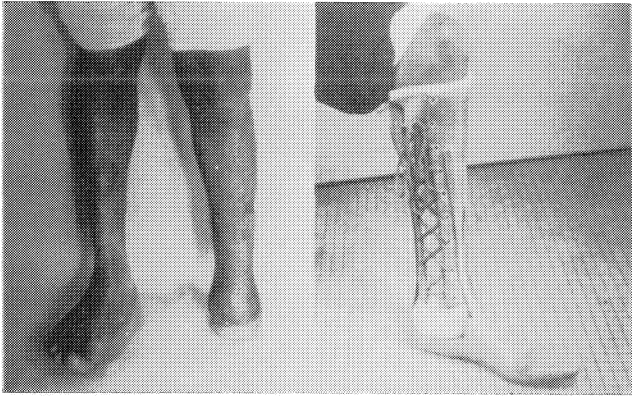


Figure 20. Boyd amputation stump and prosthesis (Reprinted from *An Atlas of Amputations*, C.V. Mosby, 1949).

putation in which the foot, including the talus, is excised, and the os calcis is allowed to ride in the ankle mortise. Boyd's modification involved fusion of the calcaneus to the tibia. Figure 20 shows the stump and the prosthesis. This produces a good end-bearing stump which is longer than the Syme stump.¹⁴ One disadvantage is the need for a long plantar flap to close the incision. Also, this requires bony healing, rehabilitation is delayed, and non-union is always a possibility.

In amputations, recent advances mostly involve preoperative decision making and post operative care. In prostheses, most of the advances have been in materials. The use of Doppler probes to measure blood pressure at various levels in the lower limb allows a more accurate prediction of whether a below-knee amputation will heal. Radioactive Xenon washout rates from the skin, and temperature measurements of the skin, can provide similar data. The use of rigid plaster

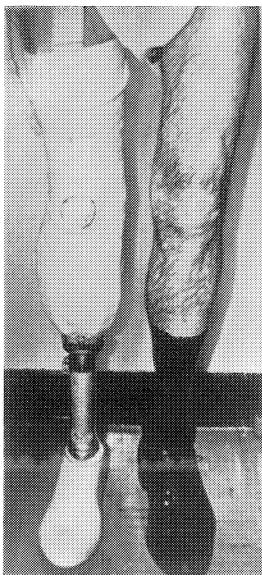


Figure 21. Below knee amputee wearing rigid dressing with pylon (Reprinted from *Campbell's Operative Orthopaedics*, C.V. Mosby, 1980).

dressings in the immediate post-operative period of one to two weeks postoperatively, allows earlier stump shrinkage and maturation, and shorter rehabilitation time (Figure 21).

The introduction of plastics for sockets, more intricate hydraulic braking mechanisms for knees, and in certain cases, myoelectric arms, have helped to improve the function of the amputee. However, one must always keep in mind Paré's patient of four hundred years ago. His circular amputation, a hands breadth below the knee joint, was done through healthy tissue, and with the use of ligatures. The soft tissues were cut more distally than the bone, providing good coverage. The patient walked in a leather and metal prosthesis with a thigh cuff and a hinged knee, and, by most accounts, functioned quite well. Obviously, we of the twentieth century have little to be smug about when we compare ourselves to our surgical ancestors. We have made some improvements, but we have changed the principles very little, and we have far to go before we can become complacent about our results in the field of lower limb amputations and prosthetics.

Bibliography

¹Edwards, J.W.: *Orthopedic Appliance Atlas*, Vol. I. American Academy of Orthopaedic Surgeons, Ann Arbor, Michigan, 1960.

²Bick, Edgar: *Source Book of Orthopaedics*. Hafner Publishing Co., New York, pp. 230-238, 1968.

³Daniel, Earle H.: *Amputation Prosthetic Service*. Williams and Wilkins, Baltimore, 1950.

⁴Friedmann, Lawrence W.: *Amputations and prostheses in primitive cultures*. *Bulletin of Prosthetics Research*, pp. 105-138, Spring, 1972.

⁵Hamby, Wallace B.: *Ambroise Paré, Surgeon of the Renaissance*. Warren H. Green, Inc., St. Louis, 1967.

⁶Harris, R.I.: *Symes amputation—The technical details necessary for success*. *J. Bone and Joint Surg.*, 38B: 614-632, 1956.

⁷Keynes, Geoffrey (ed.): *The Apology and Treatise of Ambroise Paré*. University of Chicago Press, Chicago, 1952.

⁸Northwestern University Prosthetics Course Manual, 1978.

- ⁹Packard, Francis: *Life and Times of Ambroise Paré*. Paul B. Hoeber, Inc., New York, 1926.
- ¹⁰Paget, Stephen: *A Good Example*. from *The Good Physician—A Treasury of Medicine*, Chapter I, The MacMillan Company, New York, 1962.
- ¹¹Paget, Stephen: *Ambroise Paré and His Times*. G.P. Putnam's Sons, The Knickerbocker Press, New York, 1897.
- ¹²Peterson, Leonard T.: *The Army amputation program*. *J. Bone and Joint Surg.*, 26:4, 635-638, October, 1944.
- ¹³Putti, Vittorio: *Historic Artificial Limbs*. Paul B. Hoeber, Inc., New York, 1930.
- ¹⁴Slocum, Donald: *An Atlas of Amputations*. C.V. Mosby, St. Louis, 1949.
- ¹⁵Vasconcelos, Edmondo: *Modern Methods of Amputation*. Philosophical Library, Inc., New York, 1945.
- ¹⁶Vitali, Miroslaw, et. al.: *Amputations and Prostheses*. Bailliere Tindall, London, 1978.
- ¹⁷Wangensteen, Owen, and Wangenstein, Sarah: *The Rise of Surgery: From Empiric Craft to Scientific Discipline*. University of Minnesota Press, pp. 16-52, 1978.
- ¹⁸Wilson, A.B., Jr.: *Limb Prosthetics—1972*. Robert E. Krieger Publishing Company, Huntington, N.Y., 1972.
- ¹⁹Wilson, A.B., Jr.: *Introduction to Atlas of Limb Prosthetics*. American Academy of Orthopaedic Surgeons, C.V. Mosby, St. Louis, 1980.

THE CERVICAL SPINE IN RHEUMATOID ARTHRITIS

Charles R. Clark, M.D.*

Rheumatoid arthritis frequently involves the cervical spine. Greater than 85% of patients with moderate to severe rheumatoid arthritis show some radiographic abnormalities.^{5,6} Physicians frequently overlook the cervical spine in rheumatoid patients. Few articles deal with the subject in the Orthopaedic literature.^{8,20,21,22} Physicians should recognize this involvement because of the possible serious consequences. Progressive instability of the upper cervical spine may lead to upper spinal cord, medullary, and vertebral artery compression with resultant severe neurological deficit or even death.^{16,23} Cranial settling is probably the most serious life-threatening complication.¹⁰

Fifteen to thirty-six percent of rheumatoid patients demonstrate atlanto-axial instability,⁹ and 5-8% demonstrate some degree of cranial settling.¹⁰ There is little correlation between the duration of the disease, the clinical manifestations, or various laboratory tests and involvement of the cervical spine.²³ Involvement, however, is more common in patients with more severe rheumatoid disease.²⁴

Three lesions most often produce neural involvement and intractable pain: atlanto-axial subluxation, subaxial subluxation (second to the seventh cervical vertebrae) and superior migration of the dens into the foramen magnum, i.e., cranial settling.²² The terminology is somewhat confusing especially with respect to cranial settling. Synonymous terms include: upward migration of the dens,¹⁸ translocation of the dens,^{19,21} vertebral subluxation of the odontoid,²⁵ and basilar²³ or pseudobasilar invagination.^{12,15} The term cranial settling most accurately represents the pathology and will be used in my classification (Table 1). Sherk emphasized the importance of differentiating cranial settling from atlanto-axial instability.²³ Atlanto-axial instability is a relatively benign process with less than 20% of patients showing progressive instability.¹⁶ Cranial settling, however, progresses in 33-50% of patients.¹⁷

This paper delineates cervical spine manifestations of rheumatoid arthritis and stresses the importance of evaluating the neck in patients with advanced disease.

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Table I

Classification of Cervical Spine Involvement in Rheumatoid Arthritis

- I. Atlanto-axial subluxation
 - II. Cranial settling
 - III. Subaxial subluxation (C2-C7)
-

Pathology

The pathology of rheumatoid arthritis in the cervical spine resembles that in peripheral joints. Inflammation of the synovium leads to ligament attenuation and disruption as well as to bone and cartilage destruction. The primary joints involved include the atlanto-occipital, atlanto-axial, atlanto-dental and the neuro-central joints or joints of Luschka. These joints are all lined by synovial tissue and are a feature only of the cervical spine. This appears to account for the tendency of rheumatoid inflammation to involve this portion of the spine while dorsal and lumbar portions generally escape.²⁴

In atlanto-axial subluxation, osteoporosis, synovial effusion, and proliferation of synovial tissue combine to cause destructive changes in the odontoid process, the transverse and alar ligaments, and the lateral masses of the atlas and occipital condyles.^{2,7,13} Early in the disease, synovitis and effusion in the atlanto-dental joint permit an abnormally large excursion of the atlas on the axis. Later, progressive erosion of the dens often accompanies attenuation or destruction of the transverse and alar ligaments. Instability of the atlas becomes greater and the effective cervical canal diameter decreases as these changes progress.²³ The width of the cervical canal and the degree of synovial proliferation are among the most important determinants of neural deterioration.³ Synovial proliferation may be profound even in the presence of minimal subluxation and this alone may account for neurological deficit (Figure 1). Bony destruction of the dens due to proliferating pannus may also lead to significant instability and neurologic compromise.

Significant involvement of the atlanto-occipital joint may lead to destruction of the occipital atlanto-axial complex allowing the skull to settle to a lower level on the cervical spine and the odontoid process to project

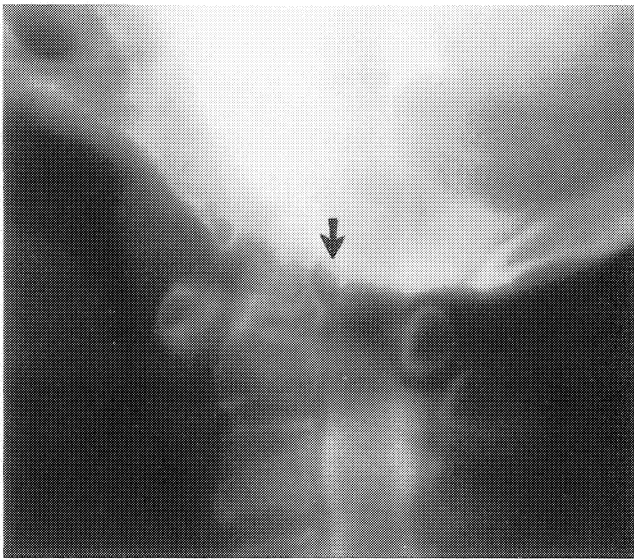


Figure 1. Lateral tomogram with Metrizamide contrast of craniocervical junction demonstrating synovial proliferation just posterior to dens with secondary erosion of the dens.

above the level of the foramen magnum.^{14,16,21,23} Neurological problems result from impingement of the medulla oblongata and proximal cord by the dens. The vertebral arteries may also be occluded as they converge to enter the skull between the dens and margins of the foramen magnum.¹⁰ Swinson noted that bone and cartilage destruction as opposed to ligamentous laxity permits the occiput and C1 to settle upon C2²⁵ (Figure 2).

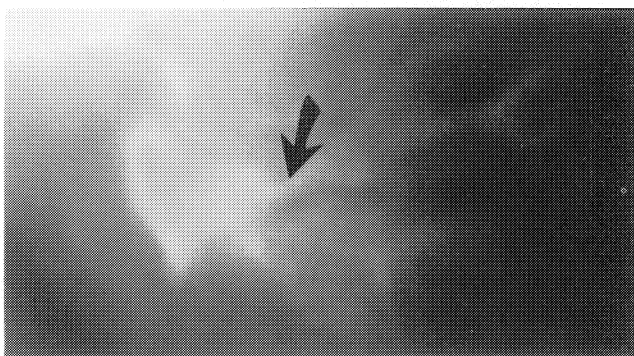


Figure 2. Lateral tomogram of craniocervical junction demonstrating bony erosion of the lateral mass of C-1.

Involvement of the neurocentral joints by the rheumatoid inflammatory process leads to instability and subluxation in the subaxial region of the cervical spine.

Clinical Presentation

The neurological status of a patient with severe rheumatoid disease can be difficult to ascertain because

of the multifocal involvement. Involvement of the hands, peripheral nerve entrapment, root involvement by foraminal encroachment, and cord or brain stem compression by bony displacement may all lead to weakness and neurological deficit. One must realize that neural deficit may not be due to peripheral involvement and may indeed be secondary to changes in the cervical spine.

Clinical signs and symptoms range from none to quadriplegia. The earliest symptoms include posterior occipital headache and pain along the course of the greater occipital nerve. Later, patients may complain of hand weakness, difficulty in walking and a sense of impending doom with head flexion.¹ Clinical signs may also be negative, or patients may present with confusing symptoms and signs such as weakness in the hands with hyporeflexia of the upper extremities and spasticity with hyperreflexia and positive Babinski signs in the lower extremities.¹ Certain findings, however, should alarm the physician: an abrupt increase in the severity of neck pain, urinary incontinence, increasing weakness, spasticity of lower extremities, or change in ambulatory status. One must always consider the possibility of cervical spine involvement when one of these changes appears. Vertebral artery thrombosis or stenosis should be suspected when vertigo, nystagmus or dysphonia develop.

Radiographic Findings

Initial radiographic examinations for evaluating the neck should include standard anteroposterior and lateral flexion/extension roentgenograms. Cervical polytomography, myelography, and computerized tomography are often required to fully evaluate the extent of cervical spine involvement.

A standard lateral flexion/extension view helps to determine atlanto-axial stability. Anatomical studies have shown that more than 4 mm. of atlanto-axial subluxation indicates a ruptured transverse ligament. Greater than 6 mm. of subluxation indicates rupture or attenuation of the alar ligaments. When the distance between the dens and the posterior atlantal arch measures less than 16 mm. on the lateral projection, there may be significant encroachment upon the spinal cord.²³ Martel states that greater than 3 mm. of subluxation on a lateral flexion/extension view is abnormal.¹⁵ Several methods help measure cranial settling. Chamberlain's line is drawn from the posterior edge of the hard palate to the posterior rim of the foramen magnum. The tip of the dens should protrude no more than 3 mm. above this line. McGregor's baseline, which is similar, extends from the caudal tip of the occiput to the posterior portion of the hard palate. The tip of the

dens is normally less than 4.5 mm. above this line. Wackenheim's clivus baseline, drawn along the cranial surface of the clivus, should normally be tangent to or barely intersect the tip of the odontoid. An abnormality beyond the limits of these indicates cranial settling. I prefer to use Chamberlain's line to determine the extent of cranial settling.

Subaxial subluxation may also result in instability. White has shown when there is greater than 3.5 mm. of subaxial subluxation, the cervical spine is unstable²⁸ (Table 2).

Table II

Radiographic Criteria of Cervical Spine Instability

- I. Atlanto-axial subluxation greater than 3 mm.
- II. Cranial Settling:
 - A. Dens greater than 3 mm. above Chamberlain's line
 - B. Dens greater than 4.5 mm. above McGregor's line
 - C. Dens above Wackenheim's line
- III. Subaxial subluxation greater than 3.5 mm.

Treatment

Treatment is based upon the presence of signs and symptoms and not strictly on the basis of radiographic findings. The presence of subluxation on dynamic roentgenograms does not per se warrant fusion. There must be symptoms sufficiently significant to warrant the hazards of surgery.¹ The patients who demonstrate a mild degree of atlanto-axial subluxation and who complain of intermittent headaches are often treated symptomatically. A hard cervical collar may be prescribed when such patients ride in a car. The key when following patients with early involvement is periodic examination including lateral flexion/extension radiographs.

The decision to operate is difficult. Relative indications for surgery include increasingly severe neck pain, severe occipital neuralgia, and progressive instability. Most authors agree that surgery is indicated when neurological signs develop. Ranawat states that because the myelopathy that occurs in these patients may become irreversible, early surgery is indicated even in patients without significant neurological involvement if they have mobile atlanto-axial subluxation greater than 4 mm. Regardless, the presence of neurological signs and symptoms indicate that the upper cervical cord and medulla are at serious risk, and treatment should be prompt.^{26,27}

We utilize several surgical procedures at our institution when surgery is indicated. A posterior fusion of the

Brook's type is utilized in patients with significant atlanto-axial instability.¹¹ We initially manage cranial settling with skeletal traction. If the dens can be reduced and the patient's neurological status improves, these patients can then be treated by posterior occipital-cervical fusion. However, if the dens cannot be reduced, or the neurological deficit does not improve, the patient may need a resection of the dens, and a posterior occipital-cervical fusion. Patients with significant subaxial subluxation are managed with posterior cervical fusions. Bone grafts are utilized in all of these fusions. Anterior fusions have not been successful in these patients.⁵

Methylmethacrylate has recently been advocated as an adjunct to cervical spine fusions in patients with rheumatoid disease.^{4,22} The use of the methacrylate as an adjunct to the standard fusion may provide several advantages including immediate rigid fixation, avoidance of post-operative orthoses, facilitation of nursing care, and decreased operative time and blood loss. The acrylic enhances the fixation of wire to bone, eliminates motion between wire and bone, thereby decreasing the chance of wire and/or bone failure, and it supports and stabilizes bone grafts. We use adjunctive methylmethacrylate sparingly and only for selected cases.

Case Histories

Case 1. N. J., a 45 year old female, had a two year history of intermittent occipital headaches. She developed severe posterior cervical pain and complained of paresthesias in both hands with neck flexion one month prior to admission. The patient also complained of vertigo and tinnitus with neck motion. Dynamic lateral flexion/extension roentgenograms demonstrated 8 mm. of subluxation. The patient underwent a Brook's type posterior cervical fusion from C1 to C2 uneventfully. One year postoperative she remains asymptomatic (Figure 3).

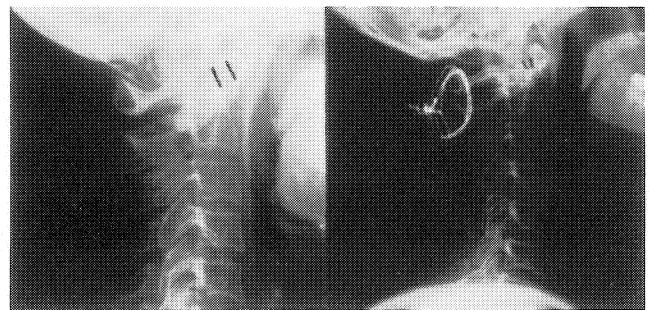


Figure 3. (Left) Pre-operative lateral radiograph demonstrating 8 mm. of atlanto-axial subluxation.

Case 2. M. L., a 47 year old female, had a five year history of intermittent posterior cervical pain and occipital headaches. Prior to admission, she had a three month history of bilateral upper extremity paresthesias and weakness. During this interval, the patient deteriorated from ambulation with a walker to a wheelchair. Cervical spine roentgenograms revealed atlanto-axial subluxation of 7 mm. and cranial settling of 8 mm. beyond Chamberlain's line (Figure 4). The patient was placed in skeletal traction. A myelogram of the cranial-

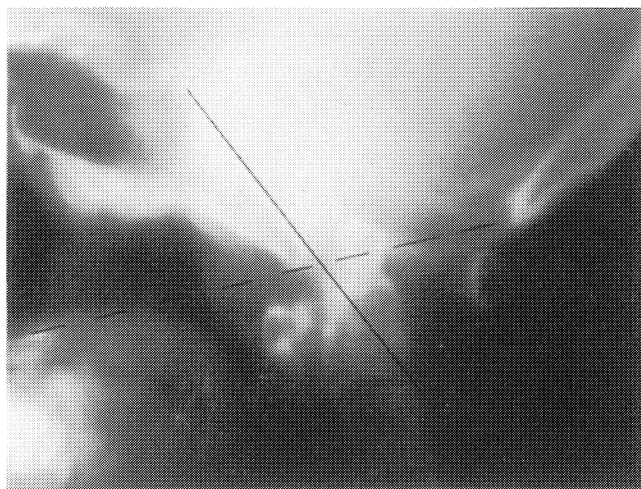


Figure 4. Lateral tomogram of cranio-cervical junction. Dashed line indicates Chamberlain's line and unbroken line indicates Wackenheim's clivus base line. Significant cranial settling is present.

cervical junction demonstrated significant compression of the medulla by the dens. Neurological status improved markedly with traction. Following two weeks in traction, the patient had only mild weakness of her upper extremities which she felt was her baseline. We therefore performed a posterior occipital to cervical fusion utilizing bone graft and adjunctive methylmethacrylate. Four months post-operation the patient walks with her walker.

Case 3. G. P., a 65 year old female, underwent a posterior C1-C2 fusion for atlanto-axial instability in 1976. In 1980, she developed paresthesias of both hands and was felt to have bilateral carpal tunnel syndromes. On further evaluation, she had weakness in both upper extremities with hyporeflexia as well as spasticity of the lower extremities. The patient was also confined to a wheelchair for three months because of weakness in her legs. Lateral flexion/extension radiographs demonstrated significant subaxial subluxation at multiple levels. After two weeks in cervical traction the alignment of her cervical vertebral column improved. Her neurological status also improved, and the patient underwent a posterior cervical fusion from C2 to T1

utilizing bone graft and adjunctive methylmethacrylate. After one and a half years of follow-up, she walks with a walker and has good strength of all extremities (Figure 5).

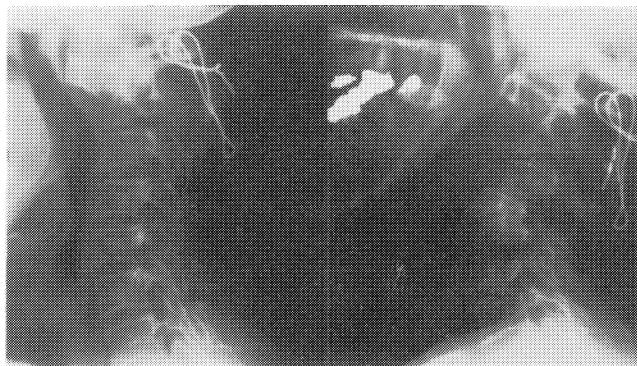


Figure 5. (Left) Lateral radiograph of patient in 1976 following a posterior C1-C2 fusion. Note the relative normal appearance of the subaxial cervical spine.

Discussion:

Rheumatoid arthritis commonly involves the cervical spine, and the physician treating such patients must recognize this. In patients with rheumatoid arthritis, the following should alert the physician to the possibility of cervical spine involvement: severe neck pain, bizarre weakness or paresthesias of the hands and upper extremities, change in ambulatory status, spasticity of the lower extremities, or urinary incontinence.

Surgery is indicated in only a small percentage of patients with rheumatoid arthritis. Ranawat has estimated that only 0.7% of patients with rheumatoid arthritis require surgical intervention in the cervical spine.²² When neurological signs develop because of involvement of the cervical spine, treatment should be prompt because the upper cervical cord and brain stem are at serious risk.

Significant atlanto-axial subluxation may be present in the asymptomatic patient. One must not have a false sense of security when examining or treating such patients. In order to rule out a significant instability, all patients with advanced rheumatoid arthritis who are undergoing anesthesia for a surgical procedure *must have* dynamic lateral flexion/extension roentgenograms prior to the induction of anesthesia.

The physician must always be cognizant of the possibility of cervical spine involvement in the rheumatoid patient. Prompt recognition of cervical spine involvement and the initiation of appropriate treatment may avoid the grave consequences of significant cervical spine instability with resulting neurological deficit and even death.

Bibliography

- ¹Bailey, R. W.: Dislocations from conditions other than trauma-postlaminectomy and in rheumatoid arthritis. *In* The Cervical Spine. R. W. Bailey, pp. 187-210, Philadelphia, Lea and Febiger, 1974.
- ²Ball, J. and Sharp, J.: Rheumatoid arthritis of the cervical spine. *In* Hill, A.G.S. (Editor): Modern Trends in Rheumatology. Ed. 2, p. 117, Landon, Butterworth, 1971.
- ³Cabot, A. and Becker, A.: The cervical spine in rheumatoid arthritis. *Clin. Orthop.*, 131:130-140, 1978.
- ⁴Clark, C. R. and Keggi, K. S.: Long-term follow-up of cervical spine stabilization with adjunctive methylmethacrylate. *Orthop. Trans.*, 5:407, 1981.
- ⁵Conlon, P. W., Isdale, I. C., and Rose, B. S.: Rheumatoid arthritis of the cervical spine. An analysis of 333 cases. *Ann. Rheumat. Dis.*, 25:120-126, 1966.
- ⁶Cregan, J. C. F.: Internal fixation of the unstable rheumatoid cervical spine. *Ann. Rheumat. Dis.*, 25:242-252, 1966.
- ⁷Crellin, R. Q., Maccabe, J. J., and Hamilton, E. B. D.: Severe subluxation of the cervical spine in rheumatoid arthritis. *J. Bone and Joint Surg.*, 52B:244-251, May, 1970.
- ⁸Detenbeck, L. C.: Rheumatoid arthritis of the spinal column. Pathologic aspects and treatment. *Ortho. Clin. N. Am.*, 2:679, 1971.
- ⁹Editorial: Rheumatoid atlantoaxial subluxation. *Brit. Med. J.*, 2:200-201, 1976.
- ¹⁰El-Khoury, G. Y., Wener, M. H., Menezes, A. H., Dolan, K. D., and Kathol, M. E. H.: Cranial settling in rheumatoid arthritis. *Radiol.*, 137:637-642, Dec., 1980.
- ¹¹Griswold, D. M., Albright, J. A., Schiffman, E., Johnson, R., and Southwick, W. O.: Atlanto-axial fusion for instability. *J. Bone and Joint Surg.*, 60A:285-292, April, 1978.
- ¹²Jones, M. W. and Kaufmann, J. C.: Vertebrobasilar artery insufficiency in rheumatoid atlantoaxial subluxation. *J. Neurol. Neurosurg. Psych.*, 39:122-128, Feb., 1976.
- ¹³Kennedy, H. C., Smith, D. A., Anton, H. C., and Buchanan, W. W.: Generalized and localized bone loss in rheumatoid arthritis. *Scand. J. Rheumatol.*, 4:209-215, 1975.
- ¹⁴Martel, W. and Page, J. W.: Cervical vertebral erosions and subluxation in rheumatoid arthritis and ankylosing spondylitis. *Arthritis Rheum.*, 3:546-556, Dec., 1960.
- ¹⁵Martel, W.: The occipito-atlanto-axial joints in rheumatoid arthritis and ankylosing spondylitis. *Am. J. Roentgenol.*, 86:223-240, Aug., 1961.
- ¹⁶Matthews, J. A.: Atlanto-axial subluxation in rheumatoid arthritis. *Ann. Rheum. Dis.*, 33:526-531, 1974.
- ¹⁷Mikulowski, P., Wollheim, F. A., Rotmil, P., and Olsen, I.: Sudden death in rheumatoid arthritis with atlanto-axial dislocation. *Acta. Med. Scand.*, 198:445-451, 1975.
- ¹⁸Park, W. M., O'Neill, M., and McCall, I. W.: The radiology of rheumatoid involvement of the cervical spine. *Skel. Radiol.*, 4:107, April, 1979.
- ¹⁹Rana, N. A. and Taylor, A. R.: Upward migration of the odontoid peg in rheumatoid arthritis. *Proc. R. Soc. Med.*, 64:717-718, July, 1971.
- ²⁰Rana, N. A. and Hancock, D. O.: Atlanto-axial subluxation in rheumatoid arthritis. *J. Bone and Joint Surg.*, 55B:458, 1973.
- ²¹Rana, N. A., Hancock, D. O., Taylor, A. R., *et al.*: Upward translocation of the dens in rheumatoid arthritis. *J. Bone and Joint Surg.*, 55B:471-477, 1973.
- ²²Ranawat, C. S., O'Leary, P., Pellici, P., Tsairis, P., Marchisello, P., and Dorr, L.: Cervical spine fusion in rheumatoid arthritis. *J. Bone and Joint Surg.*, 61:1003-1010, Oct., 1979.
- ²³Sherk, H. H.: Atlantoaxial instability and acquired basilar invagination in rheumatoid arthritis. *Ortho. Clin. N. Am.*, 9:1053-1063, Oct., 1978.
- ²⁴Smukler, N. M.: Arthritic disorders of the spine. *In* The Spine. R. Bailey (Ed.), pp. 721-789, Philadelphia, W. B. Saunders Co., 1975.
- ²⁵Swinson, D. R., Hamilton, E. B., Matthews, J. A., *et al.*: Vertical subluxation of the axis in rheumatoid arthritis. *Ann. Rheum. Dis.*, 31:359-363, Sept., 1972.
- ²⁶Webb, F. W. S., Hickman, J. A., and Brew, D. St. J.: Death from vertebral artery thrombosis in rheumatoid arthritis. *Brit. Med. J.*, 2:537, 1968.
- ²⁷Whaley, K., and Carson, D. W.: Fatal subaxial dislocation of the cervical spine in rheumatoid arthritis. *Brit. Med. J.*, 2:31, 1968.
- ²⁸White, A. A., III, Johnson, R. M., Panjabi, M. M., and Southwick, W. O.: Biomechanical analysis of clinical stability of the cervical spine. *Clin. Ortho.*, 109:85-96, 1975.

POST IRRADIATION SARCOMA OF BONE

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Introduction

The first case of post-irradiation cancer reported appeared only six years after the discovery of x-rays by Roentgen in 1895. This skin cancer involved the hand of a roentgen technician.⁶ Since that time, radiation has been used extensively for diagnostic as well as therapeutic purposes. A secondary sarcoma may rarely be induced by this treatment. This case illustrates the long latent period before the appearance of sarcoma and the value of surgical treatment for palliation in spite of the poor prognosis.

Case Report

An 80 year old white female underwent a right radical mastectomy for ductal adenocarcinoma with one positive lymph node at age 54. She then received 4,000 rads (200 keV) to her right shoulder girdle.

Twenty years later when she noted right shoulder pain, a mass was found in her right scapula. Radiographs showed some increase in density and were interpreted as an osteochondroma. Follow-up over the next six months showed no change in the appearance or size of the lesion.

The patient returned three years later with marked enlargement of the mass, and overlying tenderness (Figure 1). She was then referred to the University of Iowa Hospitals where, based on the history, physical examination and radiographic findings, the diagnosis of post-irradiation sarcoma of bone was made. A right forequarter amputation was performed (Figure 2). Pathologic examination confirmed the diagnosis of osteosarcoma of the right scapula, with areas of tumor necrosis, hemorrhage and invasion of overlying muscles (Figure 3).

Following surgery the patient remained asymptomatic and led a normal life for two years. At two years she was found to have right pleural effusion on routine chest roentgenogram. Three months later she returned with shortness of breath, difficulty swallowing

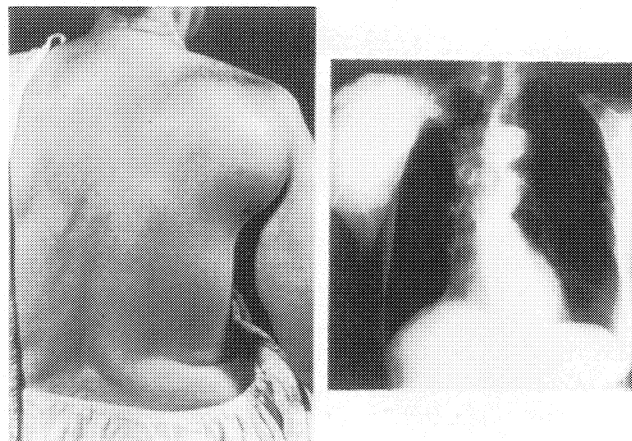


Figure 1. Pre-operative patient photograph (A) shows the prominent swelling over the right scapula, and chest radiograph (B) revealing fluffy bony density in that area.

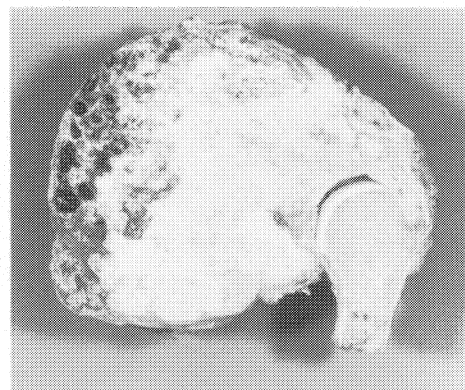


Fig. A



Fig. B

Figure 2. Cross-section of the gross specimen shows dense lobular masses of tumor (A) and its radiograph (B): Note areas of focal necrosis and hemorrhage. The tumor did not involve the shoulder joint or proximal humerus.

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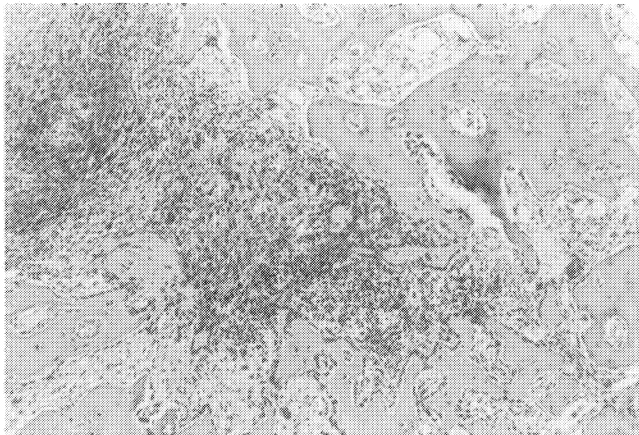


Figure 3. Photomicrograph characteristic of lesion (H & E, 200 X) shows the proliferation of osteoblasts with interstitial ossification and invasion of surrounding bone.

and right thigh pain. A bone scan (Tc 99m polyphosphate) revealed mediastinal and rib metastases, as well as lesions in her right ischium, femur and liver (Figure 4). Her symptoms progressively worsened and she died within three weeks.

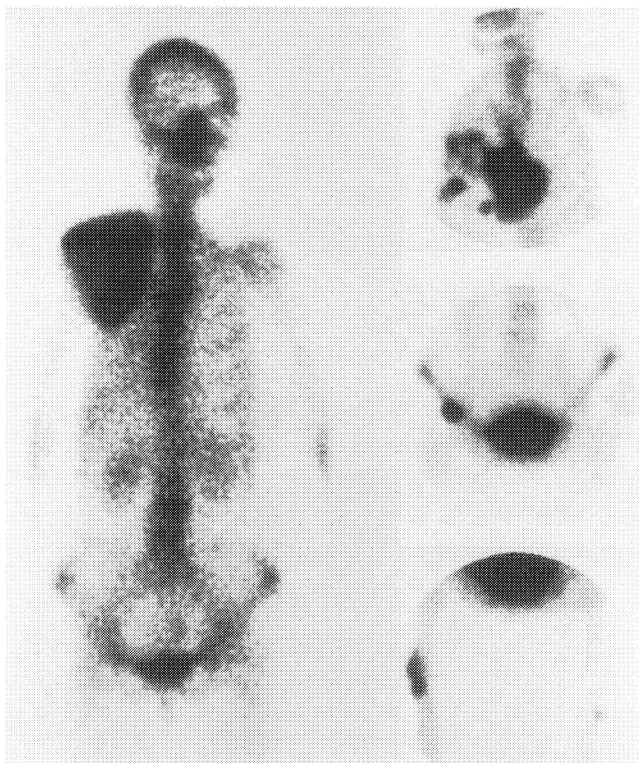


Fig. 4A

Figure 4A. Bone scan (tc 99m polyphosphate) twenty years after radiation: The increased uptake is limited to the right scapula.

Fig. 4B

Figure 4B. Bone scan three years after amputation: The uptake in the mediastinum, ribs, right ischium and femur.

Discussion

The overall incidence of post-irradiation sarcoma ranges from 0.1 to 0.2 percent.³ Characteristically there is a history of low-voltage irradiation (less than 200 keV).

Little has been written about the neoplasm-inducing potentials of the new high voltage equipment currently used in radiation therapy. Obviously, not enough time has elapsed since their introduction for a reliable evaluation, since the latent period from time of radiation to appearance of the sarcoma can be over forty years! Bone does absorb a great deal more energy with extremes of voltage.⁵ However, there have been cases of radiation-induced sarcoma within the current photon energy range.⁹ Radiation quality and dosage, method of delivery and the patient's age all seem to have little bearing on the incidence.²

In order to qualify as a radiation-induced sarcoma, a lesion must: (1) arise in an area previously free of malignancy. (2) develop within the radiotherapeutic field. (3) appear after a relatively long latent period. (4) be proven histologically.²

Post-irradiation sarcomas have occurred as early as three years after radiation and as late as forty-two years following treatment.^{3,7} The great majority of reported cases became symptomatic five to fifteen years after radiation. Most lesions have been osteogenic sarcoma and fibrosarcoma with a few chondrosarcomas, undifferentiated sarcomas and others.^{1,3,8} Average survival has been approximately one year.^{4,7} The aggressiveness of these lesions varies.⁴ Our patient was submitted to low voltage irradiation for a breast carcinoma; a bone sarcoma developed in that region twenty years later. She was asymptomatic for four years following the appearance of her sarcoma, and an additional two and one-half years after her forequarter amputation, suggesting a relatively dormant stage of the tumor. This became fulminant only during the last three weeks of her life.

No criteria presently available will allow us to select patients at high risk to develop post-irradiation sarcoma. A high index of suspicion must be maintained for every patient treated by radiation. A new lesion in a previously irradiated part should be considered a malignancy (recurrence, metastasis, or post-irradiation sarcoma) until proven otherwise. Since the prognosis is unpredictable, appropriate treatment, including ablative surgery should be initiated promptly. Any period of symptom-free survival would justify this approach.

References

- ¹Arlen H., Higinbotham N., Huvos A., Marcove R., Miller T., and Shah I.: Radiation induced sarcoma of bone. *Cancer*, 28:1087-1099, 1971.
- ²Cahan W. G., Woodard H. Q., Higinbotham H. L., Stewart F. W., and Coley B. L.: Sarcoma arising in irradiated bone. *Cancer*, 1:3-29, 1948.
- ³Hatfield P., and Schulz M.: Post-irradiation sarcoma. *Radiology*, 96:493-602, 1970.
- ⁴Mindell E., Shah N. and Webster J.: Post-radiation sarcoma of bone and soft tissue. *Ortho. Clinc. of N. Am.*, 8:821-834, 1977.
- ⁵Parker R., Berry H.: Late effects of therapeutic irradiation on the skeleton and bone marrow. *Cancer*, 37:1162-1171, 1976.
- ⁶Petersen, O.: Radiation cancer. *Acta Radiologica*, 42:221-236, 1954.
- ⁷Senyszyn J., Johnston A., Jacox H. and Chu F.: Radiation-induced sarcoma after treatment of breast cancer. *Cancer*, 26:394-403, 1970.
- ⁸Sim F., Cupps R., Dahlin D., Ivins J.: Post-radiation sarcoma of bone. *J. Bone and Joint Surg.*, 54A:1479-1489, 1971.
- ⁹Tewfik H., Tewfik F., Latourette H., and Christie J.: Radiotherapy-induced rib osteosarcoma after successful treatment of lung cancer. *Radiology*, 125:503-504, 1977.

ASSESSMENT OF BACK PAIN FOR THE PURPOSES OF CLINICAL TRIALS: PART I

Malcolm I. V. Jayson*†

Introduction

Back pain is one of the most frequent causes of disability. Sooner or later it affects most members of our society. Despite the substantial morbidity and loss of work that it produces, objective data evaluating the values of various forms of treatment are largely lacking. There is obvious interest in knowing the relative merits of various therapeutic programs, but despite that, few controlled trials have been conducted comparing different types of treatment. The reasons for the lack of adequate studies include: the difficulties in diagnosing the precise source of symptoms in the individual patient, the variable and fluctuating course that back pain pursues in any one subject, the high incidence of spontaneous remission and recurrence, and the lack of generally acceptable methods of assessing progress. Selection of clinical material also plays a highly significant role in determining the prognosis in any group of patients. For example, patients in a factory environment, on the whole, have far more trivial and shorter lasting problems than those who need referral to a specialist clinic; therefore, the population group under study must be defined.

Mobilization and Manipulation

Our interest in assessment techniques was stimulated by two studies of the management of nonspecific low back pain based on a widely used form of mobilization and manipulation used in many countries and described by Maitland.¹ These studies included two population groups. The first was a series of patients with nonspecific back pain under the care of their general practitioners (Primary Care Physicians) for whom a specialist opinion had not been sought (GP patients)² and the second was a series of patients referred to hospital rheumatological or orthopaedic specialists for a further opinion because of persistent low back pain (Hospital patients).³

They all had low back pain for at least one month. Inflammatory or other specific disorders such as ankylosing spondylitis, Paget's disease, vertebral collapse,

bladder and bowel disturbances, muscle wasting, previous spinal surgery, pregnancy, gross psychological disturbances and other medical disorders that might contraindicate the forms of treatment used excluded patients from the trial.

All patients attended the physiotherapy department three times a week for four weeks. They were randomly allocated to treatment by mobilization and manipulation or to placebo therapy, which was microwave radiation at the lowest possible setting given by the physiotherapist, with comparable degrees of enthusiasm.

The assessments were performed by a trained physician without knowledge of which form of treatment was given. A detailed history and physical examination gave particular reference to the spine with attention to:

1. The subjective assessment of severity of pain scored on a scale: completely better, much better, slightly better, no change, slightly worse and much worse.
2. Physical activity which was divided into: completely normal, restricted activity and unable to work.
3. Opinion of the value of treatment divided into: very helpful, some help, useless and made it worse.

Spinal movements including flexion and extension and lateral flexion to the right and left and straight leg raising of both right and left lower limbs were measured using a spirit level goniometer.⁴ Assessments were performed prior to entry in the trial, at four weeks immediately after the course of treatment, and two months after the conclusion of treatment. At one year all patients received a postal questionnaire with a personal visit to those who failed to reply in order to ensure a high completion rate.

Ninety-four patients were entered into each of these two trials and randomly allocated between the two forms of treatment. The patients in the GP and Hospital series were similar in most respects but the latter were significantly older, more severely restricted in physical activity, had a longer duration of pain, more frequently suffered from night pain, had a greater restriction of spinal movements, and showed a higher frequency of degenerative changes on roentgenograms of the spine.⁵

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Immediately after the four week course of treatment the majority of patients in both groups thought that their symptoms were improved, irrespective of whether they were treated by placebo or by mobilization and manipulation. In the Hospital series the improvements were similar in both groups, whereas in the GP series there was a slight but definite advantage in favor of the mobilization and manipulation patients.

At three months these assessments were again repeated. The majority of patients in both trials were still improved. There were no differences between the mobilization and manipulation and the control groups in the Hospital series. In the GP study most of the advantages of the mobilization and manipulation patients had disappeared.

At one year most patients were still better than when first seen. The GP patients had fared better than the Hospital series as would be expected. No differences were found between the mobilization and manipulation and the control groups either in the GP series or in the Hospital series.

Analysis of the data suggested that those with the shortest length of preceding history had improved the most.

Conclusions

This study emphasizes the importance of conducting controlled trials in the management of back pain. If these had been uncontrolled studies of patients treated by mobilization and manipulation alone, the benefits would have appeared extremely impressive; but the presence of the control group showed little advantage to this form of treatment. The GP patients on the whole improved more than the Hospital series, emphasizing the need to define the population group from which the subjects are drawn.

The majority of patients will recover from the immediate attack of back pain. This form of treatment may hasten the resolution of symptoms in a few but makes no difference in the long run.

However, these studies were only directed at one particular form of mobilization and manipulation performed by a trained physiotherapist. There are other techniques and they may be practiced by orthopaedic surgeons, physiatrists, specialists in manipulative medicine, osteopaths and chiropractors. Further trials are required to determine whether these methods have anything additional to offer.

References

- ¹Maitland, G.D.: *Vertebral Manipulation*. Fourth Edition, London, Butterworth's 1977.
- ²Sims-Williams, H., Jayson, M.I.V., Young, S.M.S., Baddeley, H., and Collins, E.: Controlled trial of mobilization and manipulation for patients with low back pain in general practice. *Brit. Med. J.*, 2:1338-1340, 1978.
- ³Sims-Williams, H., Jayson, M.I.V., Young, S.M.S., Baddeley, H., and Collins, E.: Controlled trial of mobilization and manipulation for low back pain: hospital patients. *Brit. Med. J.*, 2:1318-1320, 1979.
- ⁴Loebl, W.Y.: Measurements of spinal posture and range of spinal movements. *Ann. Phys. Med.*, 9:103, 1967.
- ⁵Jayson, M.I.V., Sims-Williams, H., Young, S., Baddeley, H., and Collins, E.: Mobilization and manipulation for low back pain. *Spine*, 6:409-416, 1981.

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ASSESSMENT OF BACK PAIN FOR THE PURPOSES OF CLINICAL TRIALS: PART II

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Studies have been performed in order to try and improve the measurement of back pain for the purposes of clinical trials. These assessment techniques can be divided into those which examine the experience of pain by the subject and the resulting incapacity and interference with normal life, and those measuring the alterations in physical signs, particularly the movements of the back and straight leg raising. The former are termed subjective assessments and the latter objective assessments.

The objective assessments are relatively easy to quantify and techniques have been developed and validated by Loeb¹ and Moll and Wright² to quantify spinal movements. In particular, flexion, extension, lateral flexion and straight leg raising are easily measured; whereas there are greater difficulties in measuring lateral rotation. However, the ability of the spine to move correlates poorly with the development of low back pain. Many subjects have severely restricted motion yet few symptoms, and the rigid spine in severe ankylosing spondylitis may be painless. One form of treatment of the painful back may be a spinal fusion when the loss of movement relieves symptoms. At the other extreme, some patients with hypermobility syndromes and excessive spinal movements suffer severe pain.³ For these reasons, it appears that in assessing the progress of back pain, the emphasis should be on the pain and on the resulting disability.

Experience made us dissatisfied with the use of digital scales such as scoring symptoms and other features on a better, same or worse or similar type of basis. These simple descriptive terms are ill-defined with usually no examination of their reliabilities. Use of these types of assessments should be validated both by examining their reproducibilities when the tests are repeated by the same observer and also when repeated by another observer. Clearly if different results are found then the test has no value and the results have no meaning.

Another problem commonly arises when many different types of tests are used. In many studies the standard level of statistical significance is $p < 0.05$, which

means that the result could have occurred by chance in 1 in 20 tests. As the number of tests increases so does the chance of reporting results of no true significance.⁴ When many different assessments are made and only a few yield significant results, the interpretation must incorporate the number of tests used as well as the statistical significance of individual tests. A method is required to integrate the information to provide an index of overall progress.

One of the most commonly used and extensively investigated techniques of pain assessment uses the Visual Analogue Scale (VAS).⁵ A straight line 100mm long is drawn on a piece of paper, and the end points of the scale represent at one extreme no pain and at the other the pain as most severe. This scale is explained to the patient who is then asked to mark on the line exactly where he or she feels his or her own problem lies. The patient's rating is converted to a score by measuring the distance of the mark from the origin of the scale. In other applications these ratings have been used to measure feelings.⁶ We have used the principles of these methods, not only for assessing pain, but also for other subjective symptoms and disabilities in the low back pain subject.

Although the VAS technique is extremely helpful, many applications of it suffer from the problem of 'representativeness.' The patient is being asked to average his experience of pain over both time and situations. However, as many patients point out, the amount of pain depends upon what the patient is actually doing. Further assessment of pain should include reference to disruption of life style, although the patient's estimation of this is likely to affect his or her judgment of the severity of the pain.

We therefore developed a series of 15 questions with respect to various aspects of pain (Appendix A). The direction of these questions was as follows:

1. The severity of the pain as perceived by the patient.
2. The magnitude of the type of problem that will make the pain worse.
3. The disruption of normal life style.

We also developed a method of integrating the results of these 15 different assessments to provide a unified overall subjective index.

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We made 10 measures of spinal movement and straight leg raising which included flexion, extension, lateral flexion in both directions using both the tape measure method² and the spirit level goniometer,¹ and straight leg raising in both lower limbs using the spirit level goniometer, and again have been able to combine these to provide a single overall objective index. The 10 objective assessments are listed in Appendix B.

Suitable patients were of either sex, over 18 years of age and had suffered from chronic low back pain for at least 6 months. The blood sedimentation rate, full blood count, biochemical profile, routine examination of urine and plain radiographs of the spine were performed, and patients were excluded if any abnormality other than lumbar spondylosis was found.

The subjective and objective assessments were separately repeated by the same observer and the subjective assessments by separate observers. In the light of experience we subsequently modified the assessment procedures.

In order to obtain the overall indices of progress, the 15 subjective and 10 objective measurements were combined to form the subjective and objective indices respectively. These were taken by normalizing the data for each variable in order to make them comparable and then combining them. All scores were standardized by subtracting from each score the mean of the group and dividing the difference by the standard deviation so that the scores for each question had the same mean (namely zero) and the same standard deviation (namely 1.0). If this standardization had not been formed and the raw scores simply added together, the resulting indices would have been particularly influenced by the scores with the highest readings and standard deviations. This equalization of the mean and spread of results for each patient meant that they could be combined in a useful fashion.

The initial studies of the subjective assessments showed a high degree of intra-observer reproducibility both for the individual questions and for the overall subjective index. However, when two separate assessors used the same questionnaire on the same subjects the results showed a satisfactory degree of agreement in certain questions but in a number there were poor correlations. Clearly certain questions were being interpreted by the observers and therefore by the subjects in different ways. Therefore, certain questions were replaced and others redesigned in order to seek similar information but to reduce the degrees of confusion. Potential ambiguities in each question were discussed and agreement reached on the precise procedures to be adopted in answering particular patient enquiries. The questions were asked in a standardized fashion using a standard script for each.

Instead of asking patients to mark their line on a piece of paper, a process that generated a large quantity of paperwork, a modified slide rule was used. One side of this was blank except for the defined end points of the 100mm line. The other side of the rule was marked in graduations of 1mm on the back. The patient scored his rating by moving an arrow along the blank side of the 100mm line and the observer was able to read and record the measurement directly and then return the arrow to zero for the next reading. This technique provided no difficulties for the patient, saved a considerable amount of time and paper and eliminated problems of interpretation about where the subject made his mark.

With these modifications repeat inter-observer studies showed a high degree of reproducibility both for the individual questions and also for the overall subjective index.

The objective measures, previously tested by other authors, were repeated on separate occasions on the same day by a single observer. These showed acceptable degrees of reproducibility. The global objective index derived in the manner described above also showed a high degree of reproducibility.

Application of assessment methods to determine the contribution of the spinal support in a lumbar corset.

A clinical trial has been conducted in order to obtain experience with these assessment methods in practice and also to evaluate the mechanisms of pain relief provided by lumbar corsets. This relief of symptoms may be due to the spinal support restricting the motion of the spine and making the subject sit and stand with a better posture, or alternatively by the tight corset increasing intra-abdominal pressure thus allowing a substantial proportion of the body load to be transmitted through the abdomen rather than the spine. Advantage was taken of a new design of lumbar corset, in which the spinal support is provided by a removable head-moldable plastic insert, to examine the contribution of the insert to relief of symptoms.

Included were back pain patients with the previously mentioned characteristics. They were allocated randomly to be provided with corsets either with or without the spinal support, but were not told whether the type of support was of any significance. The corset (Johnson & Johnson Limited) consisted of a wide wrap-over bodybelt made in appropriate sizes and fastened by a strap. A plastic insert was placed in a large pocket in the back of the corset. This insert was made of Orthoplast,* a synthetic thermoplastic material which is rigid at and below body temperature but is moldable when heated to 70-75°C. By heating the insert to this temperature it could then be molded to the patient's

back in a suitable posture and the shape retained thereafter. The patients were asked to wear their corset during the day and were given appropriate instructions on bending, lifting and care of the back.

The subjective and objective assessments as described were performed by the same observer who was unaware of the type of corset that was provided. The assessments were performed on entry to the trial and after 4 and 8 weeks of corset use.

Results

Statistical correlations compared the progress of individual scores in the two groups and also the relative changes of the two groups. There were significant improvements in a number of the subjective questions in the patients with the corset but only limited improvement in those with the corset without the support. In several of these questions these improvements were significantly greater in the corset with support group than in those without support. The overall subjective index improved significantly in the patients with the support but not in those without the support, and the difference between the two groups was highly significant (Figure 1).

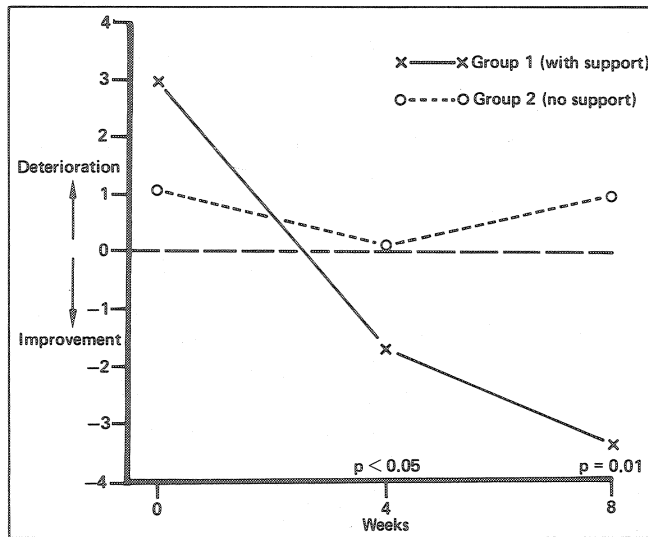


Figure 1.

Subjective change in patients with lumbar corset with support and without support.

With respect to the objective assessments there were significant improvements in both groups in the individual measurements and in the overall objective indices. There were no significant differences in the changes between the two groups (Figure 2).

The corset with the spinal support provides significantly greater relief of symptoms than the corset without the support. There were no differences in the objective changes of spinal motion and straight leg raising between the two groups.

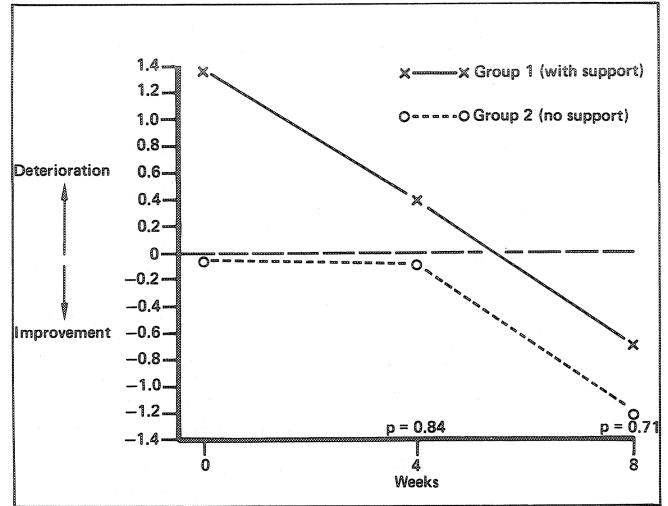


Figure 2.

Objective change in patients with lumbar corset with support and without support.

This study has demonstrated the practical use of these methods for assessing the progress of back pain. The individual subjective problems of the back pain patient can be recorded in a way that can be used sequentially for following progress. These many different items of information can be integrated to provide a global index. These techniques can satisfactorily differentiate a corset with a lumbar support from a similar corset without the support.

We have separated these subjective parameters from objective measurements. The severity of symptoms and their interference with life style are of fundamental concern to the patient. The ranges of spinal movement and straight leg raising are useful objective measurements of spinal function but show very poor correlation with the patient's problems. Here we have shown that there may be significant differences in subjective performance and yet no changes in spinal movements. The emphasis in assessing the progress of back pain must be on the subjective parameters, and the objective measurements, although superficially attractive, are of limited if any value. Measurement of spinal motion in assessing the progress of back pain should only be used when there is a defined underlying disease such as ankylosing spondylitis for which it seems most appropriate to increase spinal movements.

There are two postulated mechanisms for the relief of symptoms by lumbar corsets. First they restrict motion and preserve good posture, although there is conflicting information about whether spinal movements are actually restricted by wearing a lumbar corset.^{7,8} Anderson⁹ showed the influence of a well designed lumbar support in maintaining the lumbar lordosis and minimizing the stresses transmitted by the intervertebral

disc. The alternative hypothesis is that the corset acts as an abdominal binder. By increasing intra-abdominal pressure it allows an alternative route for transmission of body load, so relieving the spine of a portion of its stress.

The present study does not support the concept that the symptoms are relieved by the corset acting as an abdominal binder although it does not exclude that possibility as in both subjects a tight corset would have raised intra-abdominal pressure. However, there was no improvement in the overall subjective index in the patients wearing the corset without the spinal support. On the other hand, in the group wearing the corset with the support, there was a considerable and significant improvement in symptoms. This suggests that restriction of spinal motion is an important mechanism of relief of symptoms by a lumbar corset.

Conclusions

In assessing the treatment of back pain, one must carefully define the population group and conduct studies as controlled trials. Assessment methods are all important, and the techniques used must be reproducible to provide valid results. The method using the VAS is specifically directed toward assessing the progress of back pain patients for purposes of clinical trials and seems particularly useful for making sequential measures in the same subjects. It is possible to integrate the information to provide overall indices of progress. In trials of the progress of the back pain patient, the emphasis must be on the severity of the symptoms, the magnitude of problems required to produce exacerbations of symptoms and the interference with life style. Measurements of spinal motion and straight leg raising are of relatively little, if any, value.

Bibliography

¹Loebl, W.Y.: Measurements of spinal posture and range of spinal movements. *Ann. Phys. Med.*, 9:103, 1967.

²Moll, J. and Wright, V.: Measurement of spinal movement in the lumbar spine and back pain. 2nd Edition, Edtd. M.I.V. Jayson, Pitman Medical 157-183, 1980.

³Howes, R.G. and Isdale, I.C.: The loose back: an unrecognized syndrome. *Rheumatology and Physical Medicine*, 11:72-77, 1971.

⁴Miller, R.C.: *Simultaneous Statistical Inference*. McGraw-Hill, New York, 1966.

⁵Huskisson, E.C.: Measurement of pain. *Lancet*, 2:1127-1131, 1974.

⁶Aitken, R.C.B.: A growing edge of measurement of feelings. *Proc. Roy. Soc. Med.*, 62:989-993, 1961.

⁷Norton, P.L. and Brown, T.: The immobilising efficiency of back braces: their effect on the posture and motion of the lumbo-sacral spine. *J. Bone and Joint Surg.*, 39A:111-139, 1957.

⁸Grew, N.D.: Functional assessment of lumbar spine. *Oxf. Orthop. Eng. Ann. Rep.*, 45-53, 1979.

⁹Anderson, E.J.G.: On myoelectric back muscle activity and lumbar disc pressure in sitting postures. Thesis, University of Goteborg, Sweden, 1974.

APPENDIX A

Subjective Variables Asked on Back Pain Questionnaire for Visual Analogue Assessment

1. Do you have any pain in the back? How severe is it?
(No pain – intolerable)
2. Do you have any pain in the night? How severe is it?
(No pain – intolerable)
3. If activity gives you pain, how much does it need to give you backache?
(A great deal – almost none)
4. Do you get relief from pain killers?
(Complete relief – no relief)
5. Do you have any stiffness in the back?
(No stiffness – intolerable stiffness)
6. Does your back pain interfere with your freedom to walk?
(Complete freedom to walk – completely unable to walk because of pain)
7. Do you have discomfort when walking?
(None at all – intolerable)
8. Does your pain interfere with your ability to stand still?
(Stand still for a long time, that is an hour – not able to stand still at all)
9. Does your pain prevent you from turning and twisting?

(Complete freedom to twist—completely incapable of twisting)

10. Does your back pain allow you to sit on an upright hard chair?
(Complete freedom to sit on a hard chair—so much pain that you cannot sit on such a chair at all)
11. Does your back pain prevent you from sitting on a soft armchair?
(Complete comfort—such discomfort that cannot sit on a soft chair at all)
12. Do you have back pain when lying down in bed?
(Complete comfort—no comfort at all)
13. What is your overall handicap in your complete life style because of back pain?
(Completely free to perform any task—totally handicapped)
14. To what extent does your pain interfere with your work?
(No interference at all—totally incapable of work)
15. To what extent does your work have to be modified so that you are able to do your job?
(No adjustment to work—so much adjustment that have had to change your job)

APPENDIX B

Objective Assessments

1. Straight leg raising—right (degrees)
2. Straight leg raising—left (degrees)
3. Lumbar extension (degrees)
4. Lumbar extension (cms)
5. Lumbar lateral flexion—right (degrees)
6. Lumbar lateral flexion—right (cms)
7. Lumbar lateral flexion—left (degrees)
8. Lumbar lateral flexion—left (cms)
9. Lumbar flexion (degrees)
10. Lumbar flexion (cms)

FORCES ON THE FEMORAL HEAD DURING ACTIVITIES OF DAILY LIVING

Richard A. Brand, M.D.*
 Roy D. Crowninshield, Ph.D.*
 Richard C. Johnston, M.D.*†
 Douglas R. Pedersen, B.S.E.*

Estimation of muscle and joint forces has been a goal of investigators since Borelli reported the first such calculations in 1680.² However, because of technical limitations, the first reasonably accurate reports of joint forces during locomotion were not made until the mid 1960s.^{14,16} The initial motivation for such measurements or calculations was undoubtedly a fundamental interest in the way the body worked. Only within the last few years has technology evolved to such a point that measurements for calculations of muscle or joint

forces could be used to answer some clinically relevant question. This paper will review contemporary efforts to calculate hip joint forces and will report forces in the hip in a variety of activities of daily living.

Background

Any work is better understood with an historical perspective. This is particularly true in the case of studies requiring complex technology. We will therefore review our general approach to the problem of

Table I

Mathematical Predictions of Muscle and Joint Forces	
A. Advantages	
1. Many subjects	
2. Flexible—many problems	
3. Normal and abnormal joints	
4. Inexpensive/Subject	
B. Disadvantages	
1. Many assumptions	
2. Many sources of error	
3. Requires attention to detail	
4. Simple activities only	
Transducer Measurements of Muscle and Joint Forces	
A. Advantages	
1. Definitive	
2. Simple or complex activities	
B. Disadvantages	
1. Few subjects	
2. Few joints/muscles	
3. Abnormal joints only	
4. Expensive/subject	
5. Technical, Ethical, Legal Problems	

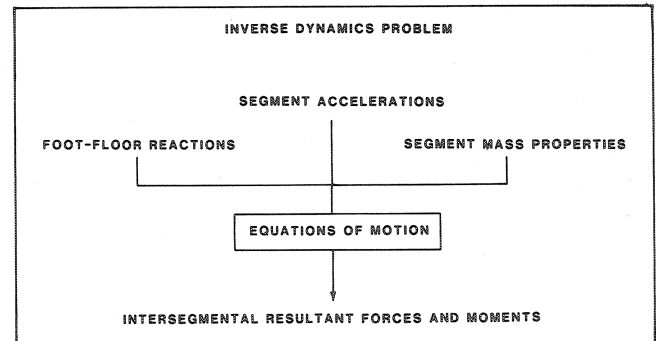


Figure 1A. Diagrammatic formulation of inverse dynamics problem showing input and output.

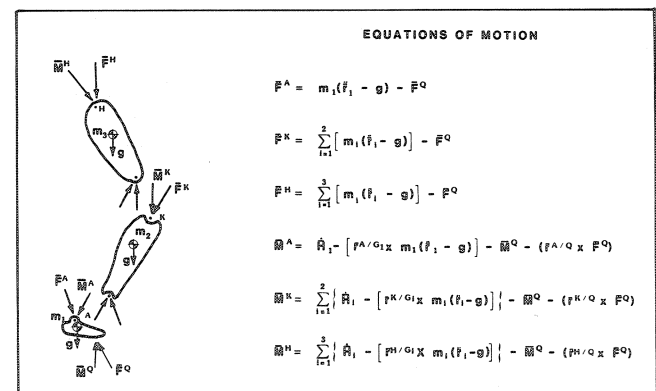


Figure 1B. Equations of motion needed to calculate intersegmental resultant forces at the ankle (\bar{F}^A), knee (\bar{F}^K), and hip (\bar{F}^H) and the intersegmental resultant moments at the ankle (\bar{M}^A), knee (\bar{M}^K), and hip (\bar{M}^H). The input to these equations includes foot-floor reactions (\bar{F}^Q, \bar{M}^Q), segment accelerations ($\bar{f}_1, \bar{f}_2, \bar{f}_3$), and segment mass properties (mass, mass center location, mass moment of inertia).

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calculating muscle and joint forces and then place that approach in an historical perspective.

Muscle and joint forces potentially may be measured by transducers or predicted by mathematical models. Each approach has inherent advantages and disadvantages (Table I). The two methods share few limitations and therefore can potentially be used to great advantage when combined; we say potentially because there are only two reports of successful implantation of transducers in humans: Rydell's report of two patients with instrumented endoprostheses,¹⁶ and the report of Frankel and Burstein of an instrumented hip nail.¹³ We chose a modeling approach principally because of its inherent flexibility, its relatively low cost, and because the goal was more immediately realizable.

Our technique to predict muscle and joint forces requires two major steps. The first step may be called an *inverse dynamics problem*. This analysis is based on Newtonian principles and equations of motion formulated by Euler and LaGrange. Braune and Fischer elegantly performed the first such analysis of locomotion in the late 1800s.⁶ The problem may easily be described as force equals mass times acceleration, as one can see from the first equation (Figure 1B). However, the subsequent equations become more complex. The input to the equations of motion includes external reactions, segment accelerations, and segment mass properties (Figure 1A). The output of these equations is the intersegmental resultant forces and moments. These intersegmental resultants do not represent the forces of any anatomic structures, but rather represent the vector sums of all the forces in the muscles and ligaments and on the joint surfaces, and the vector sums of all the moments generated by those forces. Note that there are only six equations of motion at the ankle, knee, and hip. Resolution of these six equations into X, Y, and Z components results in a maximum of eighteen equations describing leg motion. Since there are far more unknown muscle, ligament, and joint forces than equations the problem is indeterminate. This means that one cannot calculate a unique certain set of muscle, ligament, and joint forces. In fact, there will be many mathematically feasible solutions to the equations, only one of which is the correct solution under given conditions. It is this indeterminacy which necessitates the second major step.

The second step we call a *distribution problem*. That is, we distribute or apportion the intersegmental resultants to the load-carrying anatomic structures. As earlier stated, one cannot uniquely calculate the muscle, ligament, and joint forces from the equations of motion alone since there are far more unknown forces than equations. A unique solution, although not necessarily

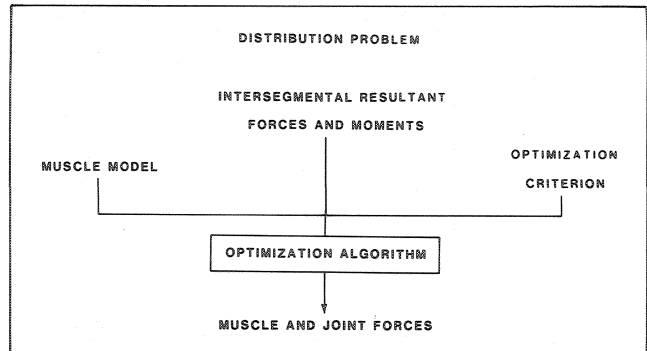


Figure 2A. Diagrammatic formulation of distribution problem showing input and output.

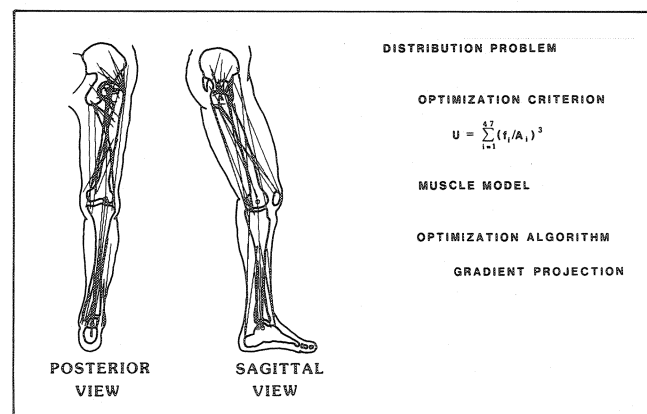


Figure 2B. Depiction of three-dimensional straight line muscle model and optimization criterion; the optimization criterion is nonlinear. A gradient projection optimization algorithm is utilized.

the correct one, can be obtained by a mathematical technique called "optimization." These techniques applied to muscle force predictions were demonstrated by Barbenel,¹ Seireg and Arvikar,¹⁷ and Penrod and Davey,¹⁵ all working independently in the early 1970s. Optimization is the process of using a computer algorithm to repeatedly solve the equations of motion so as to minimize or maximize an independent relationship called an optimization criterion (or cost function or objective function). This optimization criterion may be thought of as a mathematical analog of the rationale the brain uses to select muscles for a given activity. One may hypothesize many optimization criteria; indeed, the brain uses different rationale to select muscles in widely differing situations. Some optimization criteria predict unrealistic solutions with high forces in small muscles, and no forces in large, obviously active muscles. The choice of optimization criterion is therefore critical and each choice must be validated. The first input of the distribution problem is the intersegmental resultants, the calculation of which was just previously described (Figure 2A and B). The second requirement is a three-dimensional model of the subject

tested which quantitatively establishes the relationships of the origins and insertions of all muscles and ligaments to the bones' and joints' centers. The third requirement is an optimization criterion sometimes called an objective function or cost function. The output of the distribution process is a prediction of the muscle forces. The joint forces can then be calculated by vectorally subtracting the sum of muscle forces from the intersegmental resultant forces.

Now that we have described the general approach, we will give you some historical perspective on our work. Mechanics as a science began with the ancient Greeks. Statics developed much as we presently understand it by Archimedes in Alexandria while dynamics did not develop until the experimental studies of Galileo in the 1600s and the theoretical works of Newton, Euler, LaGrange, D'Alembert, and others in the 1600s and 1700s.

The first effort to calculate muscle and joint forces was by Borelli, whose work *De Motu Animalium* was published in 1680 shortly after his death.² Borelli's analysis was static since dynamics as a science had not yet been formulated in a usable manner. Nonetheless, *De Motu Animalium* made several fundamental contributions. The first was a practical use of the notion that man behaved as a machine. This notion dated back to the 1400s and reached its ultimate formulation with Descartes, but Borelli was the first to make practical use of it. The second fundamental contribution was the modeling of complex biological structures (such as muscles) by simple mechanical elements (such as wires). We take such modeling techniques for granted, but at the time that idea must have been radical.

A dynamic analysis of locomotion was dependent not only upon the science of dynamics, but also upon the development of clocks, recorders, and transducers. These developments occurred during the 19th century. Clocks which could measure in fractions of a second, the time frame of locomotion events, were available only at the end of the 18th century. Recorders such as kymographs, were developed in the mid 1800s, while appropriate photographic techniques became available in the late 1800s. Shortly after the appropriate technology was available, Braune and Fischer, in Germany, reported the first dynamic analysis of motion in a series of papers between 1895 and 1901. Their analysis represented a solution to the inverse dynamic problem which is basically similar to the first part of our approach described earlier. They calculated the intersegmental resultant forces and moments and the foot floor reactions, but did not provide any solution to the second part of the problem of predicting actual muscle forces in a dynamic situation. (They did carry out a static

analysis of muscle forces similar to that of Borelli.) It should be noted that later investigators, including Bresler and Frankel in 1950,⁵ carried out investigations conceptually similar to that of Braune and Fischer.⁶ They noted that the calculations of intersegmental resultant joint forces and moments required 250 to 500 man hours in the pre-computer days.

The next development, a solution to the dynamic distribution problem, was dependent to a large degree upon the development of computers, since optimization techniques were impractical without computers to iteratively solve the equations of motion. As previously mentioned, these techniques were first used for muscle and joint forces by Barbenel, Seireg and Arvikar, and Penrod and Davy, all working independently in the early 1970s. The technique was first applied to gait by Seireg and Arvikar in 1975¹⁸ and we reported a related technique in 1978.¹¹

One can thus see that the ability to mathematically calculate muscle and joint forces is highly dependent upon recent technology. Since it is still largely impractical to measure muscle and joint forces with transducers, we have used the mathematical approach to predict muscle and joint forces. We will now describe the specific details of this approach and some of the results of its use.

Method

The first part of our technique involves the calculation of intersegmental resultant forces and moments by solving the inverse dynamics problem. In our labora-

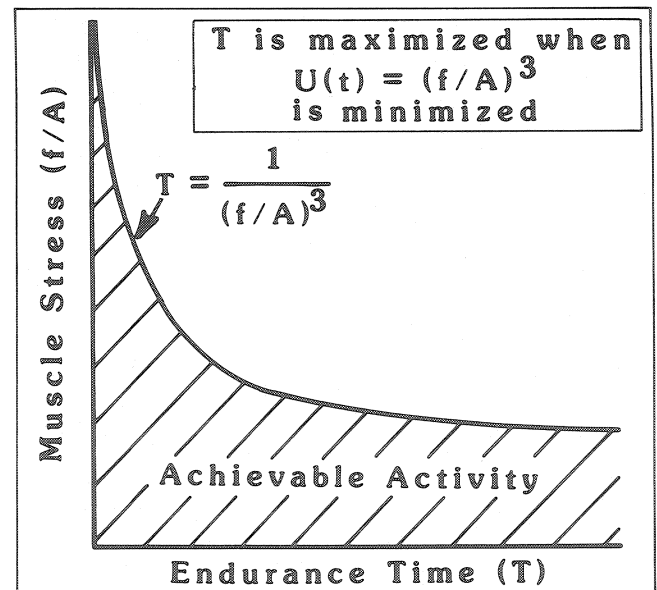


Figure 3. Physiologic basis for optimization criteria is the known nonlinear relationship between muscle stress (f/A) and muscle endurance time (T).

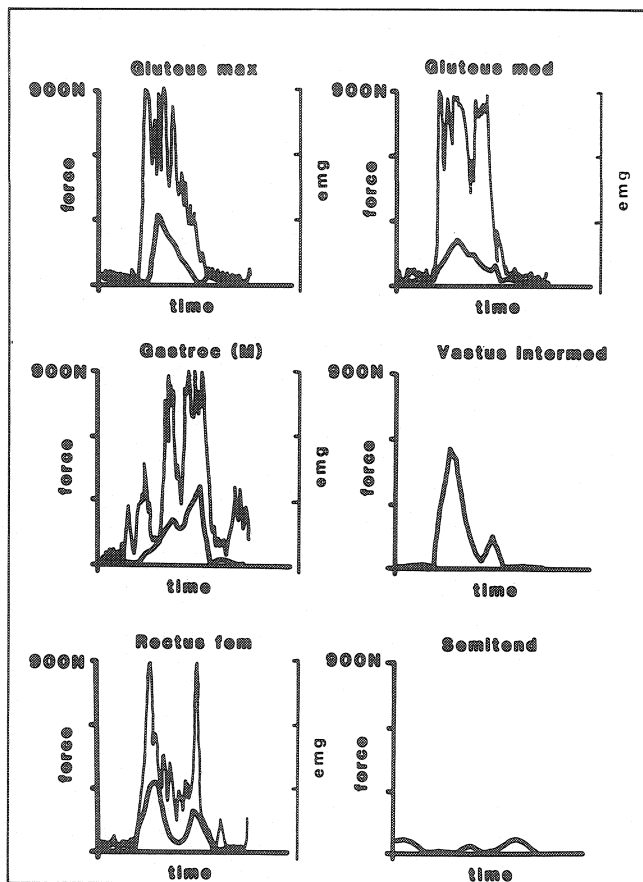


Figure 4. Prediction of forces in 6 of the 47 muscles in muscle model (see Figure 2B). EMG simultaneously collected is also shown, for 4 of the 6 muscles, showing that EMG demonstrated activity when activity was predicted.

tory, foot floor reactions are measured with a piezoelectrical force plate and motion of a subject is recorded by two cameras. Triads of noncollinear light-emitting diodes, or LED's, are fixed to the pelvis, thigh, and shank, and time-lapse photographs then allow the recording of body segment displacements during gait or some other activity. Biplanar x-rays of the pelvis are taken with the LED's in place in order to establish the location of the LED's relative to bony landmarks. Once the location of the bones' and joints' centers relative to the LED's are known, the velocities and accelerations of the bones are then calculated using numerical differentiation techniques. Mass, mass center locations, and mass moments of inertia for the subject being tested are estimated using the regression equations provided by Chandler et al.⁸ and Clauser et al.⁹ The equations of motion are then solved to obtain the intersegmental resultant forces and moments (see Figure 1B).

The intersegmental resultants are then used as one of the inputs in solving the second step, namely the distribution problem. This distribution problem also requires a three-dimensional model of the subject tested

which quantitatively establishes the relationships of the origins and insertions of all muscles and ligaments to the bones' and joints' centers. We developed the model from six cadaver limb dissections.⁵ The third requirement is an optimization criterion. While we have studied several optimization criterion, the one used for this paper is the known nonlinear relationship between muscle force or muscle stress and muscle endurance time (Figure 3).¹² Assuming this relationship, endurance time is maximized when the cube of all muscle stresses is minimized. This cost function, namely maximizing the cube of all muscle stresses, may be reasonably used only for those activities where the goal is maximizing endurance, such as level walking. It is not a reasonable criterion for stressful activities nor in pathologic conditions where the goal may be to minimize pain or joint forces. The output of the distribution problem is the prediction of muscle forces (see Figure

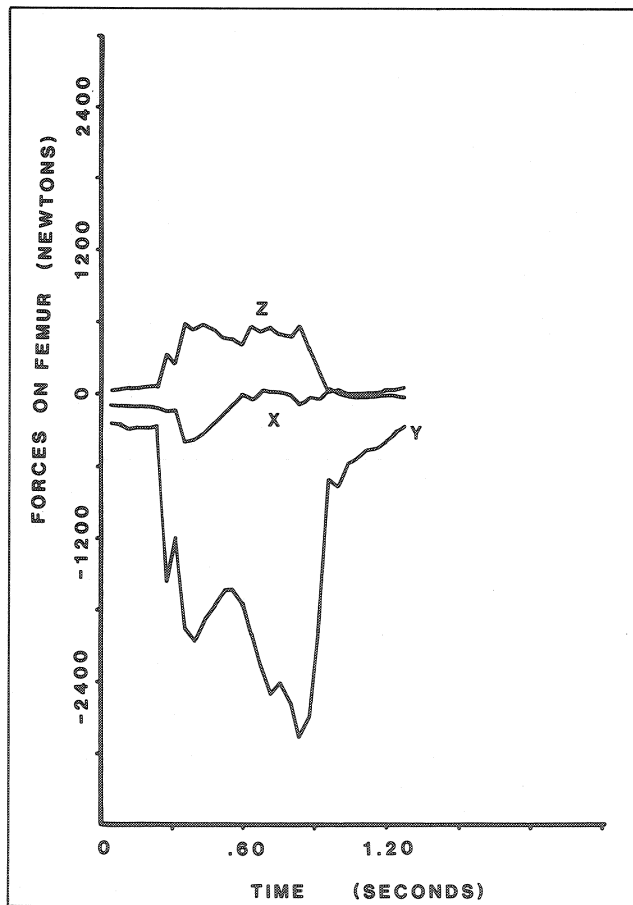


Figure 5A. Forces during single cycle of level walking on the femoral head in each of three orthogonal directions (X, Y, Z).

4). Since we do not apriori know the rationale of the brain in selecting muscles, we must validate the muscle force predictions based on any given optimization

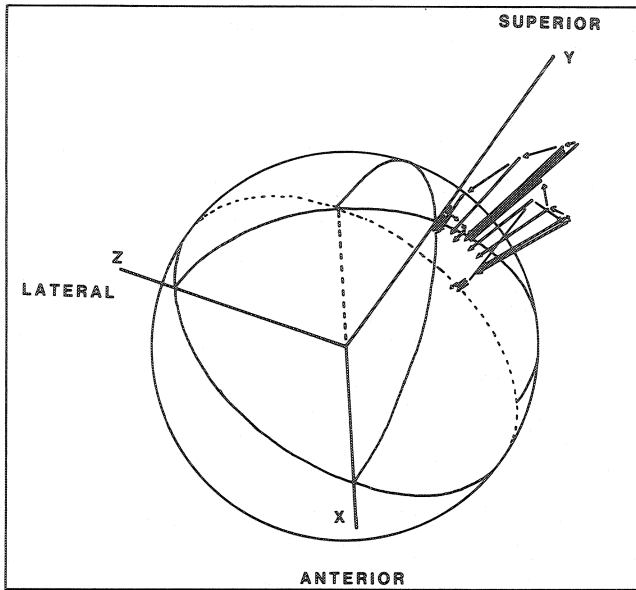


Figure 5B. Graphic depiction of forces acting on the femoral head during single cycle of level walking.

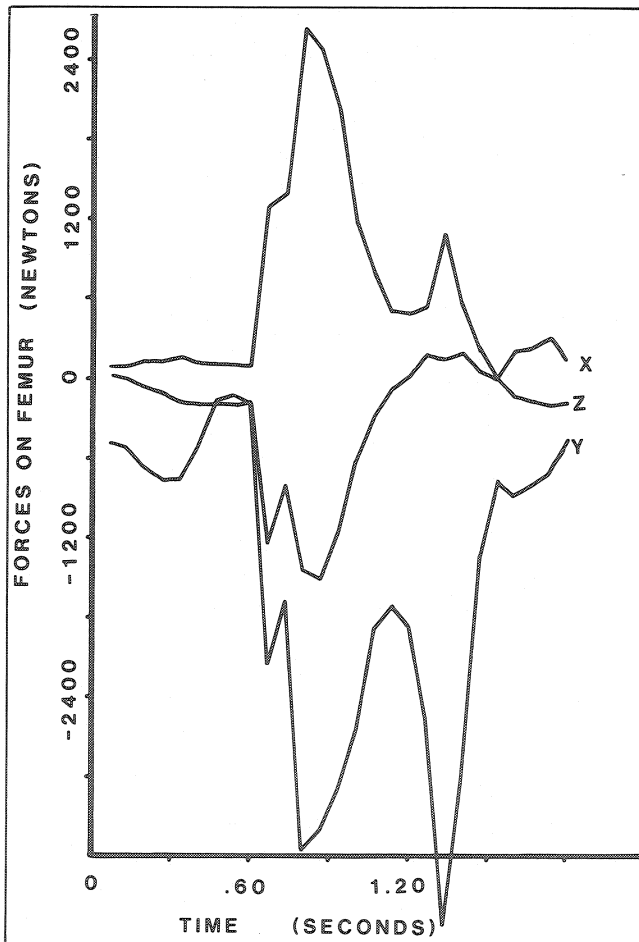


Figure 6A. Forces during single cycle of stair climbing on the femoral head in each of three orthogonal directions (X, Y, Z).

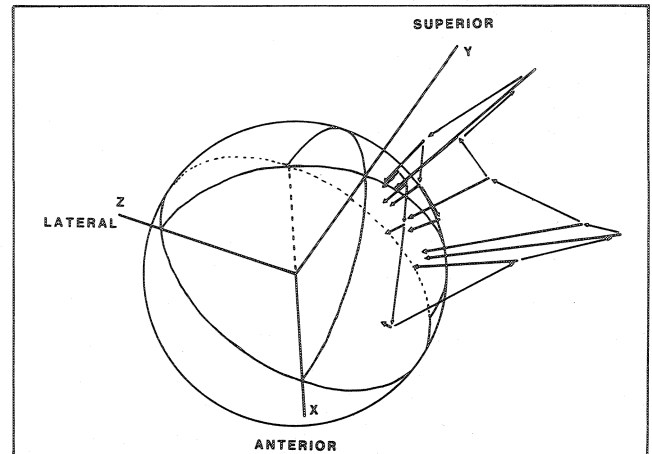


Figure 6B. Graphic depiction of forces acting on the femoral head during single cycle of stair climbing.

criterion. We do this by simultaneously collected EMG's. It is obvious that EMG signals, regardless of processing are not directly related to forces during complex, nonisometric activities. However, if the EMG's show a muscle is active when the optimization process predicts activity, if the muscle force predictions are realistic relative to muscle size, and if the optimization criterion has a sound physiological basis, then the choice of criterion seems reasonable. Once muscle forces are calculated, the joint contact forces can be calculated by vectorally subtracting the muscle forces from the resultant joint forces calculated in the first step of the problem.

Results

With the use of this tool, we can appreciate the magnitude of hip loads in many activities of daily living. Such an appreciation has implications for the treatment of many problems. We depict here the forces on the femoral head from several subjects during the following activities of daily living: level walking (Figure 5A and B), walking up stairs (Figure 6A and B), and walking down stairs (Figure 7A and B). The highest forces we have predicted are during stair climbing and range from four to six times body weight.

Discussion

Mathematical predictions of joint and muscle forces are subject to many assumptions. However, mathematical predictions are the most practical means to estimate muscle and joint forces at the present time since the actual measurement of joint and muscle forces by transducers is largely impractical, and since such measurements are inherently limited to the study of abnormal situations rather than normal situations. It would be particularly attractive to study a patient with an implanted transducer by our techniques to provide

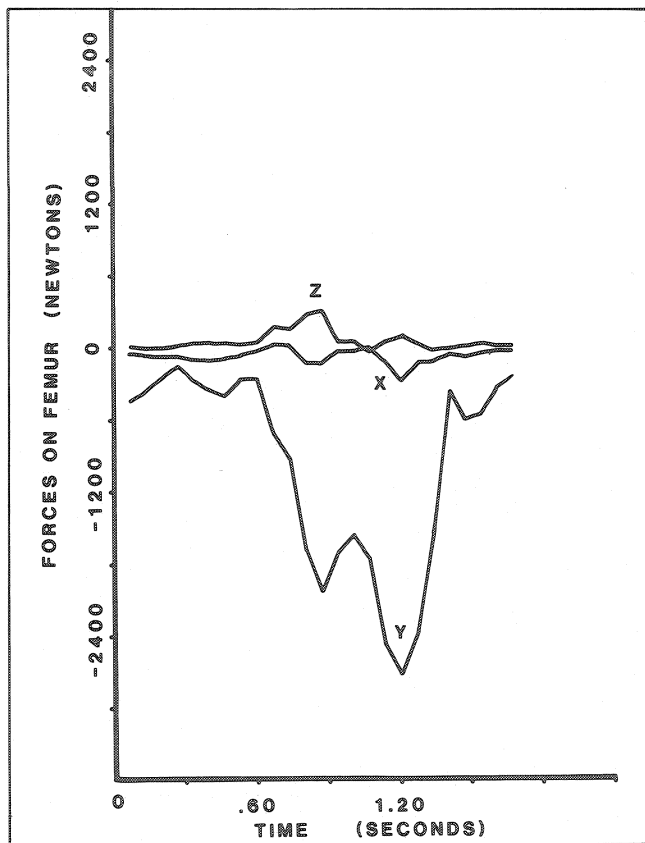


Figure 7A. Forces during single cycle of stair descending on the femoral head in each of three orthogonal directions (X, Y, Z).

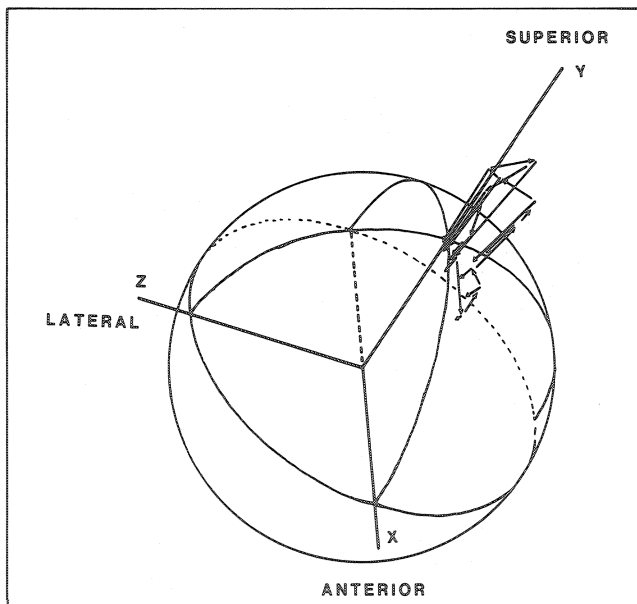


Figure 7B. Graphic depiction of forces acting on the femoral head during single cycle of stair descending.

some definitive validation. Until such a study becomes practical, however, we must rely on validation of our muscle force predictions with the use of EMG. It should

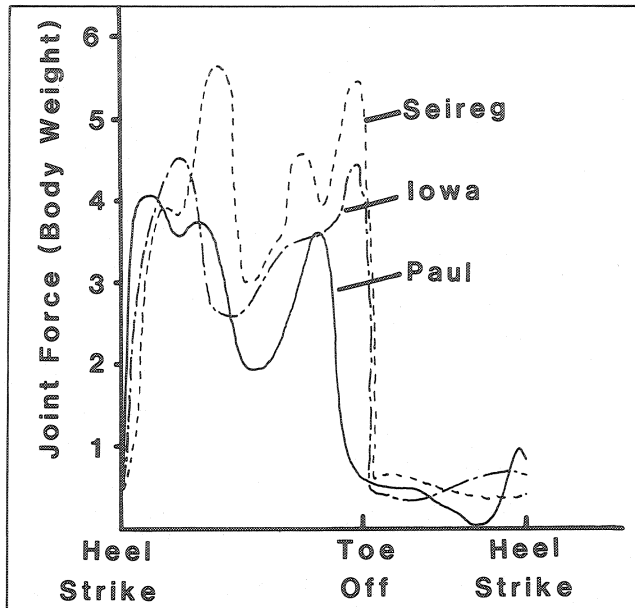


Figure 8. Comparisons of hip joint forces during single gait cycle reported by three studies (Paul, 1965; Crowninshield, et al., 1978; and Seireg and Arvikar, 1975). Considering the widely varying methods of data collection, data analysis, and muscle force predictions, the hip joint force predictions are reasonably similar.

be understood that EMG at best provides temporal validation since EMG signals are not directly related to force. It should also be understood that when a muscle is being passively stretched during locomotion, there may be some EMG signal when there is not significant force although it is not likely that there will ever be instances of significant force in the absence of EMG signal. Thus, we do not have any definitive validation for our predictions at the present time. Nonetheless, it is interesting to note that regardless of the specific technique used to calculate muscle forces, the joint force predictions are reasonably similar (see Figure 8).

A second major assumption involves the use of a particular optimization criteria. As has been pointed out, we do not a priori know the rationale in selecting muscles for a particular activity. Obviously, the brain can select many different groups of muscles and yet produce the same effect. The great redundancy of muscles around most joints suggests that the brain used different rationale under differing conditions and experimental evidence supports this notion.³ Our optimization criterion is probably reasonable only when the goal is to maximize endurance. Nonetheless, this criterion is based on a sound physiologic principle (the known nonlinear relationship between muscle force or stress and muscle endurance), and not based on some arbitrary criterion which was chosen simply for mathematical convenience as has been carried out in the past.^{10,18}

Previous papers^{10,12} have outlined further assumptions and limitations inherent to our method. The interested reader should refer to these publications for further discussion.

It is important to note that the forces on the hip are significant in many activities of daily living. Obviously, these loads must be generated by muscles acting across the hip joint rather than the body weight; any activity that requires significant muscle activity can be expected to load a joint, whether or not weight bearing is involved. Generally, the peak hip forces during the activities described is in the range of three to six times body weight. This is certainly a degree of loading which has enormous implications for the treatment of patients with internally fixed hip fractures or in patients with joint replacements. The degree of success or failure of these sorts of treatments are obviously intimately related to the ability of the implant and/or bone implant construct to hold up over a period of time. Failures of treatment can certainly be anticipated and, in fact, it is probably remarkable that the success of implants for hip fractures or joint reconstructions is as high as it is given these levels of loading. It may be expected that ambulation assists will reduce the level of loading and indeed it has been demonstrated by us that canes reduce peak hip contact forces to about sixty percent of the expected level.⁴ The effect of crutches has not been studied, but it might be anticipated that during gait they would reduce the level of loading somewhat more than would canes. It should also be noted that while our method is not suitable for studying hip loads in many activities, such as getting in and out of a bed, that Frankel and Burstein¹³ have reported substantial loads on a hip nail during activities such as using a bed pan. Thus, we must assume that many activities of daily living create substantial loads across the hip which may, in some cases, exceed the loads in level walking with the use of ambulation assists. Post-operative treatment of patients with hip implants must therefore be carried out with some appreciation of these loads.

References

- ¹Barbenel, J.C.: The biomechanics of the temporomandibular joint: a theoretical study. *Journal of Biomechanics*, 5:251-256, 1972.
- ²Borelli, Alphonso: *De Motu Animalium*. Angeli Bernabo, Rome, 1680.
- ³Bosco, C. and Komi, P.V.: Mechanical characteristics and fiber composition of human leg extensor muscles. *European Journal of Applied Physiology*, 41:275-284, 1979.
- ⁴Brand, R.A. and Crowninshield, R.D.: The effect of cane use on hip contact force. *Clin. Ortho.*, 147:181-184, 1980.

- ⁵Brand, R.A., Crowninshield, R.D., Wittstock, C.E., Pedersen, D.R., and Clark, C.R.: A model of lower extremity muscular anatomy. Submitted to *Journal of Biomechanical Engineering*, 1981.
- ⁶Braune, Wilhelm and Fischer, Otto: *Der Gang Des Menschen*. I. Teil (1895); II. Teil (1899); III. Teil (1900); IV. (1901). Leipzig, Bei B. G. Teubner.
- ⁷Bresler, B. and Frankel, J.P.: The forces and moments in the leg during level walking. *Transactions of the American Society of Mechanical Engineers*, pp. 27-35, January, 1950.
- ⁸Chandler, R.F., Clauser, C.E., and McConville, H.M.: Investigation of inertial properties of the human body. Department of Transportation and Highway Safety, 801:430, 1975.
- ⁹Clauser, C.F., McConville, J.T., and Young, J.W.: Weight, volume, and center of mass segments of the human body. Air Force Systems Command, Wright Patterson Air Force Base, AD-710:622, 1969.
- ¹⁰Crowninshield, R.D.: Use of optimization techniques to predict muscle forces. *Journal of Biomechanical Engineering*, 100:88-92, 1978.
- ¹¹Crowninshield, R.D., Johnston, R.C., Andrews, J.G., and Brand, R.A.: A biomechanical investigation of the human hip. *Journal of Biomechanics*, 22:75-85, 1978.
- ¹²Crowninshield, R.D. and Brand, R.A.: A physiologically based criteria for muscle force predictions on locomotion. *Journal of Biomechanics*, 14(11):793-801, 1981.
- ¹³Frankel, V.H., Burstein, A.H., Lygre, L., and Brown, R.H.: The telltale nail. *Proceedings A.A.O.S. Scientific Exhibits-1971*, J. Bone and Joint Surg., 53:1232, 1971.
- ¹⁴Paul, J.P.: Bio-engineering studies of the forces transmitted by joints. I. Engineering analysis. In *Biomechanics and Related Bio-Engineering Topics*. R.M. Kennedy, editor, Pergamon Press, Oxford, 1965.
- ¹⁵Penrod, D.D., Davy, D.T., and Singh, P.P.: An optimization approach to tendon force analysis. *Journal of Biomechanics*, 7:123-129, 1974.
- ¹⁶Rydell, Nils W.: Forces acting on the femoral head prosthesis. A study on strain gauge supplied prostheses in living persons. *Acta Orthopaedica Scandinavica*, Supplementum 88, 1966.
- ¹⁷Seireg, A.H. and Arvikar, R.J.: A mathematical model for evaluation of forces in lower extremities of the musculoskeletal system. *Journal of Biomechanics*, 6:313-326, 1973.
- ¹⁸Seireg, A.H. and Arvikar, R.J.: The prediction of muscular load bearing and joint forces in the lower extremities during walking. *Journal of Biomechanics*, 8:89-102, 1975.

SELECTIVE USE OF THE ANTEROMEDIAL APPROACH FOR CONGENITAL DISLOCATION OF THE HIP: INDICATIONS AND ANALYSIS OF FAILURES

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Treatment for congenital dislocation of the hip (CDH) in infancy has evolved to a point where results are predictable because of the great success of the Pavlik harness. In contrast, obtaining and maintaining reduction without damaging the femoral head remains difficult in the child older than age four months who has developed a more fixed deformity.^{2,6,10} Intraarticular soft tissue interposition as well as capsular constriction by the tight iliopsoas tendon often preclude deep seating of the femoral head in the acetabulum. The use of a medial (Ludloff) approach for open reduction has been advocated by several authors for cases in which concentric reduction cannot be obtained or maintained by closed methods.^{1,3,4,5,9} An anteromedial variant (Mau) of Ludloff's medial approach⁵ has been used at the Texas Scottish Rite Hospital since 1972 for selected cases in which reduction could not be achieved by closed methods. This provides better visualization of the anterior hip capsule. Our series differs from previous ones^{1,5,9} in that we have experienced a relatively high incidence of redislocation and subluxation following reduction by this method. We analyzed the factors involved in these failed cases and from this analysis identified the patient who will benefit from anteromedial open reduction for congenital dislocation of the hip.

Materials and Methods

Between 1972 and 1979 a total of 172 patients between the ages of three and twenty-four months were referred to the Texas Scottish Rite Hospital with a diagnosis of CDH. We excluded patients with known neuromuscular disease from this series. Seventy-three patients were successfully treated with abduction splinting or a Pavlik harness. Forty-nine patients underwent closed reduction under anesthesia, while fifty patients required open reduction. Twenty-two of the fifty open reductions were performed via an anteromedial approach.

At our hospital, children under the age of four months whose hips are reducible upon physical examination and in whom there is no significant adduction contraction are placed in a Pavlik harness or modification thereof. Older children (aged four to twenty-four months) whose hips are not reducible, who have a significant adduction contracture, or whose femoral head is not directed toward the triradiate cartilage after one month in a Pavlik harness are admitted for two weeks of either Bryant's or skeletal traction. After this arbitrary period, the child is taken to the operating room where an arthrogram, percutaneous adductor tenotomy, and an attempt at closed reduction are performed. If the physical examination under general anesthesia and the arthrogram fail to demonstrate a stable concentric reduction, open reduction follows. The staff surgeon selects the anteromedial approach versus the traditional anterior approach based upon preference. This resulted in eighteen patients with a total of twenty-two dislocated hips who had open reduction by the anteromedial approach. Fifteen females and three males ranged in age from four to twenty-five months, with a mean age at surgery of 10.5 months. The mean follow-up time averaged forty-nine months with a range from seventeen months to seven years.

Surgical Technique and Operative Findings

The skin incision paralleled the adductor longus beginning at its origin on the os pubis and extending five centimeters distally. The interval between the superolateral border of the pectineus and the femoral triangle (neurovascular bundle) was identified by careful blunt dissection. Effort was made to save branches of the medial femoral circumflex artery, however, ligation was required to provide adequate exposure in ten of twenty-two hips. The iliopsoas tendon was found to be tight and significantly blocked reduction in twenty-one of twenty-two cases. The hip capsule was then exposed and was found constricted in the region of the overlying psoas tendon (hour-glass deformity) in twenty of twenty-two hips. The capsule was incised longitudinally from its attachment on the anteromedial portion of the acetabulum to its insertion on the medial portion of the femoral neck. An additional capsular incision

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parallel to the rim of the acetabulum and perpendicular to the initial longitudinal capsular incision was performed in many patients to improve exposure (T-incision of capsule). The ligamentum teres was noted to be hypertrophic or redundant in twelve cases and was excised in ten of these. A deformed or obstructing labrum blocked reduction in only three cases; however, the head could be reduced below the labrum in these cases. Thus, in no case was the labrum excised. The redundant fat in the base of the acetabulum (pulvinar) was removed with a rongeur in all cases. In only three cases did the operative note state that the transverse acetabular ligament had been sectioned. The femoral head was then reduced under direct vision and the hip position which provided maximum stability was determined. The capsule was loosely reapproximated in only one case. Blood loss ranged from fifteen to forty cubic centimeters for each hip with two patients requiring transfusions during bilateral cases. Postoperatively, the patients were placed in one and one-half hip spica casts with the hip held in a position of maximum stability. Twenty hips were held in the flexed-abducted position as described by Mau. Early in the study, two patients were held in a relatively extended position as advocated by Ferguson. Time in plaster averaged three months. Abduction bracing following the plaster immobilization ranged from zero to thirty-six months with a mean of eight months.

Results

The patients were divided into three groups based on surgical results. Group I includes nine patients (twelve hips) in whom concentric reduction was obtained and maintained. These patients have pain-free hips without contractures and have acetabular indices which are normal or approaching normal and continuing to improve. Group II consists of one patient (one hip) who has not required subsequent surgery but whose acetabulum has failed to develop fully and is currently being considered for an acetabuloplasty. Group III includes eight patients (nine hips) who have required a total of ten subsequent operations on nine hips, including four patients who redislocated.

Group I. The mean age at open reduction was 9.3 months. They spent an average of 14.4 weeks postoperatively in plaster and had subsequent abduction bracing for an average of twelve months. Although four of these patients developed mild aseptic necrosis (as will be discussed subsequently), in no case did this affect hip function or acetabular development.

Group II. The one patient in Group II had open reduction at age eleven months. She spent three months postoperatively in plaster in the flexed-abducted position

and subsequently wore an abduction brace for six months. Her acetabular index measures 35 degrees two years postoperatively. She is currently being observed for further acetabular development and may require an acetabuloplasty.

Group III. The mean age at the time of open reduction in this group was twelve months. The mean time of postoperative plaster immobilization was nine weeks. Post-cast abduction bracing averaged three months. The patients in this group required a total of ten subsequent operations on nine hips. The three patients with lateral subluxation were treated by varus derotational osteotomy of the proximal femur eight to twenty-four months following open reduction. Four patients redislocated in plaster. One was treated successfully by a repeat Ludloff approach. Three patients underwent open reduction and capsulorrhaphy through an anterior approach and two of these required subsequent varus derotational femoral osteotomy. One patient underwent an open reduction, capsulorrhaphy, and Salter innominate osteotomy. The length of time from open reduction to recognition of posterior dislocation ranged from two to twelve weeks with an average of four weeks.

These nine hips produced an overall failure rate of 40.5 percent, if failure is defined as the need for subsequent surgery. Because there were no significant differences in the operative techniques used in the three groups, an examination of patient factors was made. Features common to a majority of the patients in the failure group include anteversion greater than 50 degrees in six of eight patients and generalized ligamentous laxity in four of eight patients. Postoperative hip position in plaster was felt to be a factor in at least two. Both of these children were placed in the hip-extended position after the anteromedial open reduction and upon return for cast change were found to have redislocated. Another patient, because of an associated hemangioma of the thigh, could not be adequately secured in a well-fitting cast and subsequently redislocated. Lateral subluxation was noted with increased frequency in children who received little or no post-cast abduction bracing. In children who spent a greater length of time in abduction bracing, progressive improvement of acetabular index and center-edge angles was noted.

Aseptic Necrosis

Aseptic necrosis, as determined by the relatively strict criteria of Salter,⁷ was noted following open reduction in five of twenty-two hips (23 percent). Four of these hips were in Group I patients who were considered to have a good result from their Ludloff ap-

proach. Thus, all hips with aseptic necrosis had minimal head involvement and had subsequent normal hip function. Of these five hips, all but one had had previous unsuccessful attempts at closed reduction with cast immobilization. One hip developed aseptic necrosis after an open reduction through an anterior approach which followed a failed anteromedial approach. In only one hip could the anteromedial procedure, as an isolated entity, be identified as a possible cause for aseptic necrosis. Patients who developed aseptic necrosis had at least two weeks of Bryant's or skeletal traction prior to reduction. All patients who developed aseptic necrosis were immobilized in the flexed-abducted position and, according to operative notes, only two of the patients had branches of the medial circumflex vessels ligated during the approach to the hip capsule.

Illustrative Case Reports

The following cases illustrate the spectrum of results obtained by this method.

J.J. (Group I). This twenty-two month old white female presented with bilateral CDH (Fig. 1A). After two weeks of skeletal traction, she underwent bilateral

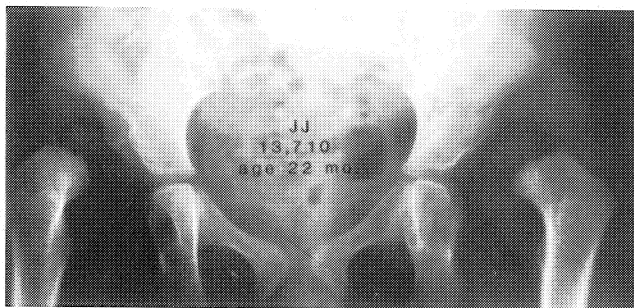


Figure 1A. Pelvic radiograph of a twenty-two month old female with bilateral hip dislocation.

arthrograms with an attempt at closed reduction. The right was successful, but the left side required open reduction (Fig. 1B). Postoperatively, she was immobilized in plaster in the flexed-abducted position for ten weeks, then treated with full-time abduction splinting

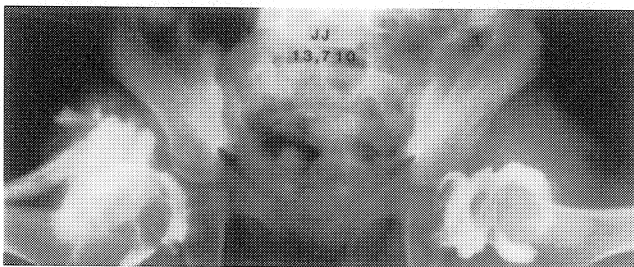


Figure 1B. Bilateral hip arthrogram in the same patient. The right hip is well-centered, however, there is soft tissue obstructing reduction on the left. The left hip was subsequently openly reduced.

for three months, and at night for another nine months (Fig. 1C). Radiographs six years postoperatively revealed that the left hip had moderately better acetabular development than did the right, which was

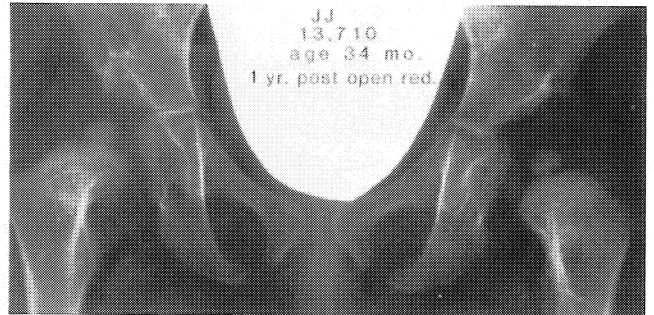


Figure 1C. One year after open reduction. Acetabular development is still poor.

treated by closed methods (Fig. 1D). Both hips are considered to be quite satisfactory, however. This is an example of a Group I patient with a good result following open reduction via the anteromedial approach.

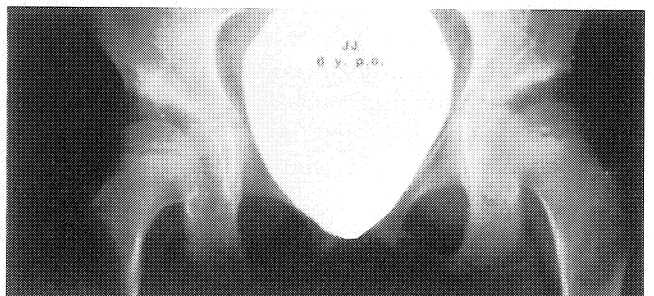


Figure 1D. Six years after open reduction on the left, closed reduction on the right. Both hips remain well-reduced.

M.M. (Group I). This child presented at age seven months with a left dislocated hip (Fig. 2A). The referring physician unsuccessfully attempted to reduce her hip and hold it reduced with a Pavlik harness. She was placed in skeletal traction for three weeks and then

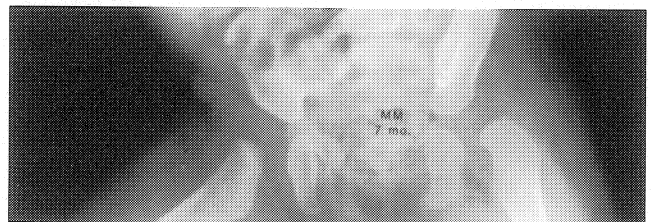


Figure 2A. Pelvic radiographs of a seven month old child with left CDH.

underwent an open reduction. Ten month postoperative radiographs demonstrated residual subluxation (Fig. 2B). However, she was treated with continued abduction bracing and by eighteen months after surgery acetabular development improved (Fig. 2C). Four years

after surgery, the left hip continues to develop well (Fig. 2D). This child demonstrates the benefit of con-

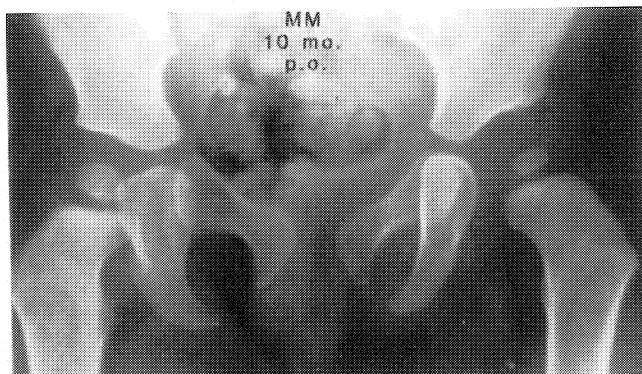


Figure 2B. Ten months after open reduction. Note the residual left hip subluxation.

tinued night abduction bracing, which decreases the need for subsequent surgery to correct residual subluxation.

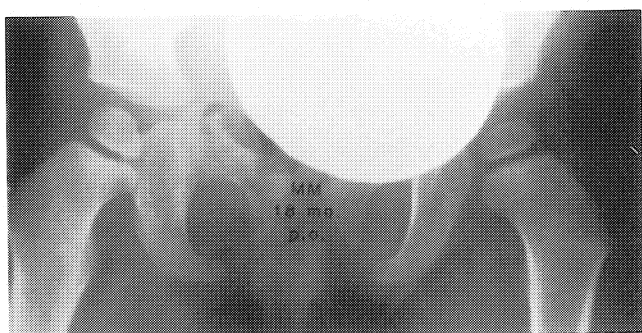


Figure 2C. Eighteen months after open reduction. The acetabular coverage of the femoral head has improved.

K.B. (Group II). This eleven month old girl presented with a dislocated left hip, torticollis, and cardiac anomalies (Fig. 3A). After traction, closed reduction was unsuccessful; therefore, the hip was reduced by

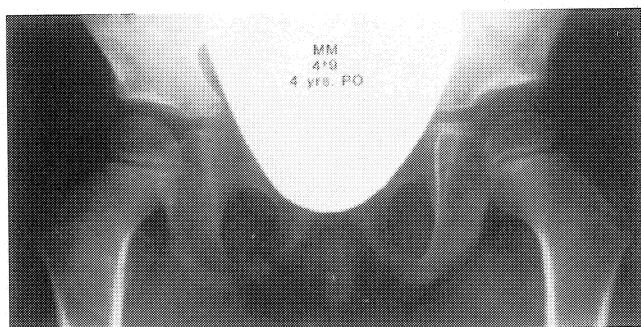


Figure 2D. Four years after surgery. The hip continues to develop well.

anteromedial open reduction. She was treated in plaster for three months, followed by full-time abduction splinting for three months and night-time splinting for two

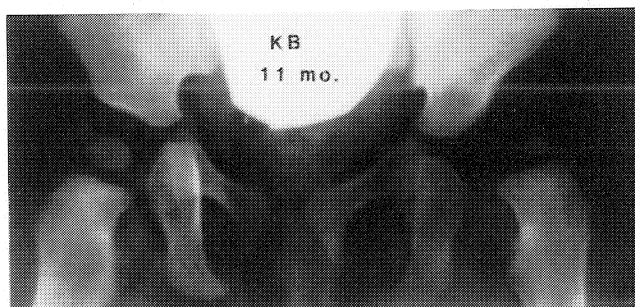


Figure 3A. Pelvic radiograph of an eleven month old girl with left CDH.

additional years. Three and one-half years after surgery she still has residual acetabular dysplasia and femoral anteversion (or coxa valga)(Fig. 3B). We anticipate improvement in the acetabular index, which has previously been reported to improve until age eight years;⁶ however, she may require further surgery.

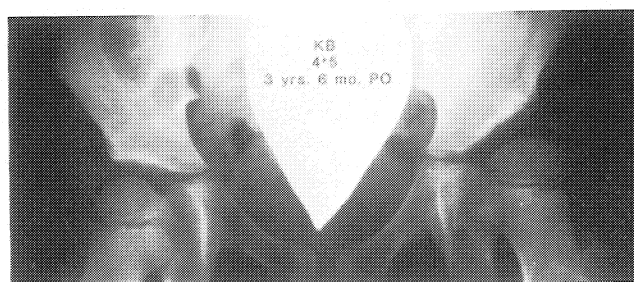


Figure 3B. Same patient three years, six months after surgery (age 4-5 years). The left hip is not yet adequately covered and surgery to improve hip coverage may be necessary.

C.M. (Group III). At age three months this girl (Fig. 4A) underwent bilateral open reductions via the

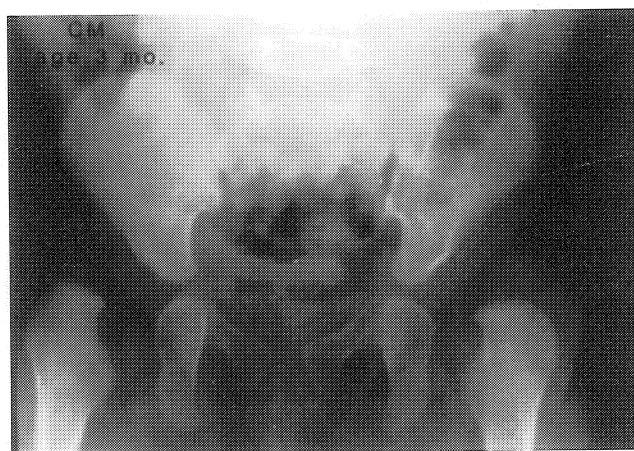


Figure 4A. Pelvic radiograph of a three month old girl with bilateral CDH.

anteromedial approach after failed closed reductions. Total blood loss during the procedure was twenty-five cubic centimeters. She was maintained in plaster for only six weeks and received no abduction bracing. Despite excellent reduction at the time of surgery and at initial follow-up, sixteen months after surgery she had bilateral subluxation (Fig. 4B) which was treated by



Figure 4B. Sixteen months after open reduction. Residual subluxation is noted, left greater than right.

bilateral varus derotational femoral osteotomies (Fig. 4C). She had done well and four years after the femoral osteotomies has adequate acetabular development with

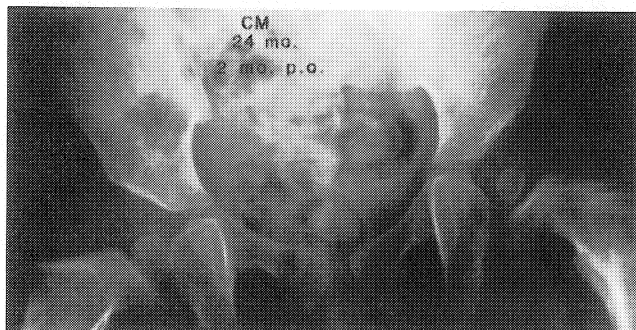


Figure 4C. Two months after varus derotational femoral osteotomies. The femoral heads are now directed toward the triradiate cartilage.

no evidence of aseptic necrosis (Fig. 4D). The importance of both the physician and the patient understanding the need for postoperative casting and bracing is illustrated here.

R.T. (Group III). The ten month old boy presented with a dislocated right hip as well as a large hemangioma involving the right thigh and groin (Fig. 5A). An attempt at closed reduction following traction was unsuccessful; therefore, he was treated by open reduction via the anteromedial approach. He was treated in the extended position described by Ferguson because his thick, swollen thigh (due to hemangioma) made hip flexion impossible. The hip was found dislocated one month after surgery and he subsequently underwent varus derotational femoral osteotomy. In

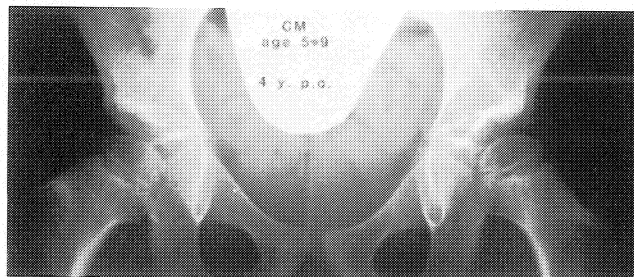


Figure 4D. Four years after the femoral osteotomies. The hips are developing well although acetabular coverage on the left may still be somewhat deficient.

retrospect, we noted that femoral osteotomy will not reduce a hip which is dislocated. Because the hip remained severely subluxated, he later underwent open reduction, capsulorrhaphy, and Salter innominate osteotomy (Fig. 5B and 5C).

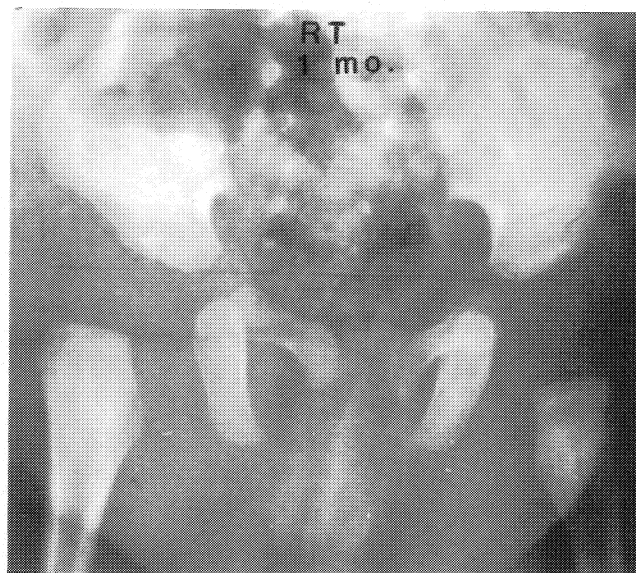


Figure 5A. Pelvic radiograph taken at age one month. Open reduction of the dislocated right hip was performed at age ten months.

Discussion

The medial adductor approach for open reduction of congenitally dislocated hips has been reported to decrease the risk of aseptic necrosis from open reduction.^{1,5,9} In addition, certain authors have reported less postoperative stiffness with the medial approach compared to the anterior approach.⁸ Our data confirms the observations of other authors that the Ludloff procedure is shorter, simpler, with less blood loss as compared to the classic anterior approach. In addition, reduction can almost always be obtained through this approach. Our results differ from those of Weinstein and Ponseti, Mau, and Ferguson in our high number of redislocations. Weinstein and Ponseti,⁹ in their initial

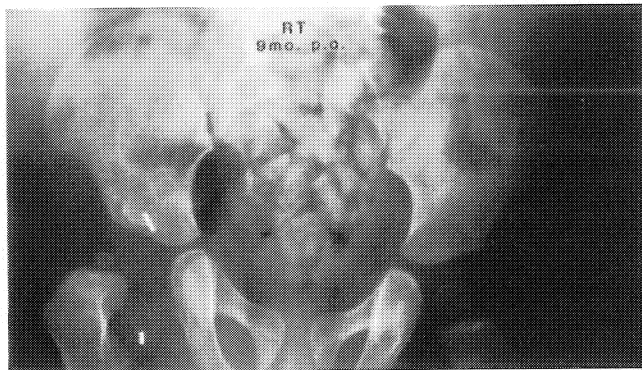


Figure 5B. Radiograph taken nine months after the anteromedial open reduction of the right hip. The hip redislocated.

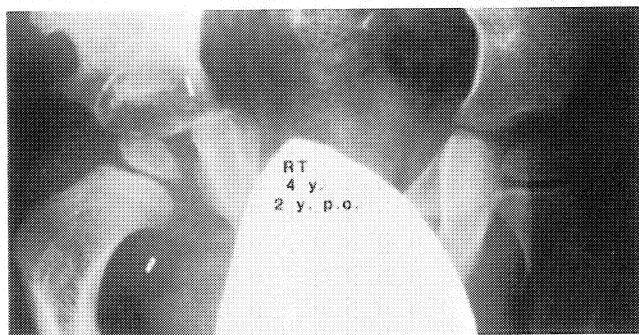


Figure 5C. Two years after open reduction (anterior), capsulorrhaphy, and Salter innominate osteotomy.

report on twenty-two hips, found no redislocations and only two subluxations. Ferguson¹ found only two redislocations in his series, both occurring in patients who had been held in plaster for only six weeks.

Redislocation and residual subluxation occurred in 23 percent of the hips we treated. Factors which could be identified and associated with redislocations were (1) poor cast technique, with the hips being reduced and held in a position of relative extension, (2) patients with marked anteversion, and (3) patients with marked ligamentous laxity. Because there is no capsular closure, no internal stability is provided by the Ludloff approach. One must then rely solely on the external support provided by a plaster hip spica to maintain reduction. This must be well molded to avoid early redislocation in plaster. We feel strongly that the flexed-abducted position (Mau, Ponseti) is preferable to the extended hip position described by Ferguson. In other words, since the medial open reduction provides no internal stability (no capsulorrhaphy), the position of postoperative hip immobilization should be identical to that used after closed reduction.

We agree with Weinstein and Ponseti that postoperative abduction bracing is extremely important in the management of patients with congenital dislocated hips treated by open reduction through the Ludloff ap-

proach. Persistent abduction bracing has resulted in improvement in the acetabular indices for up to five years postoperatively in our series. The two varus derotational osteotomies for subluxations done early in this series might well have been avoided if this factor had been recognized.

Aseptic necrosis has been reported to be as low as zero percent by Ferguson¹ and as high as 11 percent by Lipscomb and Sherman³ in medial approach open reductions. Although five of twenty-two patients (23 percent) had aseptic necrosis, the involvement was mild and all but one of these patients had undergone repeated attempts at closed reduction and immobilization prior to open reduction via the Ludloff approach. The aseptic necrosis rate in patients without prior treatment was only 7 percent. Previous failed attempts at closed reduction were the probable cause of aseptic necrosis in our patients rather than our sectioning of the small branches of the medial femoral circumflex artery at the time of open reduction.

We continue to use the Ludloff procedure for open reduction for congenitally dislocated hips between the ages of three and twenty-four months but add several precautionary notes. Familiarity with the anatomy in the adductor region and experience in performing hip surgery in infants seem important prerequisites for obtaining predictable results. High success rates are reported from centers where experienced surgeons have developed large series. Obviously, this advice applies to the anterior approach as well since obtaining a reduction and providing an adequate capsulorrhaphy also requires significant experience. An additional technical point concerns the use of too extensive a capsulotomy, which may actually allow anteroinferior subluxation. In certain early cases, the T-portion of the capsulotomy (parallel to acetabular rim) was extended excessively. This may have led to hip instability in certain cases. We now prefer a complete longitudinal incision (parallel to the neck) with the T-incision kept to a minimum. Access for cutting the transverse ligament at the base of the acetabulum medially must be maintained, however.

In addition, certain patients may have predisposing factors which make them poor candidates for reduction by the anteromedial approach. Our experience suggests that patients with severe anteversion, marked ligamentous laxity, or high bilateral teratologic dislocations are best treated by anterior approach and capsulorrhaphy, which provides internal stabilization.

Summary

Performing the surgery and obtaining a concentric reduction is only the initial step in treating a dislocated

hip by anteromedial open reduction. Because the procedure is designed only to allow safe atraumatic reduction, and does not provide internal stabilization, careful attention must be given to postoperative hip position and cast application. Experienced surgeons have good results from this procedure, not only because they do the surgery technically well, but, more importantly, because they know how to apply an infant hip spica which maintains the reduction postoperatively. After plaster immobilization, further abduction splinting is necessary, and in families who appear to be unable to follow this protocol, anterior open reduction plus capsulorrhaphy may be advisable.

Bibliography

¹Ferguson, A.B.: Primary open reduction of congenital dislocation of the hip using a median adductor approach. *J. Bone and Joint Surg.*, 55A:671-689, 1973.

²Gage, J.R. and Winter, R.B.: Avascular necrosis of the capital femoral epiphysis as a complication of closed reduction of congenital dislocation of the hip. *J. Bone and Joint Surg.*, 54A:373-388, 1972.

³Lipscomb, R.M. and Sherman, F.C.: The medial adductor open reduction approach for resistant congenitally dislocated hips. Presented at the Forty-Fourth Western Orthopaedic Association Convention, Honolulu, Hawaii, 1980.

⁴Ludloff, K.: The open reduction of the congenital hip dislocation by an anterior incision. *Am. J. Ortho. Surg.*, 10:438-454, 1913.

⁵Mau, H., et al.: Open reduction of congenital dislocation of the hip by Ludloff's method. *J. Bone and Joint Surg.*, 53A:1281-1288, 1971.

⁶Ponseti, I.V.: Nonsurgical treatment of congenital dislocation of the hip. *J. Bone and Joint Surg.*, 48A:1392-1403, 1966.

⁷Salter, R.B., Kostuik, J., and Dallas, S.: Avascular necrosis of the femoral head as a complication of the hip in young children: A clinical and experimental investigation. *Canadian J. Surg.*, 12:44-61, 1969.

⁸Scaglietti, O., and Calandriello, B.: Open reduction of congenital dislocation of the hip. *J. Bone and Joint Surg.*, 44B:257-283, 1962.

⁹Weinstein, S.L., and Ponseti, I.V.: Congenital dislocation of the hip. Open reduction through a medial approach. *J. Bone and Joint Surg.*, 61A:119-124, 1979.

¹⁰Weintroub, S., Green, I., et al.: Growth and development of congenitally dislocated hips reduced in early infancy. *J. Bone and Joint Surg.*, 61A:125-130, 1979.

TECHNIQUE OF CORE BIOPSY AND TIBIAL BONE GRAFTING (PHEMISTER PROCEDURE) FOR TREATMENT OF ASEPTIC NECROSIS OF THE FEMORAL HEAD

Michael Bonfiglio, M.D.*

Treatment for aseptic necrosis of the femoral head following trauma or other causes should be instituted before severe secondary arthritic changes occur either in the femoral head or acetabulum in order to be effective.

At what point in the progress of repair of a femoral neck fracture or after hip dislocation is it possible to tell whether or not necrosis of the femoral head exists? Interruption of blood supply at the time of an injury causes necrosis; however, the moment of insult in non-traumatic necrosis is more difficult to pinpoint.

The gross appearance of dead bone may be suggestive but is not pathognomonic for necrosis. Living bone appears pink to red, dead bone yellow to white. Histologic studies indicate that regardless of the etiology of necrosis, the amount of involvement in each femoral head may vary greatly from complete necrosis to minimal necrosis involving only the anterior superior portion of the head. At less than three days, little evidence of necrosis is present histologically. From three days to three weeks osteocytes disappear from lacunae, and marrow necrosis becomes apparent. Thus from the time of injury to ten days, microscopic sections are of uncertain value in making the diagnosis of dead bone.

Core biopsies, by assessing the amount of repair, are of value in predicting the approximate length of time until final repair.

Roentgenograms show no difference in density between viable and necrotic bone at the onset of necrosis. The necrotic femoral head is capable of weight bearing stresses until weakened by the repair process. Many have attempted to use radioisotope techniques to assess vascular supply to the femoral head at the time of a fracture. The results are equivocal and the techniques too specialized and time consuming for general use. Furthermore, many of the radioisotope counts have not been made from the area at risk, i.e., the anterior superior portion of the

head.^{5,7} Similarly, results of angiographic techniques or intramedullary pressure measurements are too inconsistent for general adoption.⁶ Radionuclide bone imaging with Tc-99m labeled phosphates shows promise for identifying femoral heads with deficient circulation which would be at risk for later collapse.²

Clinical and experimental studies by Phemister⁸ and Bonfiglio^{3,4,11} on the treatment of aseptic necrosis of the femoral head have established the technique of drilling and insertion of two autogenous tibial bone grafts as a method of treatment. The method has proved most effective when applied *early* in the course of treatment of femoral head necrosis after a femoral neck fracture, hip dislocation, etc. *Early* means as soon as radiographic density differences are detected between the femoral head and surrounding bone, and preferably before stress fractures and collapse of the femoral head have occurred.

In nontraumatic necrosis best results are obtained when the femoral head has no collapse (Stage I) or minimal collapse of 1-2mm.¹³ Good results can also occur with greater than 2 mm. collapse if range of motion is excellent and there are no degenerative changes of the femoral head.

Rationale for the Procedure

1. By drilling and removal of two cores of bone, each 1x3 cm. (18-26 sq. cm.), the channel provides a *large surface area* for blood vessels to invade and repair the necrotic bone (equal to or more than that at the junction of living and dead bone in the head and neck). Decompression of the marrow is also achieved, although the value of this is uncertain.¹⁴
2. The two tibial grafts stabilize and support the necrotic area during the repair process as union occurs between the walls of the channel and the graft. Segmental stress fractures are stabilized and unite.
3. The risk of collapse or further collapse of the femoral head is decreased as gradual repair of the necrotic bone occurs uninterrupted.

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Technique

1. Position of Patient

- A. Supine on fracture table or table for use with C-arm fluoroscopic unit as for routine two plane roentgenographic control during hip nailing.
- B. Place the hip and thigh in 10° flexion, neutral abduction and 5-10° internal rotation of the thigh. This positions the femoral neck parallel to the surface of the table.
- C. Use C-arm fluoroscope for PA view or drape C-arm free for both AP and lateral views (position x-ray tube for cross table lateral). The abducted free limb rests wrapped on a pillow on a Mayo stand. Check x-ray tube positions before draping.
- D. Prep and drape affected limb free for access to anteromedial surface of the tibia from the knee joint line to the malleoli and the posterolateral aspect of the proximal third of the upper femur including the greater trochanter.

2. Exposure

A 10-15 cm. skin incision extends along the posterior edge of the vastus lateralis muscle starting proximal to its origin from the greater trochanter (Fig. 1). The tensor fascia lata is incised from the posterior edge of the tip of the

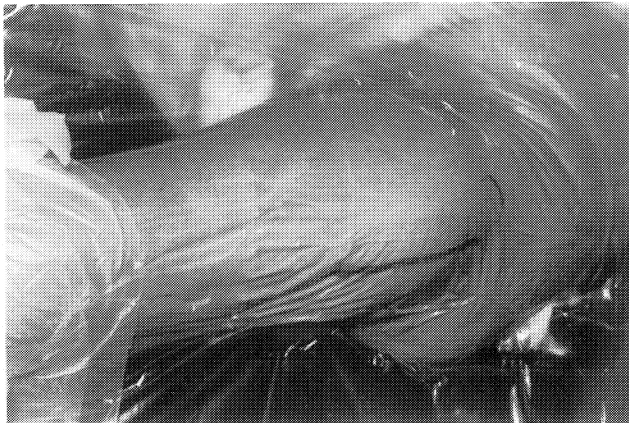


Figure 1. Side view of hip with incision marked.

trochanter to 10-15 cm. distally. The vastus lateralis muscle is identified and an L-shaped incision made in the fascia approximately 2 cm. vertically at its origin at the tubercle of the greater trochanter and along the posterior edge distally for 5-6 cm. (Fig. 2). With a sharp chisel or periosteal elevator the muscle is elevated to expose the lateral surface of the proximal femur. The muscle flap is retracted anteriorly. The

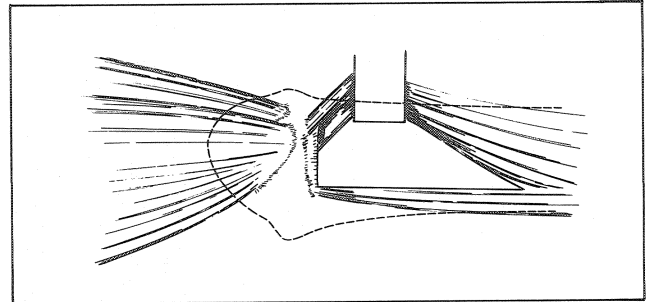


Figure 2. Line drawing L-shaped incision at origin of vastus lateralis muscle.

gluteus maximus sling, bursa and subcutaneous tissue are retracted by inserting a Bennett or Cobra retractor posteriorly behind the trochanter and proximal femur.

3. Instruments Necessary for the Procedure (Fig. 3)

- A. 2-3/32" (2 mm.) smooth pins
- B. 5/16" (7 mm.) and 7/16" (11 mm.) cannulated drill points 9" long
- C. Phemister biopsy trephine (10 mm.) with chuck adaptor and obturator
- D. Twin blade oscillating saw

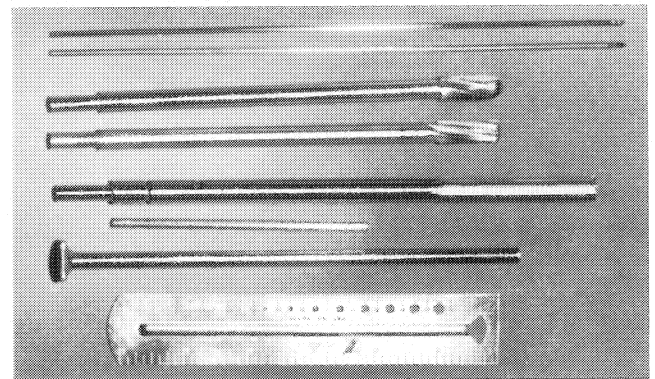


Figure 3. Photo Instruments: guide pins, cannulated drill points, Phemister biopsy trephine, wrench pin, core biopsy obturator.

4. Preparation of Channel and Core Biopsy

- A. Smooth guide pins 3/32" (2 mm.) are inserted with a power drill under fluoroscopic control into the anterior superior half of the head to the subchondral cortex. One pin is inserted 1 cm. below the tubercle of the greater trochanter and the other 1.5 to 2 cm. distal to that. The pins should taper slightly toward each other at the apex near the subchondral cortex (Fig. 4A line drawing). The pins should enter the necrotic bone in both the AP (Fig. 4A) and lateral view (Fig. 4B) so that the surface area for repair within the cored channels

Figure 4A.
Radiograph of
hip-AP with guide
pins.

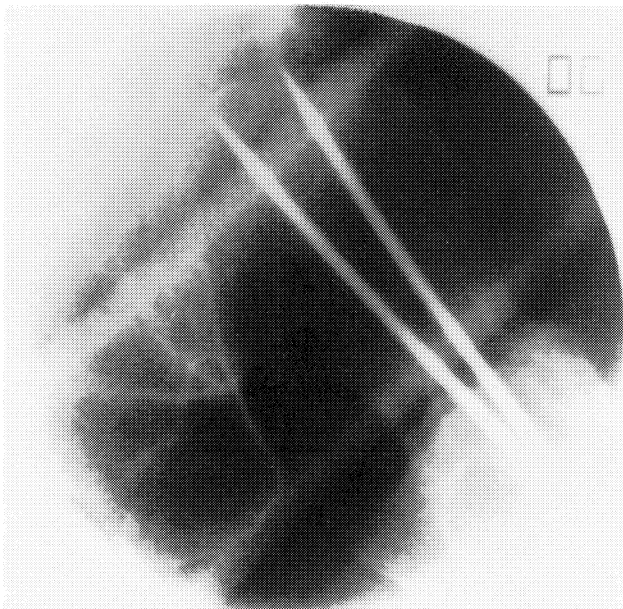
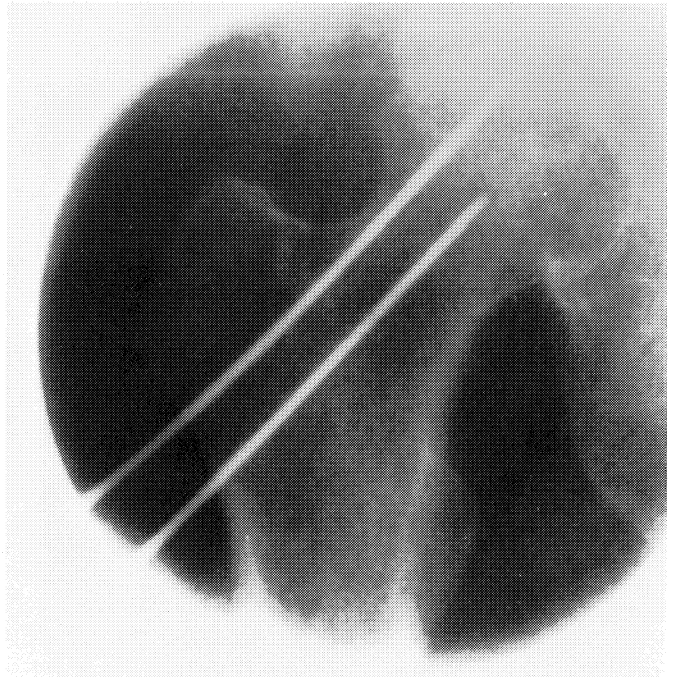
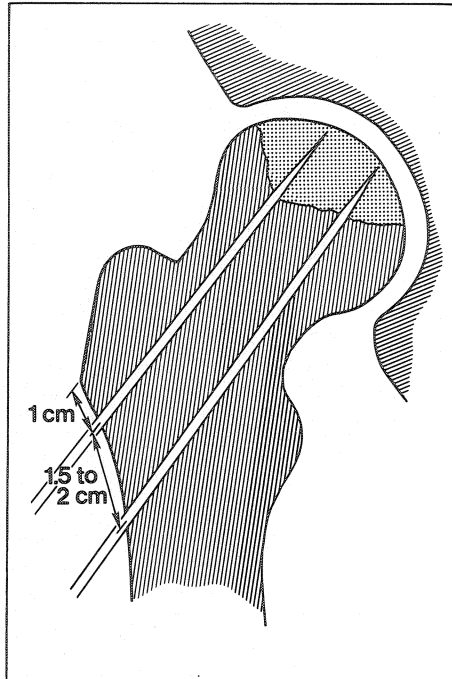


Figure 4B. Radiograph of hip-lateral with guide pins.

and the stabilizing effect of the bone grafts is maximal. Readjust position of the pins as necessary. Measure the distance each pin is in by subtraction with a free pin before preparing channels. This provides the distance to drill the biopsy trephine when removing the core of bone and determines the length of tibial grafts required; usually 9 cm. for the superior graft and 9.5 to 10 cm. for the inferior graft.

- B. Drill over each guide pin with a 7 mm. (5/16") (Fig. 5A) and 11 mm. (7/16") (Fig. 5B) cannulated drill point a distance of 4-5 cm. through the lateral femoral cortex into cancellous bone of the trochanter and femoral neck. Check to be sure drilling is free and each pin remains in place. This prepares the outer portion of the channel.
- C. *Remove guide pins.* The Phemister trephine will *not* go over the guide pin without removal (Fig. 6A).
- D. Insert Phemister trephine into the superior channel and drill further into the neck and head to the subchondral cortex (Fig. 6B). Use a power drill at slow speed. Remove the instrument to clean bone from the teeth and cutting margins if needed. Bone heated by drilling may bind and stick to the instrument. If a core of acetabulum is removed with femoral head core, shift position of limb into abduction or adduction a few centimeters.
- E. Remove the adaptor and push out the core (biopsy) with the obturator. The articular cartilage, dead bone (yellow-white) and living bone (pink or reddish yellow) should be evident.
- F. Repeat the trephine drilling process for the inferior channel (Fig. 7A, B).
- G. Leave an obturator or trephine in each channel until grafts are ready to insert. With an obturator placed in the completed channel,

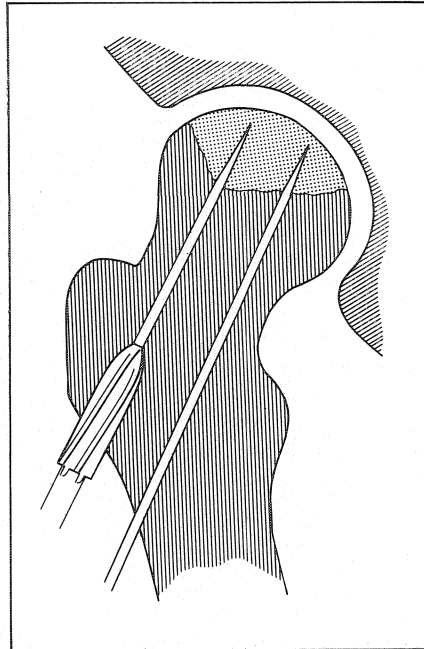


Figure 5A.
Radiograph of hip-
AP with cannulated
drill point in 4 cm.
into inferior channel.

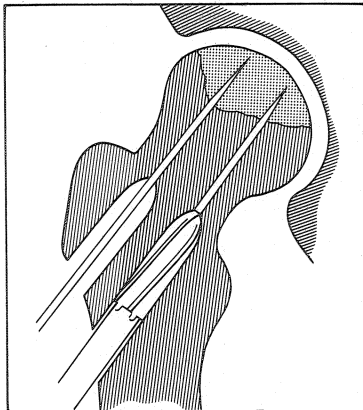
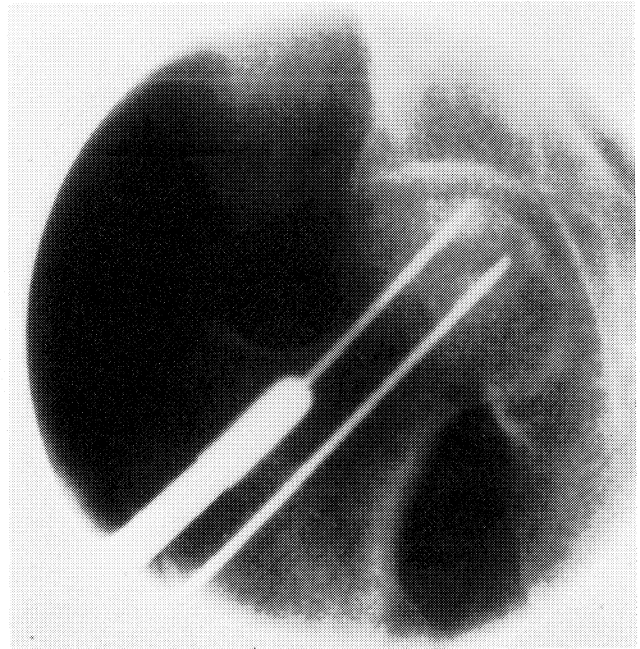


Figure 5B. Line drawing of
radiograph of hip with can-
nulated drill point in 4 cm.

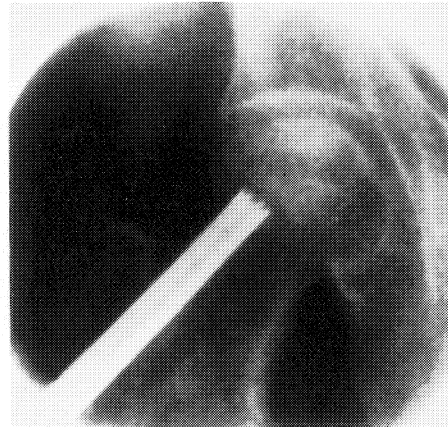


Figure 6A. Radiograph AP guide pin
out, trephine in 4 cm.

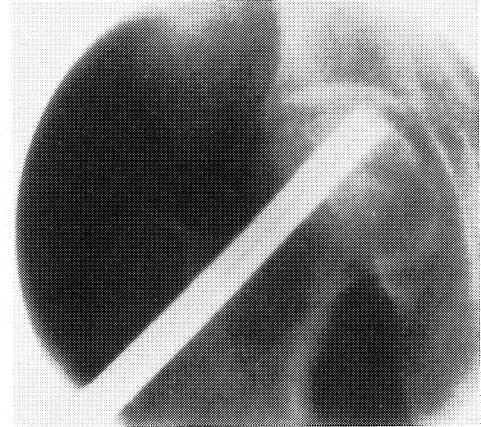


Figure 6B. Radiograph-Trephine into
subchondral cortex.

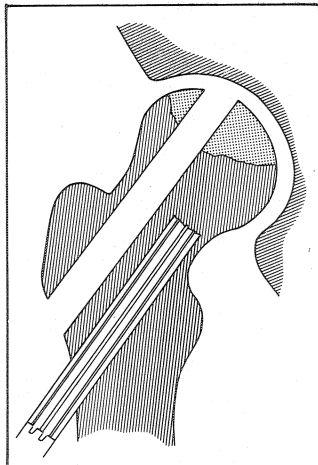


Figure 7A.
Drawing of AP radio-
graph to show prepared
superior channel and
trephine into inferior
channel.

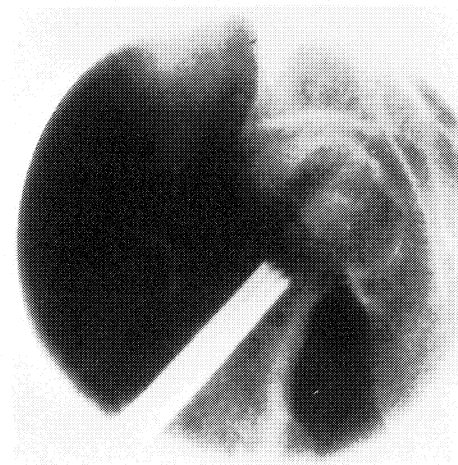


Figure 7B.
Radiograph AP to show
channel prepared and
trephine into inferior
channel.

repeat the process for the inferior channel. Pack the wound while the grafts are obtained. Photograph cores and process later for microscopic study.

5. Obtain Tibial Bone Grafts

- A. An incision 20 cm. long, through the skin and subcutaneous tissue over the anteromedial surface of the tibia starts 1 cm. below the joint line. If the patient has a wide proximal tibia, both grafts may be removed at the proximal end through the use of a 10 cm. incision.
- B. Incise the periosteum. The total length needed is measured for each channel from the lateral cortex of the femur to the subchondral femoral head cortex. Strip the periosteum the width of a 1/2" (13 mm.) chisel to guide the twin bladed saw. Stay midway between the anterior tibial crest cortex and the posterior cortex of the tibia.
- C. With a twin bladed oscillating saw, cut a 1 cm. wide graft with length measured for both grafts. *Keep blade cool* with saline!
- D. At the end of each saw cut, drill a 1/8" (3 mm.) hole. Between the holes chisel a V at each of the graft's ends. Lift the graft from its bed with a narrow osteotome.
- E. Place grafts in 37°C. lactated Ringers solution until ready to insert.
- F. Close the tibial wound in two layers; close the subcutaneous tissue and periosteum with a

continuous absorbable suture (0 plain catgut) and then close the skin separately.

5. Insertion of Bone Grafts into Channels

- A. Trim the excess cancellous bone from the posterior surface of the graft so that only cortex remains. Trim sharp edges.
- B. Measure the exact length of the graft for each channel as noted above (approximately 9 cm. and 9.5-10 cm.). Note the curve of the femoral head at the subchondral cortex of each channel (from radiograph and core biopsy). Cut the graft to that shape.
- C. Remove the obturator or trephine from one channel at a time, and insert one tibial graft in its premeasured channel so that the broad surface is in the coronal plane (Figs. 8A, B). Tap the graft gently up to the subchondral cortex and check the position to be sure the graft stays in the proper channel.

For ununited fractures, release traction before graft is inserted to full depth. The graft should fit snugly but not so tightly that it cannot be withdrawn for adjustment of depth. Accuracy is critical (Figs. 9A, B). As a final check on the depth of the bone grafts, check the range of hip motion for binding of the graft.

Obtain AP and lateral radiographs in the operating room before closing to be sure that the grafts are in deep enough but not beyond the subchondral cortex in both views.

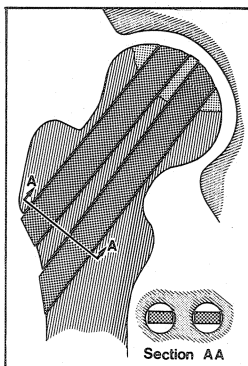


Figure 8A.
Line drawing—AP grafts
in femoral head and neck.

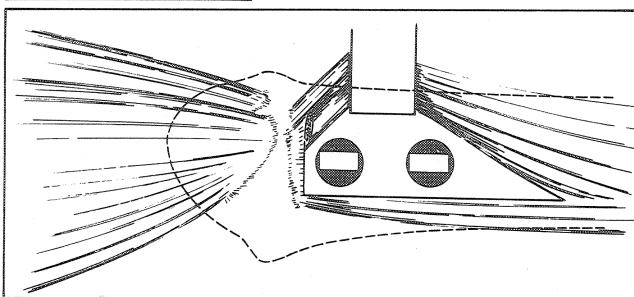


Figure 8B. Lateral femoral cortex to show position of grafts in the coronal plane.

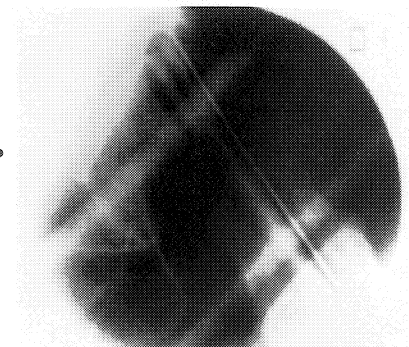


Figure 9A.
Radiographs — AP
grafts in place.



Figure 9B.
Radiographs — lateral
grafts in place.

Bibliography

- ¹Arden, G.P.: Radioactive isotopes in fracture of the neck of the femur. *J. Bone and Joint Surg.*, 42-B: 21-27, 1960.
- ²Bauer, Goran, Weber, David A., Ceder, Leif, Darte, Lennart, Egund, Niels, Hansson, Lars Ingvar, Stromqvist, Bjorn: Dynamics of technetium-99m methylenediphosphonate imaging of the femoral head after hip fracture. *Clin. Ortho.*, 152:85-92, 1980.
- ³Boettcher, W.G., Bonfiglio, M., Smith, K.: Non-Traumatic necrosis of the femoral head. Part II—Experiences in Treatment. *J. Bone and Joint Surg.*, 52-A:322-329, 1970.
- ⁴Bonfiglio, M., Bardenstein, M.B.: Treatment by bone grafting of aseptic necrosis of the femoral head and non-union of the femoral head (Phemister technique). *J. Bone and Joint Surg.*, 40-A:1329-1346, 1958.
- ⁵Boyd, H.B., Zilversmith, D.B. and Calcandruccio, R.A.: The use of radio-active phosphorous (P^{32}) to determine the viability of the head of the femur. *J. Bone and Joint Surg.*, 37-A:260-269, 1955.
- ⁶Hulth, A.: Femoral head phlebography. *J. Bone and Joint Surg.*, 40-A:844-852, 1958.
- ⁷Laing, P.G., Ferguson, A.B.: Use of radio-active sodium to determine bone viability. *Proceedings of the American Academy of Orthopaedic Surgeons. J. Bone and Joint Surg.*, 41-A:753-754, 1959.
- ⁸Phemister, D.B.: Treatment of the necrotic head of the femur in adults. *J. Bone and Joint Surg.*, 31-A:55-56, 1949.
- ⁹Rook, F.W.: Arteriography of the hip joint for predicting end results in intracapsular and intertrochanteric fractures of the femur. *Am. J. Surg.*, 86:404-409, 1953.
- ¹⁰Smith, K.R., Bonfiglio, M., Montgomery, W.J.: Non-traumatic necrosis of the femoral head treated with bone grafting. A follow-up note. *J. Bone and Joint Surg.*, 62-A:845-847, 1980.
- ¹¹Voke, E.M., Bonfiglio, M.: Aseptic necrosis of the femoral head and non-union of the femoral neck. Effect of treatment by drilling and bone-grafting (Phemister technique). *J. Bone and Joint Surg.*, 50-A:48-66, 1968.
- ¹²Bonfiglio, M.: Unpublished data.
- ¹³Marcus, N.D., Enneking, W.F., Massam, R.A.: The silent hip in idiopathic aseptic necrosis. *J. Bone and Joint Surg.*, 55-A:1351-1366, 1977.
- ¹⁴Ficat, P.R., Arlet, J.: Ischemia and necrosis of bone. Williams and Wilkins. Baltimore/London, 1980. Edited and adapted by Hungerford, D.S.

DIABETIC NEUROPATHIC ARTHROPATHY OF THE HIP A Case Report and Literature Review

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Introduction

Diabetes, a disease of protean manifestations, frequently produces late complications, including neuropathy, and its associated secondary problems. Neuropathic arthropathy, or Charcot joints, in diabetics has become well recognized, especially in recent years. Many of these Charcot joints involve the foot and ankle. Neuropathy of the larger joints, including the hips, results from other causes, but hip involvement in diabetes is extremely rare.

Case Report

A 53 year old woman had right shoulder and left hip pain for 13 months. There was no history of trauma. During the past several months the pain in her hip had diminished. She complained that her left leg was short and that she walked with a limp. She was a well controlled, insulin-dependent diabetic, requiring 30-32 units of Lente Insulin in U-80 daily.

Physical examination of the right shoulder revealed minimal pain on motion and moderate swelling. The left lower extremity measured two and one-half inches short, and no hip flexion contracture was noted. Hip motion included: internal and external rotation equal at 30°, adduction 20°, and abduction 0° and painful. No swelling or erythema was noted. All peripheral pulses were easily palpable.

Neurologic evaluation revealed decreased vibratory and position sense in the lower extremities. Knee jerks were weak and ankle jerks were absent, even with reinforcement. Funduscopic examination demonstrated diabetic retinopathy.

Original roentgenographic examination revealed loss of bone substance typical of atrophic Charcot hip arthropathy (Figures 1 and 2). A radiograph taken ten months later (Figure 3) shows progressive fragmentation of the femoral head.

Laboratory studies included: hemoglobin 10.4 gm/%, hematocrit 31.6, electrolytes within normal

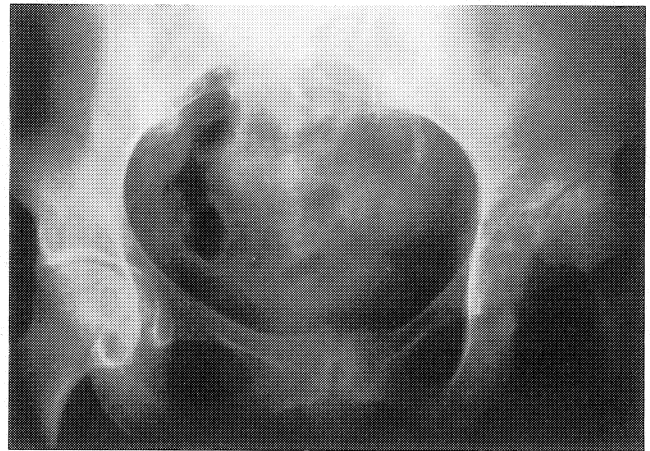


Figure 1. A.A. at time of admission. X-ray showing fragmentation and atrophy of the left femoral head.

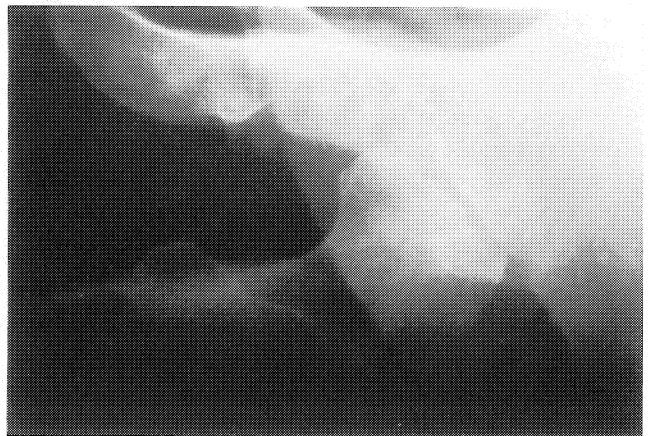


Figure 2. A close-up of x-ray of the left hip reveals no evidence of fracture or hypertrophic bone formation.

limits, fasting blood sugars between 90-156 mgs %, and RPR and VDRL nonreactive. Examination revealed no other cause of Charcot hip.

Discussion

Diabetic Neuropathy

Mitchell,³⁹ in 1831, first suspected the relationship between neurologic problems and joint dysfunction. In 1868, Charcot¹² described neuroarthropathy associated with tabes dorsalis. Jordan³² first reported a Charcot joint in a diabetic in 1936. In 1964, Robillard⁴⁴

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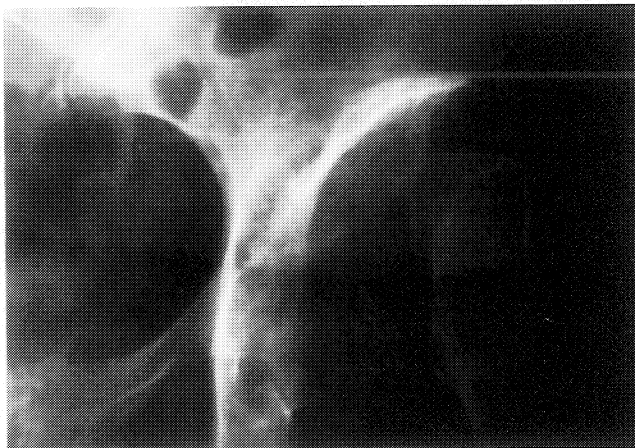


Figure 3. A.A. 10 months after admission. Roentgenogram showing marked absorption of head and neck of left femur. The trochanter is riding high against the ilium.

in Canada described four cases of diabetic neuroarthropathy. He reviewed the 109 cases which had been reported in the literature. Ninety-one of these involved the foot and eighteen involved other sites. Charcot joints of the upper extremity have also been described.^{10,29,47} He found no reported cases of hip involvement in diabetic neuroarthropathy. Sinha, et al.⁴⁸ presented a clinical study of 101 cases of neuroarthropathy in diabetes mellitus obtained from the Joslin Clinic records between 1949-1970. The incidence of Charcot joints in diabetics was found to be 1:680. None involved the hip. Many cases of diabetic Charcot joints have been reported.^{6,19,31,33,45,46,53,59,65} Diabetes is now the most common cause of Charcot joints.¹⁹ Involvement of the hip has rarely been recognized in this disease.

Neuropathic Hip

Charcot's original case of neuroarthropathic hip was reviewed by Henderson in 1905.²⁶ Charcot described a 28 year old soldier with tabes dorsalis, who marched 25-40 km/day, with mild hip pain. Eleven days after the onset of symptoms the soldier's hips were disorganized and dislocated.

Etiology

Johnson³¹ notes that Charcot hips are rare, although Conley¹⁵ described five cases in tabes dorsalis. Other cases of Charcot hip include neuroarthropathy secondary to tabes dorsalis as the major cause.^{2,3,5,7,8,13,14,15,17,22,23,28,29,35,36,37,38,40,42,51,52,55,56,61,62,64} According to Johnson,³¹ syphilis is still the most common cause of Charcot hip. Other reported etiologies include intra-articular injections of corticosteroids,^{1,11,16,21,29,57,58} paraplegia,^{17,25,50,60} syringomyelia^{22,34} pernicious anemia,¹⁴ spinal cord injury,^{27,30} and congenital insensitiv-

ty to pain.^{4,41} These cases include at least 200 cases of hip neuroarthropathy. One case secondary to diabetic arthropathy was found in the English literature.⁴³

Pathogenesis

Charcot joints probably result from an absence or reduction in pain perception and proprioception, combined with continued use and trauma to the joint. Eloesser's¹⁸ work on cats in 1917 represents a classical study in the development of Charcot joints and supports this mechanism. Johnson³¹ described two types of Charcot hip: those initiated by either minimal or severe fractures (the majority of his cases); and the truly "arthritic" reaction with attrition and fragmentation of both the femoral head and acetabulum (often with resultant subluxation and dislocation). The latter group may be divided into an atrophic type, with bone destruction alone, and a hypertrophic type, with much reactive new bone formation and myositis ossificans. The case we have presented represents an atrophic Charcot hip without known preceding fracture.

Clinical Presentation

Patients with a Charcot hip usually give a history of marked limp and minimal to moderate hip pain with swelling associated with activity. Hip motion usually causes crepitus. All patients have sensory impairment to some degree.³¹ The history is unremarkable for trauma. The changes on radiographic evaluation appear out of proportion to the mild pain. There may be a fracture of the femoral head or neck with distension of the capsule and early atrophic attrition of the bone. Atrophy and dislocation of the femoral head and neck without fracture may be present. In the hypertrophic type, striking hypertrophic and metaplastic bone reaction accompany the wearing away of bone.

Pathology

The microscopic and gross pathology of a Charcot hip has been described by Johnson.³⁰ The unprotected hip tissues, damaged from mechanical trauma, undergo a normal repair process including hyperemia and histiocytic and osteoclastic activity. The process removes dead bone, cartilage, and blood clots. Bone resorption and softening occur. With decreased pain sensation, further trauma ensues. This probably results in continued osteoclastic and leukocytic resorption of bone and the cycle continues until the joint is either destroyed or protected. If protected, the joint may stabilize. At this point soft tissue ossification can occur. Depending on the stage of the disorder, histologic sections show a wide range of findings, including fractures, callus formation, dead bone or cartilage fragments, and metaplastic changes in the soft tissues.

Treatment

In general, conservative treatment is recommended for a Charcot hip. Johnson³¹ directs treatment of the hip toward maintaining mobility and function. Crutches and a walker are of benefit. He has never seen a successful arthrodesis of a Charcot hip. A Charcot hip will dislocate or disintegrate after the insertion of a prosthesis. Conservatively treated, Charcot hips become stable with time. Campbell et al.⁹ state that surgery is not indicated except for severe disability. In their opinion, total joint arthroplasty probably is never indicated.

Summary

World literature review revealed only two previously reported cases of diabetic Charcot hip^{6,43} and a citation of one additional unreferenced case (Andresch).

Neuroarthropathy in the diabetic foot and ankle is well recognized. With an increasing population of diabetics, we must now also consider neuropathic change when hip signs and symptoms develop.

Bibliography

- ¹Anderton, J.M., and Helm, R.: Multiple joint osteonecrosis following short-term steroid therapy. *J. Bone and Joint Surg.*, 64-A: 139-141, Jan. 1982.
- ²Barr, J.S., Donovan, J.F., and Florence, D.W.: Arthroplasty of the hip. *J. Bone and Joint Surg.*, 46-A: 249-266, 1964.
- ³Batt, R.C., and Hampton, A.D.: Spontaneous subcapital hip fracture occurring in tabes dorsalis. *J. Bone and Joint Surg.*, 22: 137-146, 1940.
- ⁴Baxter, D.W., and Olszewski, J.: Congenital universal insensitivity to pain. *Brain*, 83: 381-393, 1960.
- ⁵Benassy, J., and Ramacher, J.O.: L'Arthrodesse inschio-femorale. *Revue de Chir. Orthop. et Reparatrice el L'PP. Moteur.*, 40: 481-494, Oct.-Dec. 1954.
- ⁶Borejko, M., and Jaworski, W.: Unusual case of diabetic arthropathy of the hip. *Chir. Narxadow Ruchv. Orthop. Pol.*, 41(3): 315-319, 1976.
- ⁷Burman, M.: The weight stream in Charcots disease of the joints. Charcots disease of the foot and ankle. *J. Internat. Coll. Surg.*, 28: 183-196, 1957.
- ⁸Burman, M.: The weight stream in Charcot disease of the joints. *Bull. Hosp. Joint Disease*, 17: 386-403, 1956.
- ⁹Campbell's Operative Orthopaedics. Sixth Edition, Editors Edmonson and Crenshaw. Memphis, Tennessee, 1213, 1980.
- ¹⁰Campbell, W.L., and Feldman, F.: *Amer. Journal of Roentgenol.*, 124: 7, 1975.
- ¹¹Chandler, G.H., et al.: Charots arthropathy following intra-articular hydrocortisone. *British Med. J.*, 1: 952-953, 1959.
- ¹²Charcot, J.M.: Sur quelques orthopathies qui paraissent dependre d'une lesion du cerveau ou de la moelle epinier. *Arch. Phys. Norm. at Pathol.*, 1: 161, 1868.
- ¹³Chitty, H.: Interesting case of Charcots joint. *J. Bone and Joint Surg.*, 27: 183-185, 1939.
- ¹⁴Colton, F.J.: Surgical aspects of the Charcot joint and other syphilitic bone and joint lesions. *Ann. Surg.*, 72: 488-493, 1920.
- ¹⁵Conley, A., and Miller, D.S.: Atrophic Charcots hips (Report of five cases). *J. Bone and Joint Surg.*, 22(3): 638-644, July 1940.
- ¹⁶Cruess, Richard L.: Cortisone induced avascular necrosis of the femoral head. *J. Bone and Joint Surg.*, 59-B: No. 3: 308-317, Aug. 1977.
- ¹⁷Delano, P.J.: The pathogenesis of Charcots joint. *Am. J. Roent.*, 56: 198, 1917.
- ¹⁸Eloesser, L.: On the nature of neuropathic affections of the joints. *Ann. Surg.*, 66: 201-207, 1917.
- ¹⁹Esses, S., Langer, F., and Gross, A.: Charcots joints: A case report in a young patient with diabetes. *Clin. Ortho.*, 156: 183-186, May 1981.
- ²⁰Feldman, M.J., et al.: Multiple neuropathic joints, including the wrist, in a patient with diabetes mellitus. *JAMA*, 209: 919, 1961.
- ²¹Fisher, D.E., and Bickel, W.H.: Corticosteroid-induced avascular necrosis. *J. Bone and Joint Surg.*, 54-A: 859-873, 1971.
- ²²Floyd, W., Lovell, W., and King, R.E.: The neuropathic joint. *South Med. J.*, 52: 563-569, 1959.
- ²³Guilleminet: Arthropathic tabetique de la lanch avec luxation pathologique. Osteotomie soustrochanterienne datant de deux Ans. *Lyon Chit.*, 37: 53-53, 1951-42.

- ²⁴Haboner, P.I., and Jarvinen, K.A.J.: On the occurrence of neuropathic arthropathies in pernicious anemia. *Ann. Rheum. Dis.*, 1: 152-155, 1948.
- ²⁵Heilbrun, N., and Kuhn, W. G. Jr.: Erosive bone lesions and soft tissue ossifications associated with spinal cord injuries (Paraplegia). *Radiology*, 48: 579-593, 1947.
- ²⁶Henderson, V.E.: Joint affections in tabes dorsalis. *J. Path. and Bacteriology*, Vol. X: 211-264, 1905.
- ²⁷Hildebrand, O.: Uber neuropatische gelenkerkrankungen. *Arch. Siklin Chir.*, 115: 443-493, 1921. (German).
- ²⁸Horowitz, T.: Bone and cartilage debris in the synovial membrane: its significance in the early diagnosis of neuroarthropathy. *J. Bone and Joint Surg.*, 30-A: 579-588, 1948.
- ²⁹Janicki, W., and Dylewska, D.: Rapidly progressive tabetic arthropathy of the hip. *Chir. Narsadow Ruch Orthop. Pol.*, 37 (4): 503-505, 1972.
- ³⁰Johnson, J.T.H.: Neuropathic fractures and joint injuries. *J. Bone and Joint Surg.*, 49-A, No. 1: 1-30 Jan., 1967.
- ³¹Johnson, J.T.H.: Neuropathic injuries of the hip, *Clin. Ortho.*, 90: 29-32, Jan.-Feb. 1973.
- ³²Jordan, W.R.: Neuritic manifestations in diabetes mellitus. *Arch. Int. Med.*, 57: 307, 1936.
- ³³Journal Tennessee Med. Assoc.: Diabetic neuropathic joint destruction. *Clin. Conference*, 73(4): 289-290, April 1980.
- ³⁴Kettunah, D.O.: Neuropathic arthropathy caused by spinal cord trauma. *Ann. Trauma Chir. et Gynaec. Fenn.*, 46: 95-100, 1957.
- ³⁵Kirkham, C.S.: Acute atrophic Charcots disease of both hips. *J. Bone and Joint Surg.*, 38-B, No. 3: 742-744, Aug. 1956.
- ³⁶Lance, P.: A propos du traitement chirurgical des arthropathies tabetiques de la lanche. *Rev. Med. Francaise*, 19: 543-548, 1938.
- ³⁷Manitz, V., Manits, L.: Tabetic arthropathy and its orthopaedic treatment. *Beirt. Orthop. Traumatol.*, 25 (11): 627-634, Nov. 1978.
- ³⁸Milgram, J.E.: Tabetic arthropathy. *Urologic and Cutaneous Review*, 44: 653, 1940.
- ³⁹Mitchell, J.K.: On a new practice in acute chronic rheumatism. *Am. J. Med. Sci.*, 8: 55, 1831.
- ⁴⁰Pendergrass, E.P., Gaman, G.D., and Powell, J.M.: Rapid development of bone changes in a patient with syringomyelia as observed roentgenographically. *Radiology*, 45: 138-146, 1945.
- ⁴¹Petrie, J.G.: Case of progressive joint disorders caused by insensibility to pain. *J. Bone and Joint Surg.*, 35B: 399, 1953.
- ⁴²Pomerang, M.D., and Rothberg, A.S.: A review of 58 cases of tabetic neuropathy. *Am. Journ. Syph., Gonorrhea and Venereal Dis.*, 25: 103-119, 1941.
- ⁴³Reinhard, K., and Wagner, M.: Complete destruction of both femoral heads following idiopathic necrosis of the femoral heads in a diabetic patient with hyperuricemia and hyperlipoproteinemia. *Arch. Orthop. Trauma. Surg.*, 96(2): 35-47, 1980.
- ⁴⁴Robillard, R., Gagnon, P.A., and Alarie, R.: Diabetic neuroarthropathy. *Canadian Med. Assoc. J.*, 91: 795-804, 1964.
- ⁴⁵Rosenberg, J.N.: Diabetes mellitus with osteopathy and Charcots arthropathy. *Roc. R. Soc. Med.*, Vol. 69(9): 705, Sept. 1976.
- ⁴⁶Rosenlain, F., and Milgram, J.E.: Fulminating neuropathic arthropathy. *J. Bone and Joint Surg.*, 45-A: 212, 1963.
- ⁴⁷Schwartz, G.S., et al.: Atrophic arthropathy and diabetic neuritis. *Amer. J. Roent.*, 106: 523, 1969.
- ⁴⁸Sinha, S., et al., Neuro-arthropathy (Charcot joints) in diabetes mellitus. *Medicine*, Vol. 51, No. 3: 191-210, 1972.
- ⁴⁹Solomon, L.: Drug induced arthropathy and necrosis of the femoral head. *J. Bone and Joint Surg.*, 55-B: 246-261, 1973.
- ⁵⁰Soloway, J., and Soloway, H.V.: Paraplegic neuroarthropathy. *Am. J. Reontgenol.*, 61: 475-481, 1949.
- ⁵¹Soto-Hall, R., and Haldeman, K.O.: Diagnosis of neuropathic joint disease (Charcot joint): analysis of 40 cases. *JAMA*, 114: 2076, 1940.
- ⁵²Soule, A.B., Jr.: Unusual findings in a case of Charcots arthropathy. *Am. J. Roentgenol. and Rad. Therapy*, 36: 804-808, 1936.

- ⁵³Southward, S.C.: Neuropathic arthropathy due to diabetes. *J. Am. Podiatry Assoc.*, Vol. 61: 329-334, Sept. 1971.
- ⁵⁴Steindler, A.: The tabetic arthropathies. *JAMA* 966: 250, 1931.
- ⁵⁵Steindler, A.: Post-graduate lectures in orthopaedic diagnosis and indications. Vol. IV, C.C. Thomas Publishers, Springfield, Illinois. (Lecture V on Neuroarthropathies, 281-300.)
- ⁵⁶Steindler, A., Williams, L.A., and Prig-Guri, J.: Tabetic arthropathies. *Urologic and Cutaneous Reviews*, 46: 633-649, 1942.
- ⁵⁷Sutton, R.D., Benedek, T.G., and Edward, G.A.: Aseptic necrosis and corticosteroid therapy. *Arch. Int. Med.*, 112: 594-602, 1963.
- ⁵⁸Sweetham, D.R., Mason, R.M., and Murray, R.O.: Steroid arthropathy of the hip. *British Med. J.*, 1:1392-1402, 1960.
- ⁵⁹Tamlyn, T.T.: Neuropathic arthropathy. *Minn. Med.*, 40: 117-120, 1947.
- ⁶⁰Ward, W.C.: Para-articular calcification in the lower extremities of paraplegic patients. *Am. J. Roentgenol. and Rad. Therapy*. 56: 712-712, 1946.
- ⁶¹Weinberg, E.D.: The treatment of Charcot joints. *Southern Med. J.*, 23: 527-531, 1930.
- ⁶²Wile, V.J., and Bulter, M.G.: A critical survey of Charcots arthropathy. Analysis of eighty-eight cases. *J. Am. Med. Assn.* XCIV, 1053, 1930.
- ⁶³Wirth, R.C., Jacobs, R.L., and Rolander, S.D.: Neuropathic spinal arthropathy: A review of the Charcot spine. *Spine*, Vol. 5, No. 6: 558-567, Dec. 1980.
- ⁶⁴Wolin, IL: Tabetic arthropathy of the hip. *Radiology*, 42: 79-80, 1944.
- ⁶⁵Zaafan. A., et al.: Neuroarthropathy occurring in diabetes mellitus. *J. Egypt Med. Assoc.*, 60 (5-6): 437-446, 1977.

THE AGING ATHLETE'S KNEE: JOINT DEBRIDEMENT VERSUS OSTEOTOMY VERSUS TOTAL KNEE REPLACEMENT††

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Middle aged and older athletes appear in increasing numbers as their knees fail to keep pace with their "youthful enthusiasm." The orthopaedic surgeon must treat the knee and realistically advise the patient as to his or her subsequent activities.

The following paragraphs present my perspective of the relationship of knee joint debridement, proximal tibial osteotomy, patellofemoral problems and total knee arthroplasty for the aging athlete. Only post-traumatic and degenerative arthritis are considered because debridement and osteotomy are only rarely indicated for inflammatory arthritis, and though total knee replacement is frequently indicated in inflammatory arthritis, athletic endeavors are usually contraindicated in this group.

First, one must define the aging athlete—we are all aging. Usually, the age of these patients ranges from 50 to 75. In this group the medical condition of the patient—cardiovascular, pulmonary, diabetes, obesity—must be considered not only from the standpoint of surgery but also in regard to subsequent activity levels. Goals may be modified more by medical status than by knee disease.

A second group of "aging athletes" includes chronologically younger patients with "aging knees." In these patients the activity modification protects what is left of the knee while permitting the patient to sustain vigorous activity.

Before undertaking operative treatment in the aging athlete, both the patient and the surgeon must consider the following: (1) Will non-operative treatment, including modifying or altering the athletic endeavor, provide a satisfactory solution? As an example, a 79 year old man's left knee had been intermittently sore and swollen following a hyperextension injury in the broadjump during the Senior Olympics 7 months previously. He had participated in 19 events. Examination

revealed a thin, well muscled man with severe, bilateral degenerative genu varum with medial bone attrition and large osteophytes. The right knee was stable. The symptomatic left knee had a positive posterior sag sign, the residual of a posterior cruciate injury. The patient wisely decided to alter his activities and take part in fewer events the next year. (2) Will operative intervention return the patient to his or her desired athletic endeavors? An affirmative answer to this question usually means that the knee has good, though perhaps not normal, articular cartilage. Limited debridement, consisting of removal of loose bodies, meniscectomy, and arthroscopic debridement, can be expected to return the patient to most athletic activities. The crucial difference between this type of knee and those we will subsequently discuss is the good articular cartilage. These nearly normal knees should be treated as such irrespective of the patients' chronological ages, assuming good neurovascular-muscular status. These patients deserve repair of acute ligamentous disruption with the exception of the anterior cruciate.

Disorders of the patellofemoral joint in the aging athlete frequently produce complaints. Most patients with patellofemoral problems fail to return to jumping sports. Fortunately, the aging athlete seldom pursues basketball, pole vaulting, etc. Tennis may aggravate or precipitate patellofemoral complaints. If non-operative measures fail to relieve the symptoms and the patient wishes to continue playing, he or she should be treated as the younger patient if the tibiofemoral joint remains normal. I am reserving judgment on the efficacy of arthroscopic debridement of the patellar cartilage. I do not do this procedure, so the only cases I see are other people's failures. As such, I am pessimistic.

Using the same indications as for younger patients, lateral retinacular release, proximal realignment, and combined realignment can return the aging athlete to tennis and similar activities.

Frequently, however, the patellofemoral joint in the older competitor shows radiographic evidence of arthritis with narrowing of the joint space, osteophytes and lateral tilting or subluxation of the patella. Soft

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tissue procedures alone are seldom adequate in this circumstance. Elevation of the tibial tubercle, as described by Maquet and Ferguson, with lateral release, if indicated, can return these patients to social tennis and similar activities. Jumping, prolonged running, and vigorous starts and stops usually are not tolerated.

As a general rule, patellectomy represents an end-stage procedure which, when coupled with debridement of osteophytes and extensive rehabilitation, may permit "social competition."

Proximal tibial osteotomy is indicated for symptomatic unicompartmental osteoarthritis with loss of joint space, to make the patient's daily activities and work more comfortable. I do not use an osteotomy solely to return a patient to a greater level of athletic activity. The Maquet barrel-vault technique will in addition provide some decompression of an associated arthritic patellofemoral joint. Osteotomy is an excellent procedure with a relatively long functional span and one which has burned no bridges. These patients can return to any degree of competition which the knee will tolerate. They frequently tolerate golf, hunting and limited tennis. Running, jumping and squatting should be discouraged because of the increased forces these activities apply to the knee.

After total knee replacement, an end stage procedure, the question becomes not so much what is the patient able to do, but what should the patient do. Wear and cold flow of the polyethylene component is a function of the forces applied and can be significant even

without the forces associated with athletic endeavors. Revision surgery for loosening or instability secondary to ligament injury is too high a price to pay for recreational athletics. Some patients resume golf, a low-risk activity, and a few attempt more vigorous sports. Rotation, even with light activities such as golfing or hunting, should be controlled by muscle and ligaments, alteration of the activity, or bracing. Even so, these sports should be strongly discouraged.

The current public enthusiasm for fitness and competition places a responsibility on the orthopaedic surgeon over and above selecting and performing the best form of treatment and informing the patient of activity restrictions. We often need to help our patients through the transition from their current athletic activity to other activities more compatible with their aging knees. For many aging athletes, their aging knees finally force them to cope with getting older. This seems to be more of a problem for the serious social-recreational athlete than for the ex-college football player, wrestler or swimmer who long ago learned that age old injuries and lack of time for work-outs forced a change in activities. Kayaking, canoeing, sailing, and to a lesser degree, rowing represent alternatives. If competition remains a primary goal, the shooting sports—trap, skeet, rifle, pistol, muzzleloader and archery—provide competition from local through international levels. Local and national competition is also available in a whole range of other activities from tomahawk and knife throwing through more sedentary activities.

THE FREE AUTOGENOUS VASCULARIZED FIBULA GRAFT

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Since Taylor et al.¹⁷ performed the first clinically successful autogenous free vascularized fibula graft for reconstruction of a large traumatic tibial defect in 1975, the indications have been expanded. The procedure serves well to bridge large bony defects after resection of malignant or aggressive tumors,^{15,20-22} to treat congenital pseudarthrosis of the tibia¹⁰ and of the forearm bones,² and to reconstruct long bone anomalies.¹⁴ We have performed three autogenous free vascularized fibula transfers at the University of Iowa: one for skeletal reconstruction after resection of a periosteal desmoid of the femur, one after en-bloc resection of a parosteal osteogenic sarcoma of the proximal humerus, and one for treatment of a difficult congenital pseudarthrosis of the tibia.

Case Reports

Case One: L.H.

L.H., a 16 year old female, noted painless swelling in her right thigh for one month. Fig. 1 shows the presenting radiographs. The differential diagnosis includ-

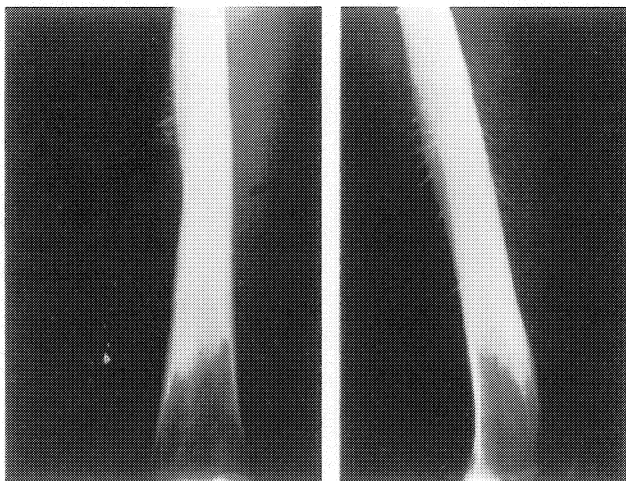


Figure 1. L.H. AP and lateral radiographs right femur.

ed osteogenic sarcoma and Ewings sarcoma. The history and physical findings were unremarkable except for a firm right thigh mass and a right thigh circumference 3.5 cm greater than the left. Laboratory values were all normal. Lung computerized tomograms showed no metastases. A bone scan demonstrated increased uptake only in the lower two-thirds of the right femur. Computerized tomography of the femur demonstrated bony spiculation arising from the entire mid shaft and extending into adjacent soft tissues. The incisional biopsy revealed a periosteal desmoid. We planned en-bloc resection of the tumor with reconstruction of the bony defect by an autogenous free vascularized fibula graft. Preoperative preparation included right lower extremity arteriograms, appropriate routine laboratory work, and a type and crossmatch for 10 units of blood.

While one surgical team resected the tumor en-bloc through both a medial and lateral approach, the other team removed the fibula through a Henry posterior-lateral approach. Following resection of the neoplasm, the ends of the fibula graft were placed into the medullary canal of the femur and stabilized with a Hoffman apparatus (Fig. 2). Anastomosing the peroneal artery and venae comitantes to the profun-

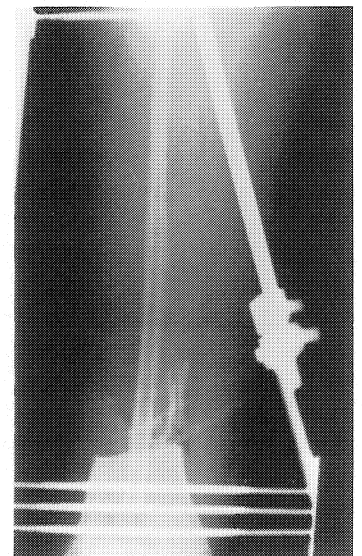


Figure 2.
L.H. Postoperative radiographs showing fixation of fibular graft.

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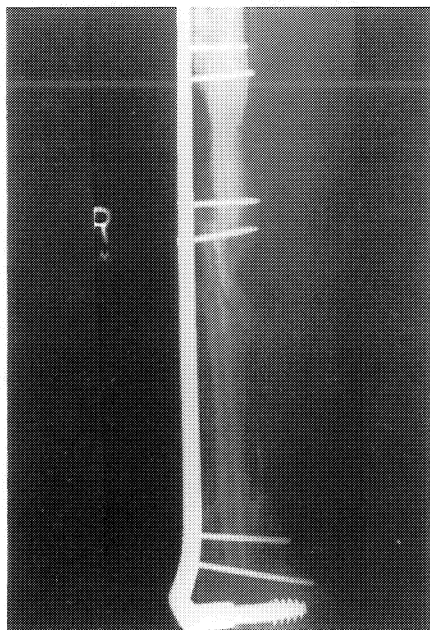


Figure 3. L.H. Fractured fibula internally fixed with a blade plate.

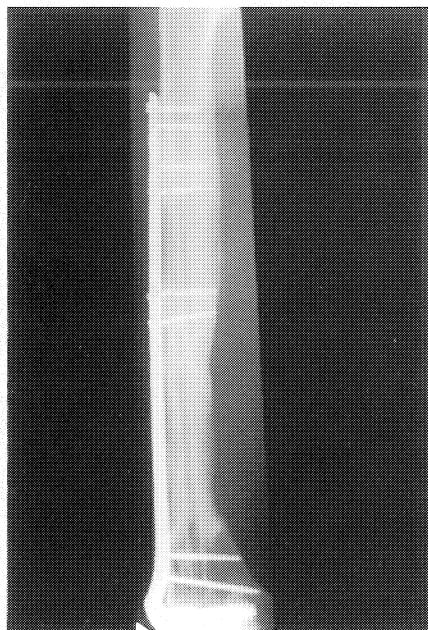


Figure 4. L.H. Radiograph 3 years after vascularized fibula grafting. The graft was hypertrophied to about the size of a normal femur.



Figure 5. J.H. Tomograms of left humerus demonstrating "fluffy" radiodense lesion.

da femoral artery and vein with 10.0 monofilament nylon re-established perfusion of the graft. Release of the clamps demonstrated moderate bleeding from the muscular cuff surrounding the fibula.

Post-operatively the grafted fibula fractured twice. The first occurred shortly after removal of the Hoffman device and the second shortly after removal of the hip spica cast. The fractured fibula graft was internally fixed with a blade plate (Fig. 3). Radiographs approximately 3 years after grafting demonstrate the hypertrophy of the fibula (Fig. 4). The patient now walks without aids and has regained full hip and knee motion. A two centimeter leg length discrepancy has remained asymptomatic, with a 3/8 inch insert in the left shoe.

Case Two: J.H.

Six weeks prior to admission, J.H., a 31 year old man noted a mildly painful enlarging mass in his left shoulder after he struck his left shoulder during a minor motor vehicle accident. Symptoms progressed over the next several weeks with a shooting pain extending down from his left arm, and he developed numbness and tingling on the dorsum of his left hand. The patient denied fevers or chills but admitted to a recent nine pound weight loss and increasing fatigability. Physical examination revealed a 10 cm. firm mass involving the posterior-medial aspect of the proximal arm. Pain limited internal and external rotation of the shoulder, and the triceps reflex was decreased.

Vascularity, erythema or warmth was not evident over the mass. Hematologic studies were normal. A bone scan showed increased radiotracer activity in the upper shaft of the humerus. Tomograms demonstrated a diffuse "fluffy" radiodense lesion approximately 10 cm. long surrounding the proximal shaft of the humerus (Fig. 5). A lucent area was noted between the lesion and the cortex; intramedullary extension was not apparent. Computerized tomography revealed a dense lesion in the proximal shaft of the left humerus extending into the anterior compartment muscles. Preoperative arteriograms (Fig. 6) demonstrated the vascular pat-

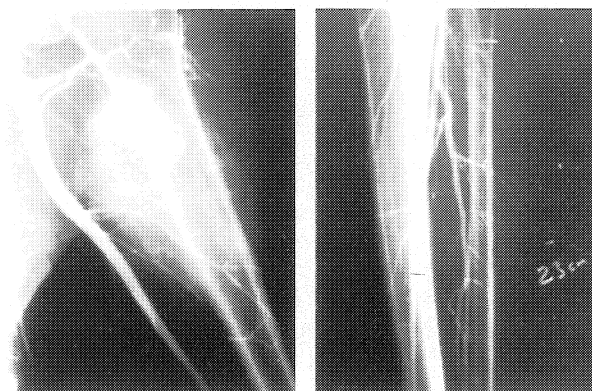


Figure 6. J.H. Preoperative arteriograms demonstrating the vascular patterns of the donor and recipient site.

terns of the donor and recipient sites. An incisional biopsy revealed parosteal osteosarcoma. Immediately after en-bloc resection of the tumor, the bony defect

was bridged with an autogenous vascularized free fibula graft. The radial nerve, encased by tumor, was removed during the en-bloc resection. We preserved the circumflex vessels. Following resection of the tumor, stabilization of the graft was achieved by doweling the fibula into the remaining humeral head proximally and the shaft distally. A single cortical screw proximally and a long offset plate contoured to the fibula and remaining humerus, proximally and distally, completed the stabilization (Fig. 7). Anastomosing the peroneal artery and venae comitantes in an end-to-

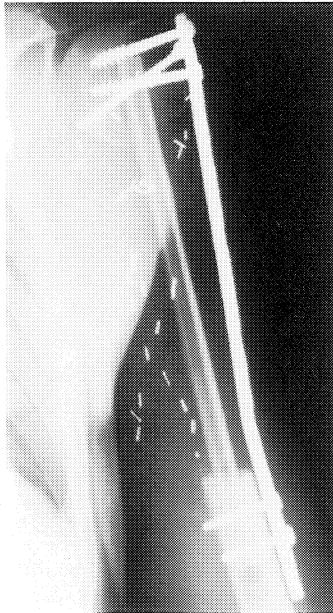


Figure 7.
J.H. Postoperative films with extensive internal fixation evident.

side manner to the posterior humeral circumflex vessels restored circulation to the graft as evidenced by intraoperative bleeding from the graft and muscular cuff and positive patency tests. Nine months postoperatively, the radial nerve deficit necessitated tendon transfers, and 14 months after tumor resection the patient has improved function of the extremity with no evidence of tumor recurrence. Radiographs one year after grafting demonstrate only minimal hypertrophy of the fibula (Fig. 8).

Case Three: B.K.

B.K., a 3½ year old white male, was noted by his pediatrician to have anterior-lateral bowing of his left tibia during the first month of life. At age 6 weeks the child did not move his left leg as much as his right. Radiographs showed a fracture at the junction of the middle and distal one-third of the tibia and fibula with a cystic lesion near the fracture (Fig. 9). This plus several cafe-au-lait spots suggested the diagnosis of neurofibromatosis with congenital pseudarthrosis. Four



Figure 8.
J.H. Radiograph one year postoperative with only minimal hypertrophy of the vascularized fibula graft.

months of casting did not result in healing of the fracture. Two attempts of bony grafting with intramedullary fixation failed to achieve union.

After consideration of other treatment alternatives (repetition of conventional bone grafting, below knee amputation, and electrical stimulation), we chose vas-

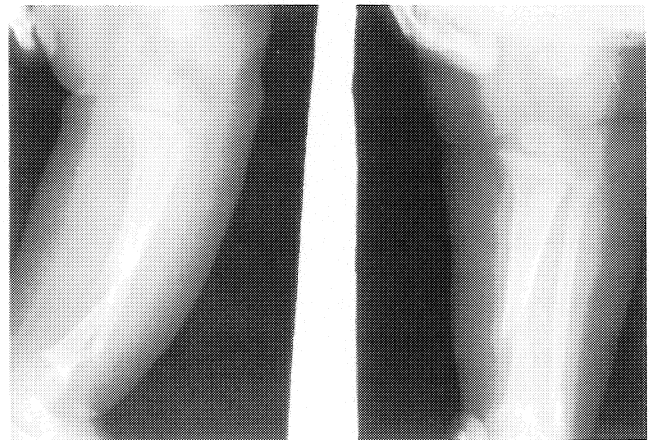


Figure 9. B.K. Initial radiographs with fracture of the junction of the middle and distal one-third of the tibia and fibula with a cystic lesion near the fracture.

cularized free fibula grafting. Preoperative preparation included routine lab work, arteriograms of both the donor and recipient legs, and type and cross match for six units of blood. Stabilization of the graft was achieved proximally with a cortical screw. The very osteoporotic nature of the remaining distal tibia prevented rigid internal fixation with screws. Therefore, we used Steinmann pins and placed the leg in a well

molded above the knee cast. Radiographs 4 months after grafting (Fig. 10) show the hypertrophied fibula incorporated proximally. Radiographic union is not evident distally, although clinical union is present.

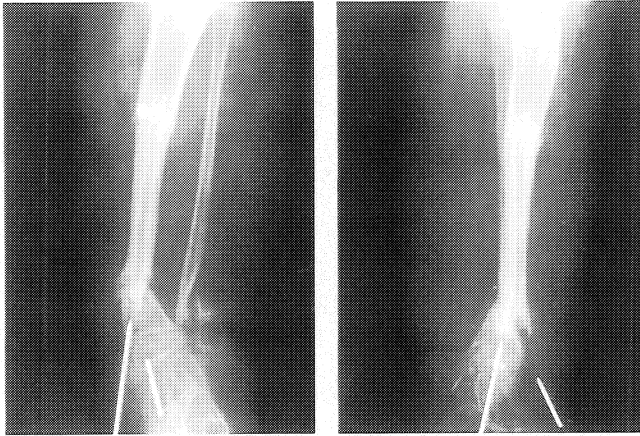


Figure 10. B.K. Radiograph 4 months after grafting. Radiographic union is present proximally, minimal healing distally; however, the graft has united clinically.

Discussion

The advantages of the autogenous vascularized fibula graft over conventional bone grafting procedures have been thoroughly discussed.^{5,12,16,17,18,20,21} This one stage procedure, using living autogenous bone, allows for more rapid healing and hypertrophy. The tubular structure of the fibula has more inherent strength than alternative free iliac crest or rib grafts. Also, bone union may eventually occur in a manner similar to a conventional graft should the anastomoses fail. The prime indication for this procedure may be in the reconstruction of major defects in long bones with decreased vascularity secondary to trauma or radiation.

Major disadvantages include long wound exposure times, the necessary sacrifice of a major artery in the donor limb, and the potential for compromise of a major artery in the recipient limb. The patient must also be capable of sustaining anesthesia time, which may be greater than 13 hours.

Careful preoperative planning is necessary. In addition to routine laboratory work and a type and cross match for a relatively large volume of blood, angiographic studies should be completed on both the donor and recipient extremity. Angiography identifies vascular anomalies, vessel adequacy, and provides an image which can be superimposed on the recipient limb with the nutrient artery of the fibula centralized in the gap between the bone ends.

Two teams experienced in microvascular surgery facilitate this procedure. The surgeon should be able to

perform end-to-end or end-to-side anastomoses with high patency rates. One team generally prepares the recipient site and vessels while the other team removes the fibula. Steps in obtaining the fibula have been well outlined by others.^{5,16-18,20,21} Many methods for stabilizing the graft in its recipient bed have been used. Intramedullary fixation is theoretically unsatisfactory because of compromise to the medullary blood supply. However, the preservation of only the periosteal blood supply in a vascularized rib graft may result in complete bone graft survival.¹⁴ Plates can also theoretically compromise the blood supply, although dynamic compression plates as well as fibular plates have been used.²³ External fixation devices are a technical alternative and may provide adequate stabilization.

Angiography may demonstrate graft viability post-operatively, although radionuclide bone imaging appears to be an accepted method.¹³ Experimentally, radionuclide bone imaging has been used to predict a potential for longitudinal growth following vascularized grafting of a long bone in puppies,¹⁷ and to sequentially assess vascularized allograft rejection in rats.¹⁰

The vascularized fibula graft has been used in reconstruction of major bone defects following resection of locally aggressive or low grade malignant tumors—including giant cell tumors,^{14,20} a low grade chondrosarcoma,²⁰ an adamantinoma,²¹ and unicameral bone cysts.⁵

Periosteal desmoids, rare, low grade, locally destructive neoplasms, characteristically grow slowly but steadily. En-bloc resection probably represents the best treatment.^{8,12} In our case this included resection of a large portion of the femur. The surgery was successful, although our patient developed several complications. Perhaps supplemental external protection would have been valuable. Despite the complications, the patient regained full range of motion of her hip and knee, walks without aids and shows no evidence of recurrence 2½ years after surgery.

Parosteal osteosarcomas comprise about 1% of all bone tumors.⁹ Patients are generally over age 20 years with the range from 12-58 years.^{2,19} Seventy-two percent involve the distal femur or proximal tibia.¹² Our case represents a fairly classical case of a parosteal osteosarcoma. The graft in this case has hypertrophied minimally when compared to the other cases. The surgery was successful, and the graft remained vascularized as evidenced by its radiographic isodensity compared to the rest of the humerus. The lack of hypertrophy can probably be explained by the extensive internal fixation taking much of the stress.

Congenital pseudarthrosis of the tibia is a difficult and often frustrating problem not only for the or-

thopaedic surgeon but also for the family involved. Many methods have been used to attempt to obtain union. Morrissy et al. recently assessed the results of several surgical procedures and concluded that the Farmer procedure (a composite skin and bone pedicle graft from the other leg) was superior to the others. However, only 9 of 17 treated with this procedure obtained union and only 5 of these were classified as good results.¹³ Despite surgical intervention the amputation rate remains high.

Results in treating congenital pseudarthrosis of the tibia with pulsing electromagnetic fields (PEMF) have been reviewed by Bassett et al.³ Seventeen of 34 patients with infantile non-union achieved complete healing as demonstrated clinically and radiographically. Union with function, i.e., healing with PEMF does not occur with Type III lesions (a significant gap greater than 5 mm, and atrophic spindled bone ends). Amputation rate in this study was around 21%.

Vascularized autogenous fibula grafts have recently been used in treatment of congenital pseudarthrosis of the tibia²³ and for treating the rare problem of congenital pseudarthrosis involving the forearm.² Our patient was not a candidate for PEMF since he had a Type III lesion. We doubt that conventional bone grafting would have been successful. We considered conventional bone grafting, amputation and vascularized free fibula grafting. It is too early to evaluate the degree of success in this patient.

Summary

The place for this relatively new technique in reconstructive surgery remains to be determined. Currently, the greatest applicability seems to be in the reconstruction of major bone defects where trauma or irradiation has produced sub-optimal conditions for conventional grafting techniques.

Bibliography

¹Ahuja, S.C., Villacin, A.B., Smith, J., Bullough, P.G., Huvos, A.G., and Marcove, R.C.: Juxtacortical (Parosteal) osteogenic sarcoma. Histological grading and prognosis. *J. Bone and Joint Surg.*, 59A:632-647, 1977.

²Allieu, Y., Gomis, R., Yoshimura, M., Dimeglio, A., and Bonnel, F.: Congenital pseudarthrosis of the tibia—two cases treated by free vascularized fibular graft. *J. Hand Surg.*, 6:475-81, 1981.

³Bassett, C.A.L., Caulo, N., and Kort, J.: Congenital "pseudarthrosis" of the tibia: Treatment with pulsing electromagnetic fields. *Clin. Orthop.* 154:136-149, 1981.

⁴Berggren, A., Weiland, A.J., Ostrup, L.T., and Dortman, H.: Microvascular free bone transfer and revascularization of the medullary and periosteal circulation or the periosteal circulation alone. *J. Bone and Joint Surg.*, 64A:73-87, 1982.

⁵Daniel, R.K. and Terzis, J.H. (eds): *In Reconstruction Microsurgery*. Boston, Little, Brown, 1977.

⁶Daniel, R.K. and Weiland, A.J.: Free tissue transfers for upper extremity reconstruction. *J. Hand Surg.*, 7:66-76, 1982.

⁷Dee, P., Lambruschi, P.G., and Hiebert, J.M.: The use of Tc-99m mdp bone scanning in the study of vascularized bone implants: Concise communication. *J. Nucl. Med.*, 22:522-525, 1981.

⁸Firminger, M.I. (Editor): *Atlas of Tumor Pathology*. Second Series, Fascicle 5. Tumors of Bone and Cartilage. Armed Forces Institute of Pathology. Washington, D.C., 1971.

⁹Huvos, A.G.: *Bone Tumors Treatment and Diagnosis* Philadelphia, W.B. Saunders Co., 1979, pp. 94-106.

¹⁰Lipson, R.A., Dief, H., Greyson, N.D., Kawano, M., Gross, A.E., Langer, F., and Halloran, P.F.: Bone scanning in assessing viability of vascularized skeletal tissue transplants. *Clin. Orthop.*, 160:279-289, 1981.

¹¹Lisbon, R., et al.: Radionuclide evaluation of free vascularized bone graft viability. *Am. J. of Radiology*, 134:387-388, 1980.

¹²Mirra, J.M.: *Bone Tumors Diagnosis & Treatment*. Philadelphia, J.B. Lippincott Co., 1980, pp. 536-550.

¹³Morrissy, R.T., Riseborough, E.J., and Mall, J.E.: Congenital pseudarthrosis of the tibia. *J. Bone and Joint Surg.*, 63B:362-365, 1981.

¹⁴Pho, R.W.H.: Free vascularized fibular transplant for replacement of the lower radius. *J. Bone and Joint Surg.*, 61B:362-365, 1979.

¹⁵Pho, R.W.H.: Malignant giant cell tumors of the distal end of the radius treated by a free vascularized fibular transplant. *J. Bone and Joint Surg.*, 63A:877-884, 1981.

¹⁶Serafin, D. and Bunke, H.J. (Eds): *Microsurgical Composite Tissue Transplantation*. Saint Louis, C.V. Mosby Co., 1979.

- ¹⁷Taylor, G.I., Miller, G.O.H., and Hamm, F.J.: The free vascularized bone graft. A clinical extension of microvascular techniques. *Plast. and Reconst. Surg.*, 55:533-544, 1975.
- ¹⁸Taylor, G.I.: Microvascular free bone transfer. A clinical technique. *Orthop. Clin. of N.A.*, 8:425-447, 1977.
- ¹⁹Unni, K.K., Dahlin, D.C., Beabout, J.W., and Ivins, J.C.: Parosteal osteogenic sarcoma. *Cancer*, 37: 2466-2475, 1976.
- ²⁰Weiland, A.J., Daniel, R.K., and Riley, L.H.: Application of the free vascularized bone graft in the treatment of malignant or aggressive bone tumors. *Johns Hopkins Med. J.*, 140:385-398, 1977.
- ²¹Weiland, A.J. and Daniel, R.K.: Microvascular anastomoses for bone graft in the treatment of massive defects in bone. *J. Bone and Joint Surg.*, 61A:98-104, 1979.
- ²²Weiland, A.J., Kleinert, H.E., Kutz, J.E., and Daniel, R.K.: Free vascularized bone grafts in surgery of the upper extremity. *J. Hand Surg.*, 4:129-144, 1979.
- ²³Weiland, A.J. and Daniel, R.K.: Congenital pseudarthrosis of the tibia. Treatment with vascularized autogenous fibular grafts. A preliminary report. *Johns Hopkins Med. J.*, 147:89-95, 1980.
- ²⁴Weiland, A.J.: Current concepts review. Vascularized free bone transplants. *J. Bone and Joint Surg.*, 63A: 166-169, 1981.

RESULTS OF TREATMENT OF 1,400 OPEN FRACTURES: 24 YEARS EXPERIENCE AT HENNEPIN COUNTY MEDICAL CENTER— MINNEAPOLIS, MINNESOTA†

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The principles and guidelines for management of open fractures advocated and discussed in this article are a product of extensive reviews both retrospective and prospective, covering the years 1955-1979. One thousand and four hundred open fractures of long bones were treated at the Hennepin County Medical Center. Except for the cases between 1976 and 1979, all have been reported previously.^{2,3,4,5} This paper consolidates these reports, including our experience during the last four years, and lists conclusions from this quarter of a century experience.

Although the review started in 1955, only after 1969 were these fractures classified as Type I, II, and III. Table I shows the fractures included between 1976 and 1979. Note the 23 per cent increase in the number of Type III open fractures treated during that time. This probably indicates that Types I and II fractures are managed by orthopaedic surgeons in suburban hos-

pitals and that the Type III fractures are referred to Trauma Facilities for treatment. Severe open fractures require hard work, expertise and prolonged treatment.

In the management of open fractures, the objectives of the treatment are (1) preventing wound sepsis, (2) achieving bony union, and (3) returning the patient to optimum function. Of the three, the initial and primary concern must be prevention of wound sepsis and achieving soft tissue healing. Many factors influence the final outcome of an open fracture wound, the more important of which are the degree of initial soft tissue injury, adequacy of debridement, antibiotic treatment, achieving fracture stability and early soft tissue coverage. The infection rate is shown in Table II. Note that in Type III open fractures, with extensive soft tissue damage, the infection rate is 10 to 20 times greater than in Types I and II open fractures. During the last 10 years, no Type I open fracture became infected, and Type II open fractures developed infection in only 1 to 2 per cent. The increase in the infection rate during the last four years is due to the 23 per cent in-

Table I

**Summary of 1400 Open Fracture Cases
Treated at the
Hennepin County Medical Center, 1955-1979**

Study Period	No. of Fractures	Type of Fracture		
		I	II	III
1955-1968	673*	—	—	—
1969-1975	520	421† (81%)	—	99 (19%)
1976-1979	207	65 (31.4%)	55 (26.5%)	87 (42.1%)

*No classification made

†Includes Types I and II

Table II

**Infection Rate in 1400 Open Fractures,
Retrospective and Prospective Studies
1955-1979**

Periods	No. of Fractures	Overall Infection (percent)	Type of Fracture (percent)		
			I	II	III
Retrospective					
1955-1960	215	11.8	—	—	—
1961-1968	458	5.2	0	0	44
Prospective					
1955-1975	520	2.4	0	1.2	10.2
1976-1979	207	10.1	0	1.81	22.9

crease in Type III open fractures. However, this still represents a marked decrease from the 44 per cent infection rate in Type III open fractures between 1961 and 1968. Hence, the real problem in the prevention of wound sepsis involves the Type III open fractures.

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Although it has been discussed in previous reports, adequate and thorough debridement coupled with copious irrigation of open fractures cannot be over emphasized. The previous four studies demonstrated repeatedly that adequate debridement of the injured soft tissue remains the key factor in the prevention of wound infection. With Type III open fractures, especially farm and vascular injuries, a second operative debridement within 24 hours after the initial debridement is imperative. In open fractures with extensive soft tissue injury, one cannot expect to do a complete debridement initially. An inspection of the wound the following day almost always reveals more dead tissues requiring debridement.

The use of antibiotics in the management of open fractures at the Hennepin County Medical Center is based upon the premise that open fracture wounds are contaminated and that antibiotics should be used as treatment rather than as prophylaxis. These points were illustrated in the prospective study by Gustilo and Anderson,⁴ showing that 70.3 per cent of the 520 open fractures seen from 1969 to 1975 were indeed contaminated at the time that they came to the hospital, and that the infection rate significantly decreased with the use of antibiotics. In the same study, cephalosporins appeared to be the most effective antibiotic for the treatment of acute and/or infected fractures. On this basis, we routinely administer antibiotics to open fracture patients pre-operatively, intra-operatively and until three days after initial debridement. Further antibiotic treatment is given only to patients who become infected. The choice of antibiotics is based on cultures and sensitivities.

Skin closure has always been a problem in the treatment of open fractures, and through the years, different attitudes have prevailed with respect to this. At our institution from 1955 to 1968, primary closure was effected whenever possible, regardless of the severity of the fracture and the soft tissue injury. There was a high incidence of infection in Type III fractures closed primarily even after what was considered a thorough debridement. During the prospective study period from 1969 to 1973, primary closure was performed in Type I and II open fractures and delayed closure in Type III. Delayed closure, when possible, was done within the first five to seven days. These guidelines have been followed for the last ten years and the resulting reduction in the infection rate indicates the efficacy of the treatment methods.

Stabilization of open fractures by immediate internal fixation is another controversial issue. During the past 25 years there have been changes in attitudes toward immediate internal fixation of open fractures. From

1955 to 1968 we avoided primary fixation, particularly intramedullary nailing and plating, because of a significantly higher infection rate (Table III). However, primary or early internal fixation during this period was always accompanied by primary wound closure. Concluding the prospective study from 1965 to 1975, Gustilo and Anderson⁴ recommended that internal fixation by plates or intramedullary nails should not be

Table III

Infection Rate in Primary Metallic Fixation in Open Fractures with Primary Closure of the Femur and Tibia 1955-1968

	No. of Cases	Infected	Per Cent
Femur			
Conservative Treatment	44	2	4.5
One Metallic Fixation	18	3	16.6
Tibia			
Conservative Treatment	194	10	5.1
One Metallic Fixation	34	7	20.6

used. External skeletal fixation by skeletal traction, pins above and below the fracture site incorporated in a plaster cast, or devices such as the Roger Anderson or Mueller apparatus were recommended. Four years later, the same authors¹ recommended employing immediate internal fixation, particularly in polytraumatized patients and others sustaining Type III open fractures, to facilitate care of the soft tissue. They advocated intramedullary nailing for polytraumatized patients with Types I and II wounds. Immediate internal fixation was also recommended for multiple fractures in one extremity involving both sides of the joint. However, in all cases the WOUND MUST BE LEFT OPEN.

In our latest review of 207 open fractures at Hennepin County Medical Center covering the period 1976 to 1979, the role of internal fixation in the management of open fractures vis-a-vis the resultant infection was studied. Table IV indicates that of the stabilization procedures, external fixation carries a higher incidence of wound infection compared to conservative methods (cast immobilization, traction, and pins and plaster) and to internal fixation methods (screws, plates, intramedullary rods). The differences in the infection rate among these three groups of stabilization procedures are statistically significant ($p < 0.005$). However, the injuries to patients in these three groups are not necessarily comparable. Patients who were treated con-

Table IV

Infection Rate with Internal Fixation of Open Fractures, 1976-1979

Type of Fracture	Conservative		External Fixator		Internal Fixation	
	No.	Infected	No.	Infected	No.	Infected
I	50	0	1	0	14	0
II	40	1(2.50%)	4	0	11	0
III	33	3(9.09%)	18	9(50%)	30	8(26.67%)
Totals	123	4(3.25%)	23	9(39.13%)	55	8(14.54%)

servatively had soft tissue and bone injuries of lesser magnitude than those patients treated with either internal or external fixation. Patients who were put in external fixators usually had the worst soft tissue damage and the most unstable fractures.

The open nature of a fracture, particularly one with extensive soft tissue injury, has always been considered a cause of delayed union or nonunion. In our 1976 to 1979 review, we found that delayed union and nonunion occurred solely with Type III fractures. Of the 207 fractures reviewed, no delayed union or nonunion was found in Types I and II fractures, but there was an incidence of 13.79 per cent delayed union or nonunion in Type III open fractures.

The above data indicates that the main problem in the management of open fractures is with Type III cases, and rightly so, since the Type III open fracture is the result of a severe and often violent force, and the injury to both soft tissue and bone is often extensive. Therefore, this group should have a higher incidence of infection, a higher incidence of delayed union or nonunion, and a higher incidence of amputation and mortality compared with Types I and II.

During the last review (1976 to 1979), we focused our attention on Type III fractures, which by definition include the following: open segmental fractures, open fractures with extensive soft tissue injury, traumatic amputations, fractures secondary to gunshot injury, open fractures caused by farm injury, and open fractures accompanying vascular injury requiring repair. During these four years, 192 patients with 207 open fractures of the long bones were treated. Of these 207 fractures, 65 (31.4 per cent) were Type I open fractures, 55 (26.5 per cent) were Type II, and 87 (42.1 per cent) were Type III.

We had 75 patients with 87 Type III fractures; 63 males and 12 females. Patients in their teens to early thirties accounted for 72.3 per cent of the group. The mechanisms of injury were motorcycle related accidents (24 cases), motor vehicle accidents and pedestrian

accidents (13 cases each), gunshot wounds (12), farm injuries (4), and crush injuries (6). Of the 87 Type III open fractures, 55 involved the tibia and fibula, 20 the femur, seven the radius and ulna, four the humerus, and one the calcaneus.

Table V summarizes the management of the 87 Type III open fractures for the study period 1976 to 1979. The differences among the infection rates associated

Table V

Stabilization Procedures, Type III Open Fractures, 1976-1979

Procedure	No.	Wound Infection	Chronic Infection	Delayed Union or Non-Union
Conservative Treatment (Cast, Traction, Pins and Plaster)	33	3(9.09%)	0	3(9.09%)
External Fixator	18	9(50%)	6(33.3%)	5(27.8%)
Screw Fixation	6	1(16.79%)	1(16.79%)	0
Plate Fixation	9	2(22.2%)	2(22.2%)	2(22.2%)
Intramedullary Rod	15	2(33.3%)	1(13.3%)	2(13.3%)
≤ 7 Days	7	3(42.8%)	2(28.6%)	1(14.3%)
8-14 Days	3	2(66.7%)	0	1(33.3%)
> 14 Days	5	0	0	0

with the different stabilization procedures are statistically significant ($p < 0.005$). Although the difference in the infection rate between the conservatively-treated group and the internally-fixed groups is apparent, the difference is not statistically significant. The same is true when the external fixator group is compared to the internal fixation groups. The difference in infection rate between the conservative treatment groups and the external fixator groups is, however, statistically significant ($p < 0.01$). Although it appears that screw fixation is associated with the lowest incidence of infection and delayed union or nonunion, the differences in morbidity incidence among the internal fixation methods (screw, plate, intramedullary rod) are not statistically significant.

In an effort to understand Type III open fractures, the fractures were grouped into special categories (Table VI). The data indicates that wound infection invariably follows an open fracture secondary to farm injury and is present in 41.66 per cent of open fractures with vascular injury and 61.9 per cent of fractures with exten-

Table VI

**Complications in Various Categories of
Type III Open Fractures, 1976-1979**

Category	No.	Wound Infection	Chronic Infection	Delayed Union Nonunion	Amputation
Gunshot Wound	12	0	0	0	0
Farm Injury	4	4(100%)	3(75%)	2(50%)	1(25%)
Segmental Fracture	11	2(18.18%)	0	2(18.18%)	1(9.09%)
Vascular Injury	12	5(41.66%)	2(16.66%)	2(16.66%)	5(41.66%)
Extensive Soft Tissue Injury	21	13(61.90%)	8(30.09%)	6(28.57%)	4(19.05%)

sive soft tissue involvement. Subsequent delayed union or nonunion and osteomyelitis are most common in the group with extensive soft tissue injuries, while the rate of amputation is high in vascular injuries (41.66 per cent), farm injuries (25 per cent), and fractures with severe soft tissue injury (19.04 per cent). These figures are statistically significant ($p < 0.01$). Although the cases of farm injuries, vascular injuries, and fractures with extensive soft tissue injury overlap, the data strongly suggests that it is in these special categories of Type III fractures that most complications of infection, delayed union or nonunion, subsequent osteomyelitis, and amputation occur.

The 41.66 per cent amputation rate for Type III open fractures with vascular injury in this 1976 to 1979 series is comparable to rates in previous studies at the Hennepin County Medical Center. A review of 89 cases in 1970 revealed a 55 per cent amputation rate, and a 1971 to 1977 review by Lundeen listed an improved rate of 16 per cent.

Open fractures secondary to gunshot wounds developed no infection, delayed union, nonunion, or subsequent osteomyelitis. Eleven of twelve cases were due to low-velocity gunshot wounds and one to a shotgun wound. There was little soft tissue damage in these cases.

The infection rate of 22.9 per cent (20/87 fractures) represents Type III open fractures which became infected early in the course of management. After three months, of the initial twenty infected fractures, only ten (11.49 per cent of the original 87 fractures) had signs of infection. At the end of this review, with at least two years of follow-up, only two fractures had persistent

drainage, representing an infection rate of 2.29 per cent for the 87 Type III open fractures seen between 1976 to 1979.

Other complications of Type III open fractures are: (1) delayed union or nonunion in 12 fractures (13.79 per cent); (2) amputations in eight (9.19 per cent); (3) knee fusion in one (1.14 per cent); and (4) death in five patients (6.66 per cent). All who died were multi-trauma patients and the cause of death was multi-systems failure.

This intensive review of Type III open fractures demonstrates that the high morbidity rate most closely relates to injuries resulting in massive soft tissue damage, compromised vascularity, and severe contamination of the involved extremity, as occurs in farm injuries, crush injuries, and severe motor vehicle or motorcycle accidents.

After 24 years of experience with the management of 1,400 open long bone fractures, we believe that the basic principles and guidelines in the current management of open fractures are sound. Although a number of incompletely resolved questions remain, especially in the areas of internal fixation, concomitant vascular injuries, extensive soft tissue loss, and sepsis, we are optimistic that further study will answer some of these questions during the next decade.

Bibliography

- ¹Anderson, J.T. and Gustilo, R.B.: Immediate internal fixation in open fractures. *Ortho. Clin. N.A.*, 11(3):569-578, July 1980.
- ²Gustilo, R.B., Simpson, L., Nixon, R., Ruiz, A., and Indeck, W.: Analysis of 511 open fractures. *Clin. Orthop.*, 66:148-154, September-October, 1969.
- ³Gustilo, R.B.: Management of open fractures. An analysis of 673 cases. *Minnesota Medicine*, 41:185-189, March 1971.
- ⁴Gustilo, R.B. and Anderson, J.T.: Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones. *J. Bone and Joint Surg.*, 58A(4):453-458, June 1976.
- ⁵Gustilo, R.B.: Use of antimicrobials in the management of open fractures. *Archives of Surgery*, 114:805-808, July 1979.
- ⁶Lundeen, J.: Arterial injury complicating fracture. Unpublished Report, 1977.

EXTERNAL FIXATION OF TIBIAL FRACTURES

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External fixation predates by twelve years plaster casting in treating fractures. In 1843, Jean Francois Malgaigne⁴⁴ devised a claw-like clamp which he applied percutaneously to reduce and stabilize fractures of the patella (Figure 1). Since then, many external skeletal fixation systems employing percutaneously applied pins incorporated into plaster, methacrylate, epoxy-filled tubing, or mechanical exoskeletons have been developed.

In 1897, Clayton Parkhill⁴⁹ devised a system utilizing percutaneous pins connected to a rigid external plate (Figure 2). Coincidentally, Albin Lambotte³⁸ of Belgium developed a system quite similar in design to Parkhill's (Figure 3).

In 1934, Roger Anderson³ invented a fracture reduction apparatus utilizing, for the first time, transfixing pins that penetrated bone in a through-in through fashion. He connected the pins to movable horseshoe-shaped clamps that encircled the leg posteriorly

(Figure 4). The movable clamps permitted multiplanar adjustments of the fracture. The device also applied significant compression across the fracture site. A surgeon, using this device, reduced the fracture and held the alignment under compression until he or she applied a plaster cast. After the plaster hardened the frame and clamps were removed. Later, Anderson⁴ fabricated a frame connecting the transfixing pins. The frame included bars attached to the pins by articulating clamps that permitted multiplanar adjustments of fracture fragments. This frame eliminated plaster casts (Figure 5).

Concurrently, in this country, Otto Stader,⁵⁵ a veterinarian, fabricated a system to treat long bone fractures in dogs. His external skeletal fixator provided reduction in three planes independently (Figure 6). Also, the frame provided stability of the fracture fragments. His system greatly improved fracture treatment in dogs who destroy casts by tearing and biting.

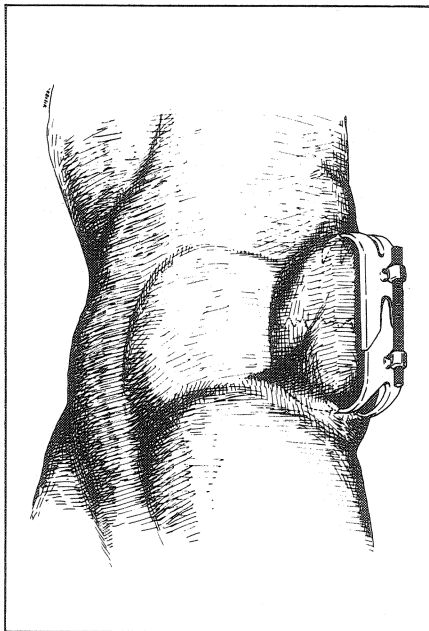


Figure 1. Malgaigne patella fixator (1843).

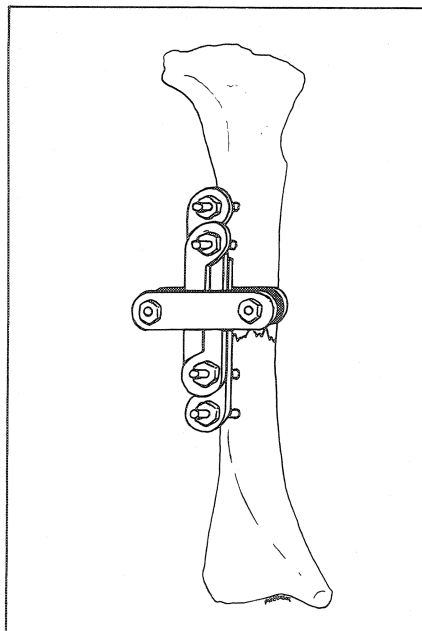


Figure 2. Parkhill's bone clamp (1897).

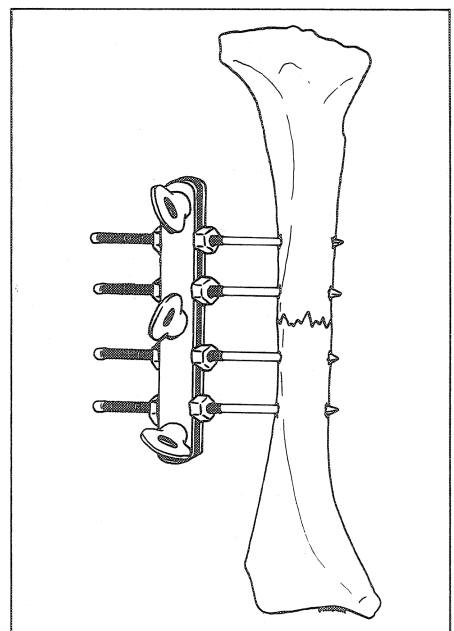


Figure 3. Lambotte's external fixator (1902).

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Dr. Stader's success encouraged surgeons to apply his system to treat human long bone fractures.^{39,51,52}

In Europe, many surgeons expanded Lambotte's original concept of external skeletal fixation. In 1938, Raoul Hoffman²⁵ devised an external fixator that in-

corporated a universal ball joint pin holder that gripped a connecting rod. The universal joint permitted fracture alignment in three planes with the fixator assembled, similar to Stader's. Additionally, Hoffman substituted a sliding compression-distraction bar for a rigid bar which connected to the pin clamps. He could achieve interfragmentary compression or limb length restoration (Figure 7).

Toward the end of World War II, military surgeons documented significant complications using external skeletal fixation.⁵¹ The surgeon general commanded military surgeons to stop using external skeletal fixation. This directive retarded the development of external skeletal fixation in the United States.

Following the war, the Committee on Fracture and Trauma Surgery of the American Academy of Orthopaedic Surgeons investigated the use of external skeletal fixation.²⁷ The committee noted many advantages, namely immediate stable fixation, mobilization of joints above and below the level of fracture, and reduced hospitalization.

However, the committee noted several major disadvantages namely pin tract infection, ring sequestra, osteomyelitis, delayed union, and non-union. Many orthopaedic surgeons responded to a questionnaire sent

should receive training by an orthopaedist who had performed at least two hundred applications of external skeletal fixation. Otherwise, they advised surgeons without the necessary experience not to use the technique.

Between 1950 and 1970, American orthopaedists generally did not favor mechanical skeletal fixation to treat difficult fractures. However, they did employ pins-in-plaster for special problems such as displaced comminuted Colles fractures and displaced fractures of the tibia and fibula.

In Europe, unlike America, surgeons continued to improve external skeletal fixation techniques after World War II. Charnley^{11,12} introduced compression arthrodesis using a simple clamp that applied compression across cut cancellous surfaces of a joint (Figure 8). During the 1960's, Jacques Vidal and Jose Adrey⁵⁶ recognized the need for rigid fixation to treat septic non-union of long bones. To obtain rigid stabilization, they modified the original Hoffman frame. Supported by data generated by biomechanical testing,¹ they showed that a quadrilateral design provided the optimum amount of rigidity (Figure 9).

In Russia, Ilisarox developed external fixators that employed rings that were connected to bone by trans-

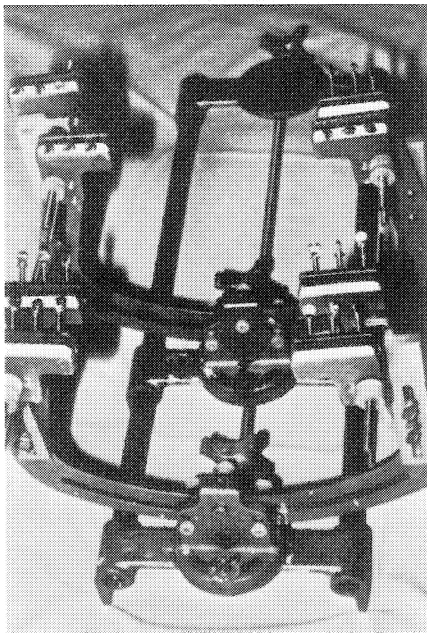


Figure 4. Roger Anderson's reduction apparatus.

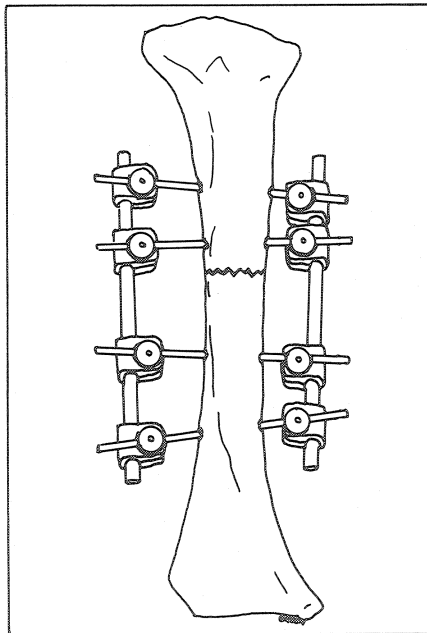


Figure 5. Roger Anderson's fixator frame.

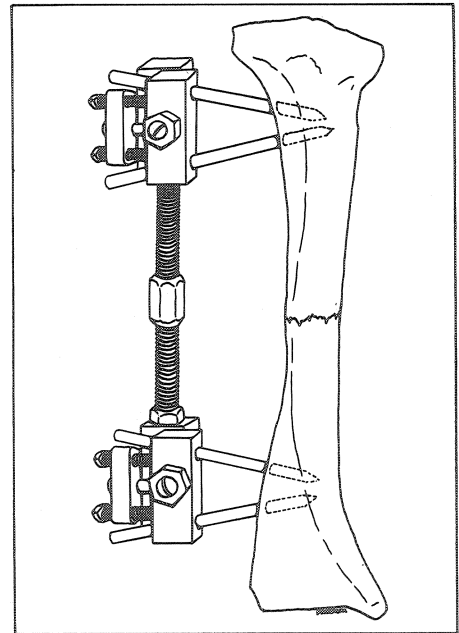


Figure 6. Stader's fixator.

by the committee reporting that they lacked experience using external skeletal fixation. This inexperience created great difficulty in obtaining and maintaining adequate reductions. Therefore, the committee recommended that a surgeon, prior to using the technique,

fixation wires²⁶ (Figure 10). Kronner,³⁷ an American orthopaedic surgeon modified the Russian design by using plaster components and transfixing pins instead of wires (Figure 11). Fischer²¹ has recently built a titanium half-ring frame. Its design allows for simpler multi-

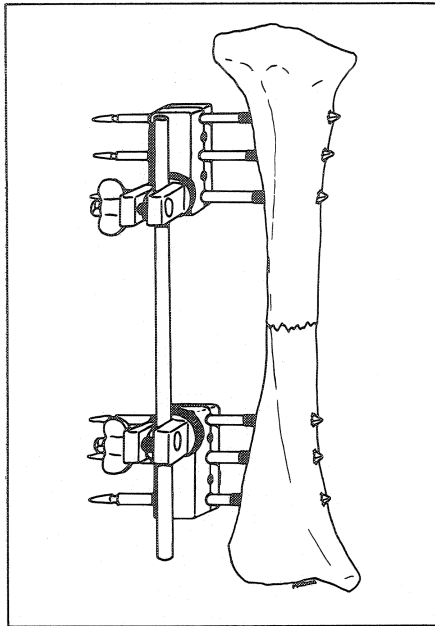


Figure 7. Hoffman's fixator.

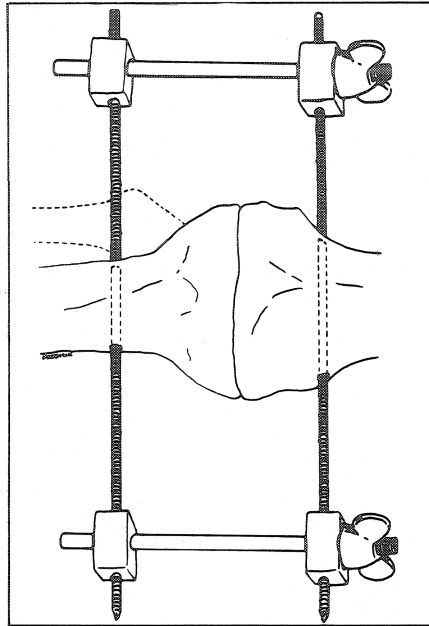


Figure 8. Charnley's compression clamp.

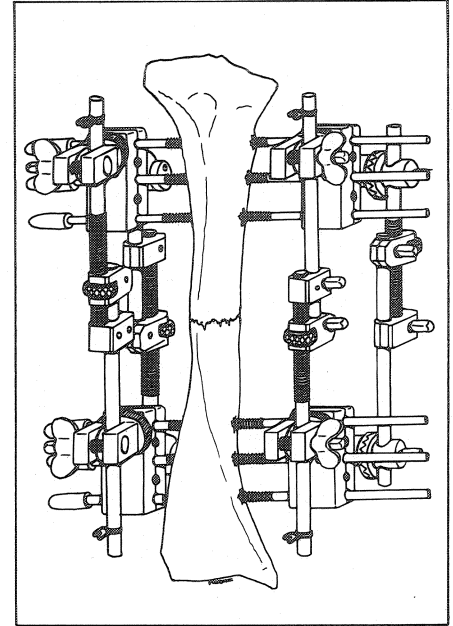


Figure 9. Vida-Adrey quadrilateral modification of Hoffman's frame.

planar fracture adjustment than the Vidal-Adrey frame. Also, the half-ring configuration permits multiplanar insertion of half-pins that provides adequate stability while minimizing complications of transfixing pins (Figure 12).

Since the development of external skeletal fixation, a variety of applications have become possible. Chao and co-workers at the Mayo Clinic devised a terminology based on frame configuration.²³ The configuration terminology follows (Figure 13).

Unilateral: The unilateral frame employs one bar or rod connecting two or more pin clamps attached to half-pins. This category includes the Hoffman and Wagner apparatus (Figures 7,14).

Bilateral: A bilateral frame uses bars on both sides of a limb connected to pin clamps attached to through-in through transfixing pins. The Roger Anderson and ASIF tubular fixator exemplifies this type (Figures 5,15).

Quadrilateral: A quadrilateral frame employs four bars within the system, two on each side of the limb. The Vidal-Adrey and Four-Bar Kronner serve as examples for this group (Figures 9,16).

Biplanar: A biplanar frame uses pins placed in two or more planes for added stability. The ASIF tubular is often used in this configuration.

Ring: This type utilize complete circular rings or hoops attached to bone by transfixing pins. The hoop

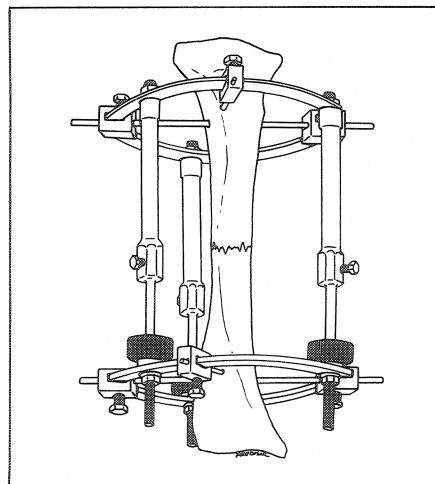


Figure 10. Ilisarov ring fixator.

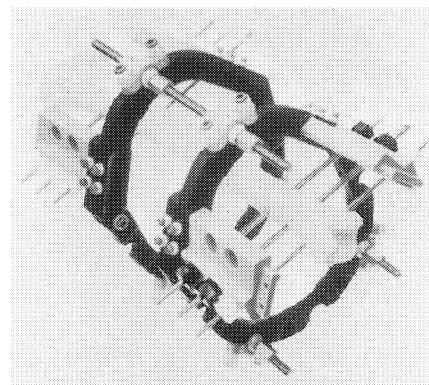


Figure 11. Kronner ring fixator.

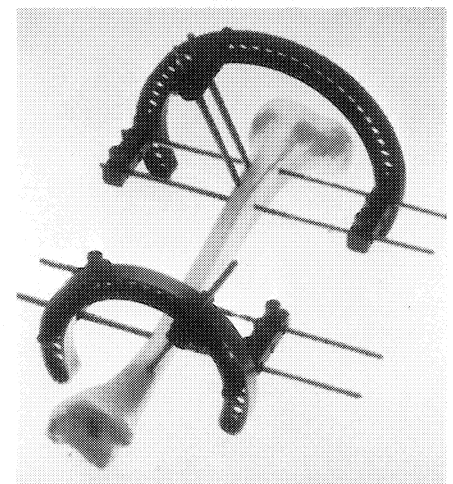


Figure 12. Fischer half-ring fixator.

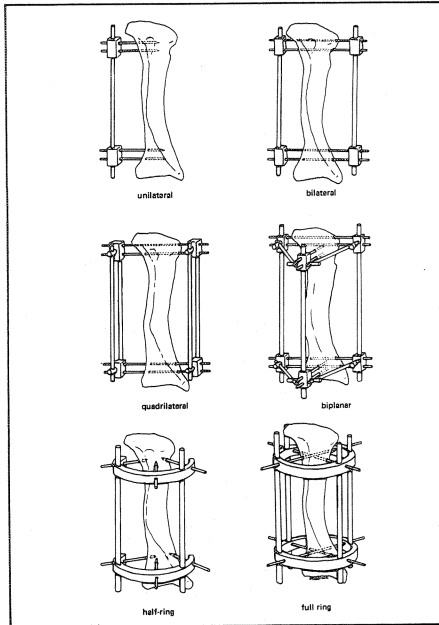


Figure 13. External fixation frame configuration.

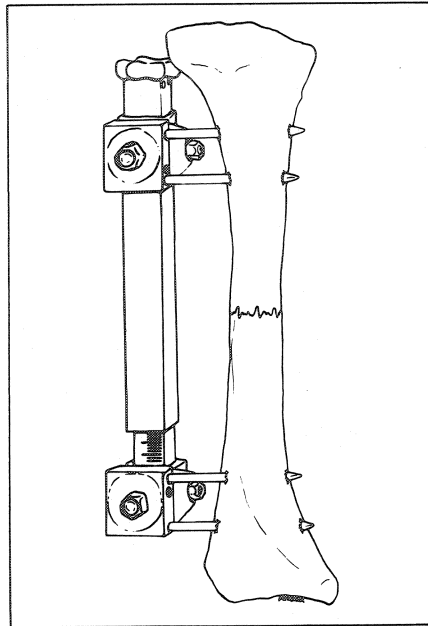


Figure 14. Wagner apparatus.

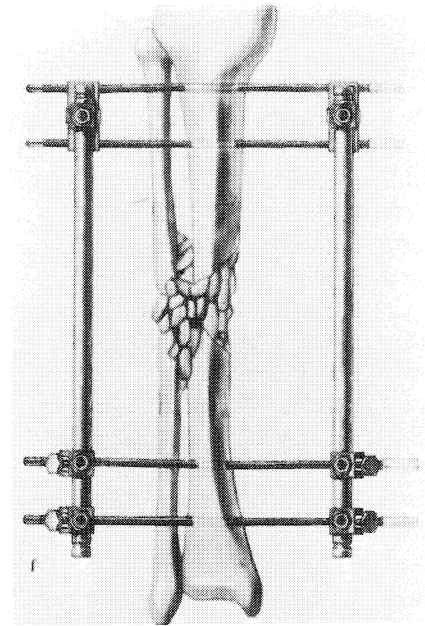


Figure 15. ASIF fixator.

surrounds the leg transverse to its long axis. This provides numerous possible pin insertion sites. Also, many connecting rods can be applied. Because of this variability in pin insertion and rod construction, a surgeon can construct extremely rigid frames. The Kronner ring typifies this group (Figure 11).

Half-ring: This type also encircles the leg transverse to its long axis. It employs transfixing pins and half-pins, alone or in combination. The fracture pattern and associated soft tissue injury determines the geometric placement of pin groups and the number and type of pin within a group. The Ace-Fischer Fixator

and Howmedica Antero-medial Fixator exemplify this type (Figure 12).

In addition to fixation frames constructed by skeletal pins to a mechanical exoskeleton, systems can employ skeletal pins incorporated into a material that solidifies. Pins-in-plaster,² pins-in methacrylate and the Murray epoxy filled tube fixator comprise this category (Figures 17,18). These systems allow variable geometric placement of pins but are not adjustable, a serious limitation.

Many authors have documented the success of treating serious open fractures of the tibia by external

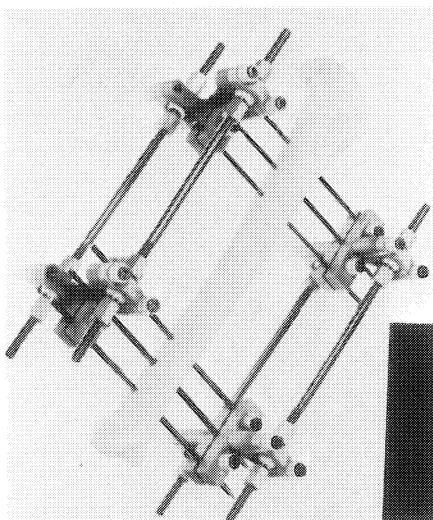


Figure 16. Kronner four bar fixator.

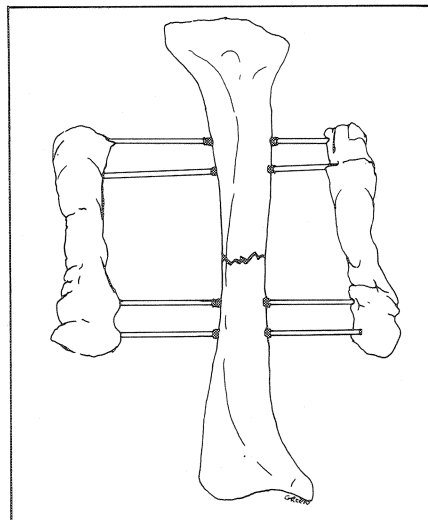


Figure 17. Methyl methacrylate external pin fixator.

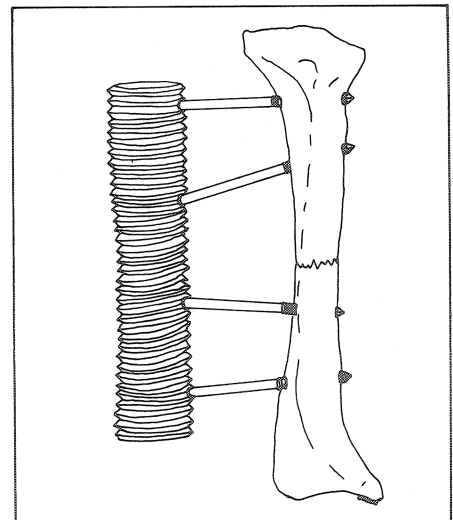


Figure 18. Murray epoxy-filled tube fixator.

skeletal fixation. Pin tract drainage, osteomyelitis, damage to neurovascular structures and muscle compartments by transfixing pins, delayed union, and non-union are complications. Authors report pinhole sepsis as the most frequently encountered complication. It is difficult to establish the exact incidence of pin tract infection. Reluctance of physicians and the lack of uniform criteria to diagnose infections can explain the variance.

Certainly, the longer percutaneously applied pins remain in place, the higher the risk of infection.⁶ Typical early reports showed 50%⁴¹ and 36%⁵⁴ incidence of pin tract drainage. Also, these authors reported 15% and 22.5% incidence of pin tract osteomyelitis using the Roger Anderson and Stader systems. Scattered optimistic reports of low incidences of drainage (less than 5%) which ceased after removal of the offending pin, have appeared over the years.^{4,46,58} However, despite recent advances when using external skeletal fixation, a surgeon should expect at least a 10% pin tract infection rate of all pins used.¹⁷ Pin tract infection rates of 50% and 80% may be more realistic.^{22,35}

Stuart Green²³ has established criteria which he uses to define "minor" and "major" pin tract infections. He formulated these criteria while treating difficult infections of bone and joints by external skeletal fixation. He noted 100% minor infections which he defined as: "a benign drainage that ceased upon removal of the infected pin."

He identified a rate of 30% major infections which he defined as infections requiring hospital admission to control sepsis, or those infections necessitating removal of one or more pins or the entire frame. Recent studies have not clearly stated the incidence of chronic osteomyelitis of pin hold despite removal of an infected pin and appropriate treatment. It is presumably exceedingly rare (less than 1%).⁷

Regardless of the exact incidence of infection, abscess formation surrounding the pin, necrotic skin, muscle, and bone in the pin tract, and excessive motion lead to infection. Green details the exact pathologic process of each of the above factors. To minimize pin tract infection following application of an external fixation frame, a surgeon should perform the following procedure:

1. Apply fixators under sterile conditions in the operating room.
2. Reduce the fracture prior to pin insertion. This eliminates tension created on the concave side.
3. Make generous skin incisions at least 1 cm. long preferably transverse to the long axis of the tibial shaft.
4. Use a drill guide to ensure parallel placement of

pins which will reduce the chance of pressure necrosis of bone.

5. Use a drill sleeve to avoid twisting soft tissue.
6. Pre-drill the pin hole using a low speed drill to avoid thermal necrosis of bone.
7. Place pin in the posterior $\frac{2}{3}$ of the shaft of the tibia.
8. Avoid placing the pin through the anterior cortex.
9. Do not displace entire muscle compartments while searching for the underlying bone with a transfixing pin.
10. Transfix muscle without displacing it to minimize pressure necrosis of muscle and overlying fat.
11. Apply compression to a fracture until "finger tight." Excessive pressure from overzealous compression, especially with non-parallel pins, creates bone necrosis.

Failure to obtain union of a tibial fracture while using external skeletal fixation has been difficult to evaluate. No controlled prospective study exists comparing union rates of tibia fractures treated by external fixation with other methods. Using historical controls as a standard may not provide a fair comparison. Certainly, a surgeon cannot expect the uniformly excellent union rates achieved by Dehne¹⁴ and Sarmiento⁵² when treating an open comminuted tibia fracture with external skeletal fixation.

Less successful rates of union may be more realistic. Rosenthal⁵¹ reported 10 non-union out of 60 open fractures treated by closed reduction and early ambulation. He notes large areas of skin avulsion and fractured fibulae in the ununited tibia fractures.

Chapman and Mahoney¹⁰ surveyed the results of internal fixation of fresh open fractures. They noted an overall non-union rate of 11.3% reported in the English literature since 1945. This compares to the average non-union rate of 11% using external fixation to treat fresh open tibia fractures.^{4,6,13} The external fixator generally was removed when soft tissue healing was complete.

Early cancellous bone grafting of fresh fractures with segmental bone loss or large cortical defects may provide uniformly successful union rates.^{16,22,48}

Many orthopaedists have reported success treating open tibia fractures with external fixation which seem to correlate well with the success rates reported using closed casting methods and internal fixation.^{6,8,13,17,20,34,36,39,40,45,47}

Large series of external fixation applications report a total lack of significant neurovascular injuries.

However, scattered reports of such injuries have been documented.

Dwyer¹⁵ noted during the development of a ring device that transfixing pins tend to push vessels aside thereby making it impossible to penetrate a major vessel. However, as a pin pushes a vessel aside without transecting it, the vessel rubs against the pin. The pin will erode the vessel by irritation causing arterial bleeding to occur through the pin hole. False aneurysms or arterio-venous fistulas have also developed in tibial fractures treated by external fixation.²³

Raimbeau⁵⁰ recognized the susceptibility of the anterior tibial artery to damage by transfixing pins at the junction of the middle three-fourth and distal one-fourth of the tibia. Using cadavers and arteriography, he identified this susceptible location where the anterior tibial artery crosses the lateral surface of the tibia.

Raimbeau⁵⁰ also noted anterior compartment syndromes developing in three patients following insertion of transfixing pins. Experimentally he measured pressure in the anterior compartment of the leg following the insertion of transfixing pins. There was a slight increase in pressure following the insertion of a single pin. After two pins were inserted pressures doubled. Finally, when the third pin was inserted an additional slight increase in pressure was recorded.

Similarly, sparse reports have documented nerve injuries by the use of transfixing pins. Olerud⁴⁸ noted transient loss of sensation on the dorsum of the foot in a "few cases." Naden⁴⁷ also reported transient lesions of the peroneal nerve. Only two cases of peroneal nerve palsy have occurred in the Mayo Clinic experience.⁷

In addition to penetrating injuries to nerve and artery, transfixing muscle and tendon should be avoided. The pins can seriously restrict joint mobility by impaling muscle and tendons.²³ To some extent this is unavoidable. Generally, the tendons can be pushed aside by the pin as it is inserted. However, Krempen described transfixing the Extensor Hallucis Longus.³⁶ Green noted serious limitation of dorsiflexion of the ankle after pin insertion. A surgeon can minimize this effect by dorsiflexing the foot prior to pin insertion. Impalement of muscle tendon and nerves can be avoided by insertion of pins into the medial subcutaneous border of the tibia. However, the commonly employed fixation frames applied with only half-pins through the medial subcutaneous border of the tibia have not been able to provide adequate stability, especially for comminuted fractures.⁹ Development of external fixation systems that provide adequate stability utilizing only half-pins may provide a solution to damage to muscle, tendon and neurovascular structures.

Few comprehensive biomechanical studies examining various external fixation systems have appeared.^{5,9,18,19,29,30,31,32,33,42,43} Most involve one system, the Hoffman and Hoffman-Vidal frame. Their efforts have focused on the relationship of the configuration to overall stability and to forces in the bone, the pins and the frame. Detailed knowledge regarding the application have noted the limitation of this device.

Chao and co-workers⁹ have been foremost in the examination of external fixation frames. They obtained quantitative measurements of the basic mechanical features of the Hoffman-Vidal frame. Their method employed simulated cadaver tibias which have similar properties to bone in bending and axial loading but which are highly variable in torsion. Using a large variety of applications of tibial frames, Chao examined the importance of different variables by generating force displacement curves under controlled loading in compression, distraction, bending and torsion.

His observations were:

Effect of pin number

Both lateral bending and torsional stiffness were significantly increased by using more pins but AP bending was unchanged. The amount of stiffness increase was found to be insignificant when the pin number was increased beyond eight. Stiffness was increased by reducing pin-group separation and length.

Effect of Pin Diameter

The use of a Rush Rod (6.35 mm.) or a Schanz pin (6 mm.) improves the stiffness of the Hoffman-Vidal frame by a factor of five since the stiffness of the pin is a function of the fourth power of the diameter.

These findings were supported by Evans and Egkher.^{18,19} Evans showed that bone stress in both shear and compression could be kept below the fatigue stress for bone if 6 mm. pins were used. Egkher recommended a Steinman pin with a diameter of 5 mm. and a short pin length to keep deflection low.

Effect of Pin Separation

Changing the pin group separation in the full Hoffman-Vidal frame did affect the stiffness but not significantly in torsion. There was no increase if the distance was greater than ten centimeters.

Effect of Connecting Rods

The number of connecting rods positively affected the stability of external fixation. When two connecting rods were used, application of rods opposite to each other were 1.7 times as stiff as two rods applied on the same side, essentially a half-pin configuration. The weakest configuration was one connecting rod.

Effect of Unilateral vs. Bilateral Fixation

Full frame and half-frame Hoffman fixation configurations have been compared under identical conditions (i.e. number and spacing of pins). The largest loss using the half-frame is axial and AP bending stiffness. In addition the half-frames lose 50% of strength in lateral bend and torsion.

However, Evans¹⁹ and Behrens⁵ have shown that unilateral fixation can have much higher axial and AP stiffness if attention is paid to the details of direction of application.

Comparison of External Fixation Stiffness

McCoy⁴⁵ et al, at the Mayo Clinic, using the same method of testing as Chao, performed the most comprehensive comparison of different designs. McCoy noted that stiffness is affected more by changing the position, material, or geometry of the pins rather than the frame. Without exception bending in the AP plane is consistently the least stiff direction.

Johnston, Fischer, and Jones²⁸ demonstrated by both clinical studies and biomechanical testing that placement of half-pins in multiple planes significantly increases fracture stability in all planes to prevent loss of reduction. Blunt tipped, predrilled half-pins minimized the pin complications of muscle penetration, drainage, and possible neurovascular damage.

To date biomechanical studies have been able to determine the optimum pin size, number, grouping, separation between groups and overall weakness of currently available external fixation systems, most notably AP bending. Few comparison tests have been made with newer designs that allow multiplanar placement of half-pins with a ring or hoop exoskeleton that would allow increased fracture stability over previously constructed half-pin frames. Using half-pins only would minimize the complication of transfixing the compartments of the lower leg.

†Figures 1, 2, 3, 5, 6, 7, 8, 9, 10, 13, 14, 17, and 18 have been reprinted from S.A. Green, *Complications of External Fixation*, 1981. Courtesy of Charles C. Thomas, Publisher, Springfield, Illinois.

Bibliography

¹Adrey, J.: Le Fixateur externe d'Hoffman couple 'en cadre. Etude Biomecanique dans les Fractures de Jambe. Paris Gead, 1970.

²Anderson, L. and Hutchins, W.: Fractures of the tibia and fibula treated with casts and transfixing pins. *South. Med. J.*, 59:1026, 1966.

³Anderson, R.: An automatic method of treatment for fracture of the tibia and the fibula. *Surg. Gyn. Obs.*, 58:639, 1934.

⁴Anderson, R.: An ambulatory method of treating fractures of the shaft of the femur. *Surg. Gyn. Obs.*, 62:865, 1936.

⁵Behrens, F., Johnson, W., and Koch, T.: Bending stiffness of unilateral and bilateral external fixator frames. *Trans. Ort. Res. Soc.*, 7:184, 1982.

⁶Burny, F.: Elastic external fixation of tibial fractures study of 1421 cases. In Brooker, A.F., Jr., and Edwards, C.C. (Eds.): *External Fixation, The Current State of the Art*. Baltimore, Williams and Wilkins, 1979.

⁷Cabanela, M.: Complications of external fixation. In Johnston, R. (Ed.): *Advances In External Fixation*. Miami Symposia Specialists, 1980.

⁸Cabanela, M. and Cooney, W.: External fixation of open tibial fractures. In *Advances In External Fixation*. Johnston, R. (Ed.): Miami Symposia Specialists, 1980.

⁹Chao, E., Briggs, B., and McCoy, M.: Theoretical and experimental analysis of Hoffman-Vidal external fixation systems. In Brooker, A. and Edwards, C. (Eds.): *External Fixation, The Current State of the Art*. Baltimore, Williams and Wilkins, 1979.

¹⁰Chapman, M. and Mahoney, M.: The role of early internal fixation in the management of open fractures. *CORR*, 138, 120, 1979.

¹¹Charnley, J.: Positive pressure in arthrodesis of the knee joint. *J. Bone and Joint Surg.*, 30B, 478, 1948.

¹²Charnley, J.: Compression arthrodesis of the ankle and shoulder. *J. Bone and Joint Surg.*, 33B, 180, 1951.

¹³Cotton, R.: A Clinical Study of Tibial Fractures Using Hoffman External Fixation, *The State of the Art*. Baltimore, Williams and Wilkins, 1979.

¹⁴Dehne, E. et al.: Nonoperative treatment of the fractured tibia and immediate weight bearing. *J. Trauma*, 1:514, 1961.

¹⁵Dwyer, N.: Preliminary report upon a new fixation device for fractures of long bones. *Injury*, 5:141, 1973.

¹⁶Edwards, C.: Management of polytrauma patient in a major U.S. center. In Brooker, A., Jr., and Edwards, C.,

(Eds.), *External Fixation, The Current State of the Art*. Baltimore, Williams and Wilkins.

¹⁷Edwards, C., Jaworski, M., Solana, Jr., and Aronson, B.: Management of compound tibia fractures in the multiple injured patient using external fixation. *Am. Surg.*, 45:190, 1979.

¹⁸Egkher, E., Martinek, H., and Wilke, B.: How to increase stability of external fixation units. Mechanical tests and theoretical studies. *Arch. Orthop. Traumat. Surg.*, 96:35-43, 1980.

¹⁹Evans, M., Kenwright, J., and Tanner, K.: Analysis of single-sided external fracture fixation. *Engin. Med.*, 8:133-137, 1979.

²⁰Fellander, M.: Treatment of fractures and pseudoarthrosis of the long bones by Hoffman's transfixation method (osteotaxis). *Acta Orthop. Scand.*, 33:132-150, 1963.

²¹Fischer, D.: ACE-Fischer external fixator. ACE Orthopaedics, 1980.

²²Fleming, L., and Velazco, A.: Open fractures of the tibia treated with the Hoffman external fixator. Presented at the 49th annual meeting, American Academy of Orthopaedic Surgeons, New Orleans, Louisiana, 1982.

²³Green, S.: Impaired joint mobility. In *Complication of External Skeletal Fixation*, Springfield. Charles C. Thomas, 1981.

²⁴Green, S.: In *Complications of External Skeletal Fixation*. Springfield, Charles C. Thomas, 1981.

²⁵Hoffman, R.: Rotules a' os pour la reduction dirigée non sanglante, de fractures (osteotaxis), *Helv. Med. Acta*, 844, 1938.

²⁶Ilisarov, L.: Results of clinical tests and experience obtained from the clinical use of the set of Ilisarov compression-distraction apparatus. *Med. Export.*, Moscow, 1976.

²⁷Johnson, H., and Stovall, S.: External fixation of fractures. *J. Bone and Joint Surg.*, 32A:466, 1950.

²⁸Johnston, R., Fischer, D., and Jones, W.: Technical considerations in the use of external fixation devices. Presented at the 49th Annual Meeting American

Academy of Orthopaedic Surgeons, New Orleans, Louisiana, January, 1982.

²⁹Jorgenson, T.: Measurements of stability of tibial fractures—a mechanical method. *Acta. Orth. Scand. (Suppl)*, 135, 1970.

³⁰Jorgensen, T.: Measurements of stability of crural fractures treated with Hoffman osteotaxis. Method and measurements of deflection on autopsy Crura. *Acta Orthop. Scand.*, 43:188-206, 1972.

³¹Jorgensen, T.: Measurements of stability of crural fractures. *Acta Orthop., Scand.*, 43:207-218, 1972.

³²Jorgensen, T.: Measurements of stability of crural fractures treated with Hoffman osteotaxis 3. The uncomplicated, terminal phase of healing. *Acta Orthop. Scand.*, 43:264-279, 1972.

³³Jorgensen, T.: Measurements of stability of curural fractures treated with Hoffman osteotaxis 4. The complicated, terminal phase of healing. *Acta Orthop. Scand.*, 43:280-291, 1972.

³⁴Karlstrom, G. and Olerud, S.: Percutaneous pin fixation of open tibial fractures. Double-frame anchorage using the Vidal-Adrey method. *J. Bone and Joint Surg.*, 57A:915, 1975.

³⁵Kimmel, R. and Neidre, A.: The use of Hoffman external fixation in fractures of the tibial diaphysis. Presented at the 48th Annual Meeting, American Academy of Orthopaedic Surgeons, Las Vegas, Nevada, 1981.

³⁶Krempein, J., Silver, R., and Sotelo, A.: The use of the Vidal-Adrey external fixation system part 1: The treatment of open fractures. *Clin. Orthop.*, 140:111-121, May, 1979.

³⁷Kronner, R.: The Kronner device. Memphis, Richards Co., 1978.

³⁸Lambotte, A.: *L'intervention operatoire dans les fractures*. Brussels, Lamertin, 1907.

³⁹Lawyer, R.: Treatment of complex tibial fractures. In Brooker, A., Jr., and Edwards, C., (Eds.): *External Fixation, The Current State of the Art*. Baltimore, Williams and Wilkins, 1979.

⁴⁰Lawyer, R. and Lubbers, L.: Use of the Hoffman ap-

paratus in the treatment of unstable tibial fractures. *J. Bone and Joint Surg.*, 62A:1264-1273, December, 1980.

⁴¹Lewis, K., Breidenbach, L., and Stader, O.: The Stader reduction splint for treating fractures of the shafts of the long bones. *Ann. Surg.*, 116:623, 1942.

⁴²Lindhahl, O.: Rigidity of immobilization of transverse fractures. *Acta Orthop. Scand.*, 32:237-246, 1962.

⁴³Lindhahl, O.: Rigidity of immobilization of oblique fractures. *Acta Orthop. Scand.*, 35:39-50, 1964.

⁴⁴Malgaigne, J.: *Treatise on fractures*. Philadelphia, Lippincott, 1859.

⁴⁵McCoy et al.: *External fixators: Biomechanical and clinical analysis of the Hoffman, Roger Anderson, Kronner and Volkox-Oganesian fixators*. Scientific Exhibit, American Academy of Orthopaedic Surgeons, San Francisco, February, 1979.

⁴⁶Naden, J.R.: External skeletal fixation in the treatment of fractures of the tibia. *J. Bone and Joint Surg.*, 31A:586, 1949.

⁴⁷Naden, J.: External skeletal fixation in the treatment of fractures of the tibia. *J. Bone and Joint Surg.*, 46B:373, 1964.

⁴⁸Olerud, S.: Treatment of fractures by the Vidal-Adrey method. *Acta Orthop. Scand.*, 44:516, 1973.

⁴⁹Parkhill, C.: A new apparatus for the fixation of bones

after resection and in fractures with a tendency to displacement. *Trans. Am. Surg. Assoc.*, 15:251, 1897.

⁵⁰Raimbeau, G., Chevalier, J., and Raguin, J.: Les risques vasculaires du fixateur en cadre a la jamb. *Rev. Chir. Orthop., Supp.* 11, 65:77, 1979.

⁵¹Rosenthal, R., MacPhail, Jr., and Ortig, J.: Non-union in open tibial fractures. Analysis of reasons for failure of treatment. *J. Bone and Joint Surg.*, 59A:244, 1977.

⁵²Sarmiento, A.: A functional below knee cast for tibia fractures. *J. Bone and Joint Surg.*, 49A:855, 1967.

⁵³Shaar, C., Kreuz, F., and Jones, D.: End results of treatment of fresh fractures by the use of the Stader apparatus. *J. Bone and Joint Surg.*, 26A:471, 1944.

⁵⁴Siris, I.: External Pin Fixation of Fractures. An analysis of eighty cases. *Ann. Surg.*, 120:911, 1944.

⁵⁵Stader, O.: A preliminary announcement of a new method of treating fractures. *North Am. Vet.*, 18:37, 1937.

⁵⁶Vidal, J. and Adrey, J.: *Hoffman external anchorage*. Paris, GEAD, 1971.

⁵⁷Vidal J. and Marchand, L.: Les fractures al l'extremite inferieure du femur. *Trartement et resultats*. *Rev. Chic. Orthop.* 52:533-550, 1966.

⁵⁸Wagner, H.: Surgical lengthening or shortening of the femur. In Gschwend, N. (Ed.): *Progress in Orthopaedic Surgery*. New York, Springer-Verlag, 1977.

AINHUM: SPONTANEOUS DACTYLOLYSIS

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Ainhum, a disease primarily affecting blacks, consists of a constricting ring of fibrous tissue at the digitoplan-tar fold of the fifth toe which causes eventual strangulation and autoamputation.

This case report delineates the diagnostic features, possible etiologies, and treatment.

Case

A sixty-three year old black man complained of painful swelling of the right fifth toe. There was no history of trauma, local infection, diabetes, peripheral vascular disease or venereal disease. The patient noted narrowing of the base of the toe for at least six months before the pain started.

On physical examination, the right fifth toe appeared constricted at its base by a narrow fibrous band continuous over the dorsal, medial, and lateral surfaces. The toe was slightly enlarged and more pigmented (Figure 1). Sensation to pinprick was present.



Figure 1A, B. Demonstrates a fibrotic band encircling the base of the fifth toe.

Radiographs revealed marked narrowing of the distal end of the proximal phalanx (Figure 2).

The diagnosis of ainhum was made. At the patient's request, the toe was amputated through the metatarsophalangeal joint. Healing was uneventful.

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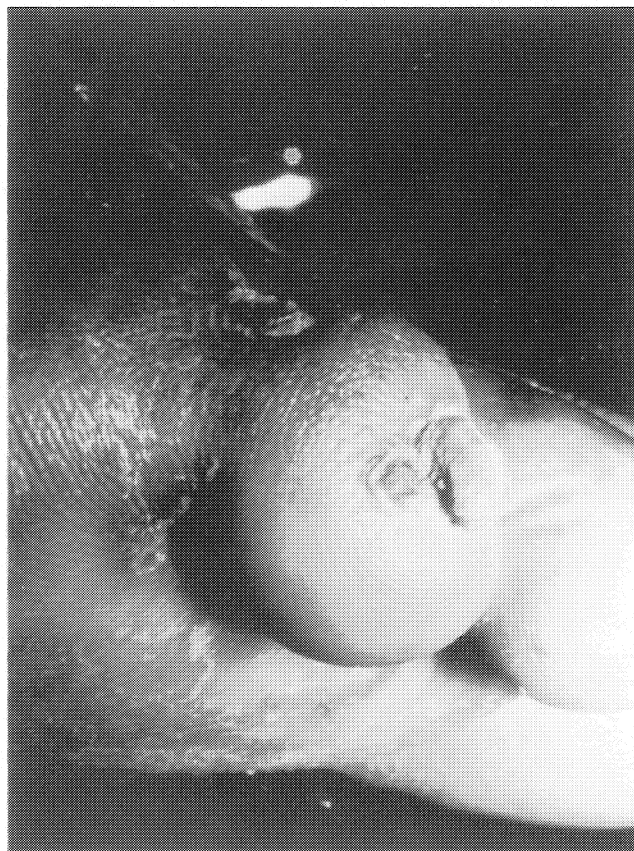


Figure 1B.

Historical Perspective

The first adequate description of the disease process and the term ainhum are credited to da Silva Lima in 1867, though the condition may have been described as early as 1821.^{1,6}

Clinical—Pathology

Ainhum occurs in both men and women, usually in the middle of the fourth decade. Cole demonstrated an age range from 7 to 75 years.¹ Frequently it is bilateral but not symmetrical in advancement. The narrow constricting band begins medially and extends dorsally and laterally, slowly autoamputating the fifth toe. The condition usually produces no symptoms, though advanced cases may be annoying enough to cause patients to request amputation.⁴



Figure 2. Demonstrates bony resorption at the proximal interphalangeal joint level.

Radiologically, the middle and distal portion of the proximal phalanx become progressively narrowed until transected.

Theories proposed to explain ainhum have included leprosy,⁶ syphilis,⁶ chronic epidermatophytosis,² fibrotic constriction from repeated injury,⁶ and foreign body reaction.³ These theories have generally been discarded.

Histologic studies have failed to demonstrate fungi, bacteria, viruses or foreign bodies. Studies by Kean and Tucker⁵ and Cole¹ demonstrated chronic inflammation deep to hyperkeratotic epithelium, with normal vessels and nerves, and sterile absorption of bone.

Treatment

Treatment may be expectant or operative. Ainhum will spontaneously autoamputate a toe in two to five years. Excision of the fibrous groove and z-plasty relieves pain and halts advancement of the disease for up to 18 months,¹ though amputation of the digit is the generally accepted treatment.

¹Cole, G.J.: Ainhum. An account of fifty-four patients with special reference to etiology and treatment. *J. Bone and Joint Surg.*, 47B:43-51, 1965.

²Davies, J.H.P and Hewer, T.F.: Ainhum: report of case in England with histological study. *Tr. Roy. Soc. Trop. Med. & Hyg.*, 35:125-128, 1941.

³Eyels, C.H.: Histology of ainhum. *Lancet*, 2:576-578, 1926.

⁴Brahms, M.A.: In *Disorders of the Foot* (Jahss, M.H. ed.). W. B. Saunders Co., Phila., 1982, 656-658.

⁵Kean, B.H. and Tucker, H.A.: Etiologic concepts and pathologic aspects of ainhum. *Archives of Pathol.*, 41:639, 1946.

⁶Tye, M.: Ainhum. *N. Eng. J. Med.*, 234:152, 1946.

⁷Pacha, Z., Cited by Butler, H.W.: Ainhum (dactylolysis spontaneous). *M. Clin. N. Amer.*, 9:1181-1185, 1926.

PEDAL EDEMA IN THE NEWBORN: A Case Report of Turner's Syndrome (XO) and Literature Review

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Introduction

In the newborn nursery, the orthopaedist sometimes examines babies with abnormalities of the feet. Congenital lymphedema of the extremities, especially the feet, may indicate the diagnosis of Turner's Syndrome.

Case Report

A term, newborn, black female weighing 2,610 grams and measuring 46 cm from crown to heel, was noted to have abnormal physical findings including coarctation of the aorta, fine facial features (Figure 1) with ptosis of the left eyelid, and pitting edema involving only the dor-



Figure 1. A small infant with fine facial features and ptosis of the left eyelid.

sum of both feet (Figure 2). There were no other gross external somatic defects. The clinical diagnosis of Turner's (XO) Syndrome was suggested by the attending orthopaedist, and chromosome smears confirmed the diagnosis. As other clinical studies were progressing, she died suddenly on the eighth day after birth.

Discussion

Turner's syndrome, a rare disorder, involves 0.01% to 0.04% of live births.^{8,13} Turner reported¹² seven teen-



Figure 2. Pedal edema, primarily of the dorsum of the foot; examination for other stigmata of Turner's syndrome is needed.

aged female patients with common features of sexual infantilism, webbing of the skin of the neck, cubitus valgus, short stature and primary amenorrhea. Subsequent studies of other patients with this clinical appearance^{3,4,7,13} revealed "streak gonads." These rudimentary ovaries, present in the broad ligament, rarely function as endocrine organs. Gonadal dysgenesis, a term broader in context, denotes conditions with streak gonads not mutually exclusive of those patients with Turner's syndrome.^{4,6,9,11}

Turner's syndrome is of genetic origin and not a defect of the pituitary gland as Turner originally thought. Deprivation of genetic material, specifically loss of either the X or Y sex chromosome, produces a 45-XO aneuploidy instead of the usual 46-XX euploidy. Although chromosomal defects involving the sex chromosomes do not have the global effects often encountered in autosomal defects, the patterns lead to a rather easy diagnosis from birth through adulthood.

The prenatal diagnosis of Turner's syndrome has been reported.⁸ The disorder is generally not related to maternal age or inheritance patterns. The phenotype may not be classic because there is variable penetrance of the various anomalies. Many of the signs, although subtle, taken together allow the neonatal diagnosis to be made. Further tests, (karyotyping, buccal smears and serum gonadotropins) help confirm the diagnosis.⁹

Infants with Turner's syndrome are phenotypic females due to loss of the powerful male determinants of the Y chromosomes, leaving the remaining female X

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chromosome unopposed.¹³ Although these patients are small for gestational age, with 50% having lengths below the third percentile, the hallmark of short stature becomes apparent with the lack of the growth spurt at puberty.^{1,5,7} Other abnormal clinical signs, none of which are pathognomonic for Turner's syndrome, may appear in any pattern, and include abnormal facies with epicanthal folds, ptosis of the eyelids, prominent ears, small mandible, low posterior hairline, shield chest, laterally displaced nipples and webbing of the posterior portion of the neck.^{2,3,4,6,10,13}

The serious anomalies, which often lead to an early diagnosis, involve the cardiovascular and urological systems. These include: coarctation of the aorta, septal defects, dextrocardia,^{4,7,10,13} horseshoe kidney, unilateral renal agenesis and duplication of the renal pelvis.^{7,10,13}

Neoplastic transformation within the gonadal streak may be heralded by calcification within the broad ligament as seen on roentgenograms of the pelvis. The possibility of tumor, usually a gonadoblastoma,⁹ demands routine periodic examinations. Proper gynecologic care is also needed to help the patient through the various aspects of gonadal failure.

Congenital lymphedema of the extremities, as seen in Figure 2, is reported in about 30% of babies with Turner's syndrome.^{4,5,13} Typically, subcutaneous fluid collects on the dorsum of the feet and hands.^{9,10,13} The etiology, although it remains unknown, has been ascribed to incomplete resorption of uterine cystic hygroma prior to birth.^{9,10,11,13} Resorption of fluid in the subcutaneous tissues of the neck leaves the classic pterygium colli (wing-like neck).^{9,11} Histologic study of lymphatic systems of aborted fetuses with 45 XO karyotypes revealed a generalized hypoplasia. Vessel walls were thin and there were few or no valves. Fetuses examined by van der Putte showed generalized lymphedema.⁵

The peripheral lymphedema seen in neonates with Turner's syndrome usually resolves within a year with or without treatment.^{4,5,7} Treatment, when undertaken, has consisted of such regimens as elevation of the extremities and use of a mild diuretic.^{5,8} Residual lymphedema of the dorsum of the fingers may persist, along with swelling of the lower extremities, into adulthood.^{4,7,11}

Summary

Although the orthopaedist's role in the management of Turner's syndrome may be small, he or she may well be the one to make an early diagnosis by recognizing the association of congenital peripheral lymphedema

with other clinical signs. The tentative diagnosis, once considered, is not difficult to make.

Bibliography

¹Brook, C.G. and Murset, G.: Growth in children with 45 (XO) Turner's syndrome. *Arch. of Dis. Child.*, 49:789-795, 1974.

²Gatrad, A.R.: Congenital dislocation of the knees in a child with mosaic Turner's syndrome. *Genetics*, 148-151, 1980.

³Greenblatt, R.B.: The spectrum of gonadal dysgenesis. *Am. J. Obstetrics*, 98:151-172, 1967.

⁴Haddad, H.M. and Wilkins, L.: Congenital anomalies associated with gonadal aplasia. *Pediatrics*, 885-902, 1959.

⁵Henriksen, H.M.: Turner's syndrome associated with lymphedema in newborns. *Z. Geburtshilfe Peri.*, 184:313-315, 1980.

⁶Keats, T.E. and Burns, T.W.: The radiographic manifestations of gonadal dysgenesis. *Rad. Clin. N.A.*, 2:297-313, 1964.

⁷Lemli, L. and Smith, D.: The XO syndrome, a study of differential phenotype in 25 patients. *J. Ped.*, 63:577-588, 1963.

⁸Leonard, C.O. and Sanders, R.C.: Prenatal diagnosis of Turner's syndrome. *Hop. Med. J.*, 145:25-30, 1979.

⁹McDonough, P.G.: Gonadal dysgenesis and its variants. *Ped. Clin. N.A.*, 19:631-652, 1972.

¹⁰McDonough, P.G. and Byrd, J.R.: Gonadal dysgenesis. *Clin. Obst. and Gyn.*, 20:565-579, 1977.

¹¹Miller, M., and Metulsky, A.: Noonan syndrome in a family presenting with chronic lymphedema. *Am. J. Med.*, 65:379-383, 1978.

¹²Turner, H.H.: A syndrome of infantilism, congenital webbed neck and cubitus valgus. *Endocrine*, 23:566-574, 1938.

¹³Weiss, L. and Reynolds, W.A.: Osseous malformations associated with chromosome abnormalities. *Ortho. Clin. N.A.*, 3:713-732, 1972.

DYNAMIC ELECTROMYOGRAPHY FOR SURGICAL PLANNING IN CEREBRAL PALSY†

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Tendon transfers, tenotomies and neurectomies are well established orthopaedic procedures used to improve the gait and hand function of patients with cerebral palsy, yet they are performed with more than ordinary caution.^{2,3,5,6,12} Hesitation in scheduling the surgery rests with the difficulties in determining exactly which muscle represents the primary offender and which procedure to choose. The diagnostic techniques used today include careful observation of the patient's

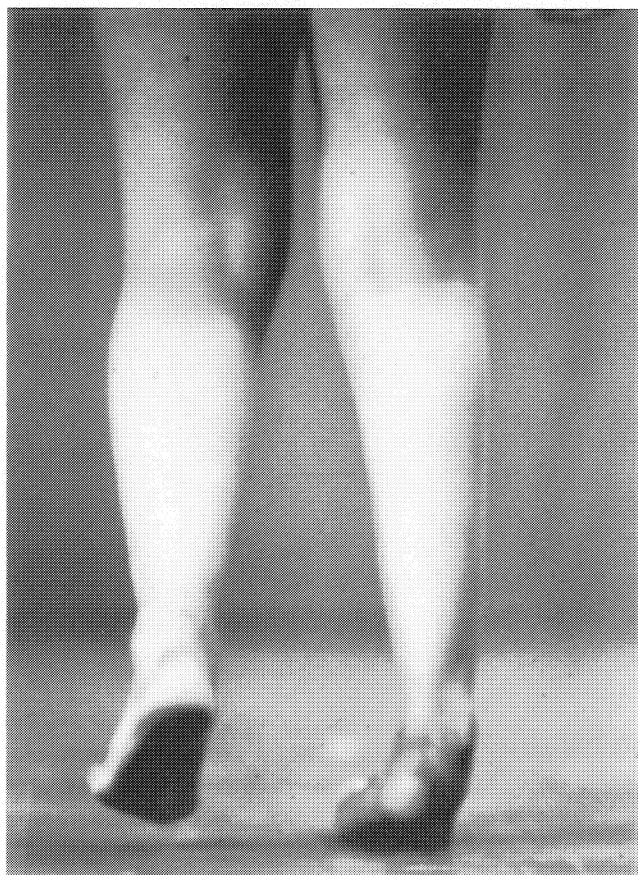


Figure 1. Child with flexible hind foot varus with three neurological patterns each indicating a different operation for correction.

gait or hand use and manual assessment of the muscles' reaction to stretch and voluntary control. For the latter tests, a variety of body and limb postures help to obtain better isolation of muscle action. Such examinations should be repeated at several different times, and generally there is careful discussion between orthopaedist and therapist before a final decision is made. Even with these precautions results are not always as predicted.¹¹ In fact, a common operating rule is "to select a procedure which may help but certainly will not do any harm."

This indecisiveness exists because the neural lesion, creating the disabilities characteristic of cerebral palsy, releases a complex of reflexes which confuse the physical examination. The patient has a greater problem than just impaired voluntary control and over-reaction to stretch.⁹

With an upper motor neuron lesion there are two types of voluntary control, selective and patterned. Selective muscle control permits the normal ability to activate a particular muscle on command, elicit maximum strength and hold it for the test period. Patterned control allows voluntary initiation of muscle action, but only as part of a mass limb synergy, and with a fixed intensity level. Further, the selectivity displayed during the less demanding situation of a manual examination may not be that which occurs during walking or spontaneous hand use. This latter finding suggests that primitive mass patterns represent a simpler mode of muscle activation.

In addition to having two means of voluntary control, effectiveness of either may be modified by changes in body position or limb posture. Sitting or standing upright produces greater extensor tone in the lower limbs and increases flexor tone in the upper extremity muscles more than when the patient is supine. If selective control is weak it may be obstructed by a change in body posture. Hence, voluntary control exhibited with the child lying on the table may not occur during walking. Shifting from sitting to standing also increases the tone. Similarly, the limb posture reflexes may facilitate activation of the flexor muscles when the joints are flexed and correspondingly obstruct isolated extensor control. The opposite is true with the limb extended. As a result the patient's voluntary control appears inconsistent. In reality it was the test position which changed.

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The same postural influences modify stretch reactions. Soleus spasticity, for example, proved to be twice as intense and obstructive of passive dorsiflexion when measured with the child upright compared to the resistance elicited in the supine position. Recording this muscle's stretch response with changes in limb position also demonstrated that either hip or knee flexion could reduce its tone.⁸ This contradicts the Silfverskiold test which identifies the gastrocnemius as the sole offender when passive ankle dorsiflexion is available when the knee flexes but not during extension.

Lastly, the rate of stretch has been identified as modifying the type of muscle response elicited rather than differentiating contracture from clonus. Spastic muscles do not remain silent when stretched slowly. Instead they display a continuous response at a fixed intensity. This is rigidity in contrast to the intermittent action of clonus. Contracture can be isolated only when the neural system is anesthetized.

Having demonstrated each one of these variables (mode of voluntary control, limb and body posture

reflexes and rate of stretch) experimentally with dynamic electromyography, the same testing technique was applied to diagnosing individual patient's function. At Rancho this has become a standard pre-surgical assessment for every cerebral palsy, stroke or head trauma patient scheduled for functional surgery. This circumvents diagnostic limitations of the traditional clinical system.

The surgeon determines that the patient has a disability sufficient to warrant surgery, and then decides whether a muscular or soft tissue procedure is indicated. When the latter is chosen the patient is referred to the Pathokinesiology Service for dynamic electromyographic testing. There, the natural pattern of muscle action occurring during walking or hand function is recorded by placing fine wire electrodes (50 μ) in each of the muscles of concern.^{7,8} These signals are transferred by telemetry to an appropriate recorder. The surgeon reads the printed record to identify which muscles are functioning inappropriately and their type of abnormality. Timing of the muscles is the first level of analysis.

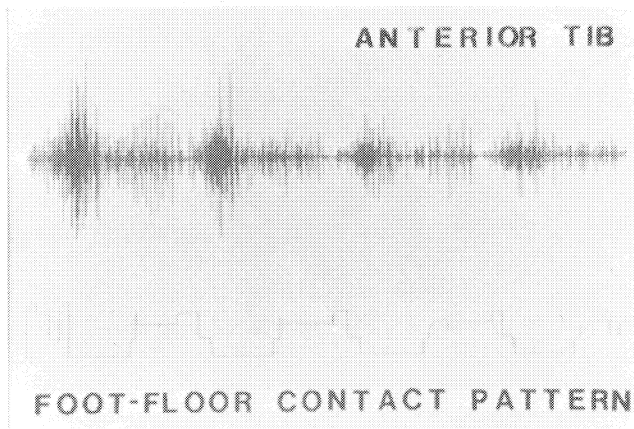


Fig. 2A.

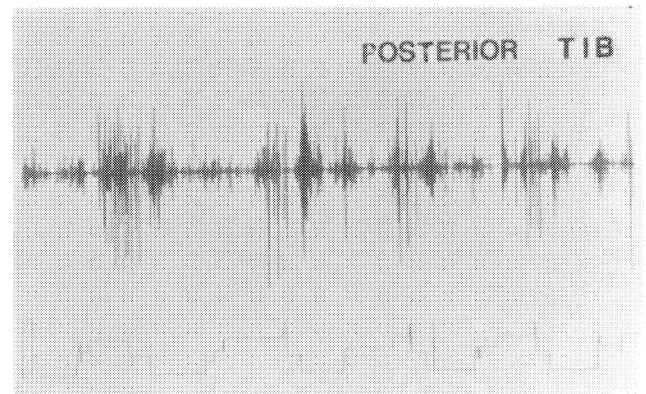


Fig. 3A.

Figure 2. Persistent tibialis anterior muscle action, (2A) an indication for a "SPLATT" (2b).

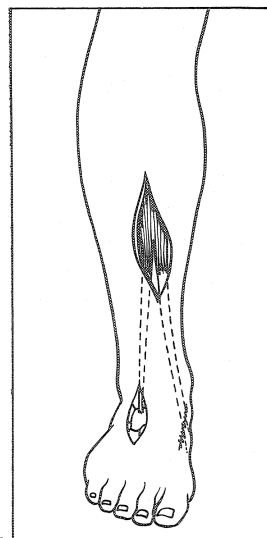


Fig. 2B.

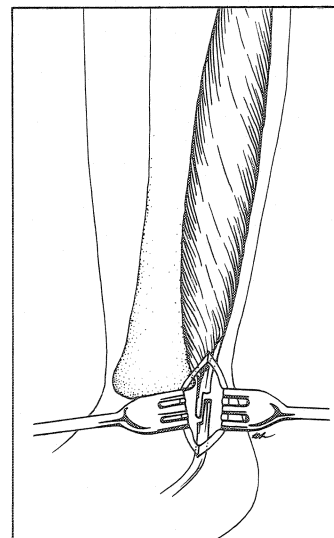


Fig. 3B.

Figure 3. Posterior tibialis muscle action, (3A) an indication for muscle tendon lengthening (3B).

There are three possible deviations from normal. (1) Phase reversal [shift from stance to swing or vice versa] (Figure 4). (2) Premature action. (3) Prolonged activity (Figures 2,3). One also can distinguish clonus and rigidity

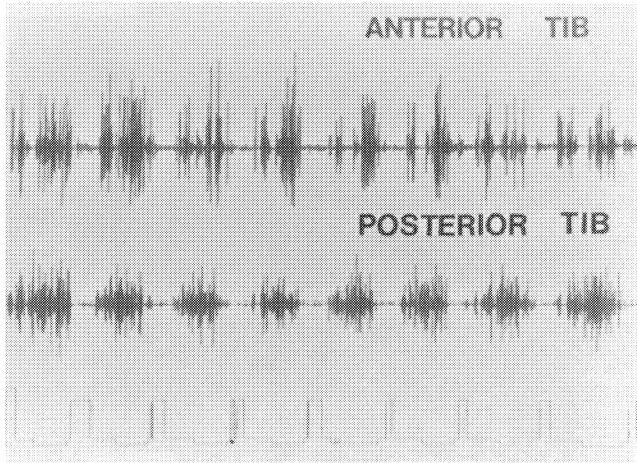


Fig. 4A.

Figure 4.
Phase reversal of the posterior tibialis muscle to swing (4A). The appropriate surgery is anterior transfer of the muscle to the lateral side of the foot (4B).

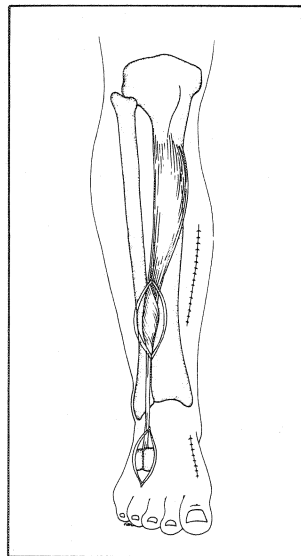


Fig. 4B.

ty from the graded pattern of central control. Surgical decisions relate to the above findings. Tendon transfers are selected only when the muscles have a dominant mode of activity during the desired phase. Hence, if a stance muscle is to be moved to function in swing, the EMG record must demonstrate that its natural timing is active in swing only. Otherwise, either a tendon lengthening or release is indicated to reduce the premature or prolonged action. When this is due to excessive stretch responses (rigidity or clonus) muscle timing will improve following surgery. Inappropriate timing due to primitive patterning will persist, but muscle force will be weakened by the surgery. A lengthening is selected if there is antagonistic muscle action needing a counterbalance or to preserve a less intense

mode of primary control. In the absence of these indications a release is sufficient.

Currently, three problems limit routine acceptance of this diagnostic procedure. For those who have the instrumentation for dynamic electromyography there is the reluctance to use indwelling wires rather than surface electrodes. The barrier is the fact that children cry when threatened with a needle stick. This does occur, but it is a temporary trauma which spontaneously abates once the needle is removed. Also, with clever distraction, many wires can be inserted without the child's knowledge. Surface electrodes, while convenient, are not selective.¹⁰ They receive the signals from all muscles in the area and thus the action of two lying adjacent to each other cannot be differentiated. Consequently, the information obtained with such electrodes is ambiguous and does not contribute to surgical planning. Hence, one has to ask if having an ineffective operation is less traumatic for the child.

The second major deterrent to using dynamic electromyography involves the difficulty and expense of establishing and maintaining a reliable system. At present the components must be gathered independently and assembled by an engineer.^{1,4} All the instruments are multi-purpose and costly. Also, their variability introduces unreliability necessitating regular calibration maintenance and technical skill in their operation. This requires an electronic technician as a member of the staff.

The third deterrent is unfamiliarity of surgeons in interpreting dynamic electromyography records. Practice gives credence to what initially appears to be a maze of scratches, but there still are many subjective decisions to be made.

To remove the latter two deterrents we are proceeding with the development of a functionally reliable, single unit system that produces a readily interpretable record. The challenge lies in handling the EMG signals. As the complex wave form of raw EMG is transformed into a single analog line, the timing distortion created by the existing electronic integrators must be avoided. Also, means of differentiating stretch responses (spasticity and rigidity) from central control must be preserved. Thirdly, there must be a representation of relative intensity of muscle action rather than a simple on/off signal. With the capability of modern microprocessors, each of these requirements has a logical and practical answer. Hence, dedicated instrumentation is a future reality.

Summary

The standard clinical tests designed to evaluate individual muscle function are unreliable in patients with

upper motor neuron lesions because they create varying situations which stimulate inconstant muscle responses.

A system of dynamic electromyography has been developed to define the natural pattern of muscle action occurring in the individual patient during walking and hand use. Surgical results become reliably predictable with this diagnostic system.

Indwelling wire electrodes are needed to accurately differentiate the action of one muscle from its neighbors.

Instrumentation is being developed to provide direct interpretation of the muscle's electromyographic patterns.

Bibliography

¹Antonelli, D.: Electrodes, amplification and filtering for dynamic EMG. *Bul. Prosthetics Research, Rehabilitative Engineering Research and Development*, 18:195-197, 1981.

²Banks, H.H.: The foot and ankle in cerebral palsy. In *Orthopaedic Aspects of Cerebral Palsy*, pp. 195-220. Edited by R.L. Samilson, J.B. Lippincott, Philadelphia, 1975.

³Evans, E.G.: The knee in cerebral palsy. In *Orthopaedic Aspects of Cerebral Palsy*, pp. 173-194. Edited by R.L. Samilson, J.B. Lippincott, Philadelphia, 1975.

⁴Freeborn, C.: Analog recording of myoelectric signals. *Bul. Prosthetic Research, Rehabilitative Engineering Research and Development*, 18:297-298, 1981.

⁵Frost, H.M.: *Orthopaedic Surgery in Spasticity*, pp. 72-92. C.C. Thomas, Springfield, Illinois, 1972.

⁶Goldner, J.L.: The upper extremity in cerebral palsy. In *Orthopaedic Aspects of Cerebral Palsy*, pp. 221-257. Edited by R.L. Samilson, J.B. Lippincott, Philadelphia, 1975.

⁷Hoffer, M.M., Perry, J., Melkonian, G.J.: Dynamic electromyography and decision-making for surgery in the upper extremity of patients with cerebral palsy. *J. Hand Surg.*, 4:424-431, 1979.

⁸Perry, J., Hoffer, M.M., Giovan, P., Antonelli, D., Greenberg, R.: Gait analysis of the triceps surae in cerebral palsy. *J. Bone and Joint Surg.*, 56A:511-520, 1974.

⁹Perry, J., Giovan, P., Harris, L.J., Montgomery, J., Asaria, M.: The determinants of muscle action in the hemiparetic lower extremity (and their effects on the examination procedure). *Clin. Orthop.*, 131:71-89, 1978.

¹⁰Perry, J., Easterday, C.S., Antonelli, D.J.: Surface versus intramuscular electrodes for electromyography of superficial and deep muscles. *Physical Therapy*, 61:7-15, 1981.

¹¹Samilson, R.L. and Hoffer, M.M.: Problems and complications in orthopaedic management of cerebral palsy. In *Orthopaedic Aspects of Cerebral Palsy*, pp. 258-274. Edited by R.L. Samilson, J.B. Lippincott, Philadelphia, 1975.

¹²Sharrard, W.J.W.: The hip in cerebral palsy. In *Orthopaedic Aspects of Cerebral Palsy*, pp. 145-172. Edited by R.L. Samilson, J.B. Lippincott, Philadelphia, 1975.

MEASUREMENT OF BONE MINERAL CONTENT USING COMPUTED TOMOGRAPHY

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Introduction

Measuring bone mineral content is an essential diagnostic procedure in evaluating patients with metabolic bone disease. Radiographic studies of the skeleton alone are not sufficient since losses of 30-40% of the bone mass can occur before noticeable changes are detected on radiographic films.¹⁻³ Although several measuring techniques are used, none has been universally accepted. The purpose of this article is to familiarize the practicing orthopaedist with these methods and to introduce a new technique which utilizes computerized tomography (CT). This technique is still experimental but quite promising.

Photon Absorptiometry^{4,5}

For the last 15 years photon absorptiometry (Figure 1) has been the most commonly used technique for

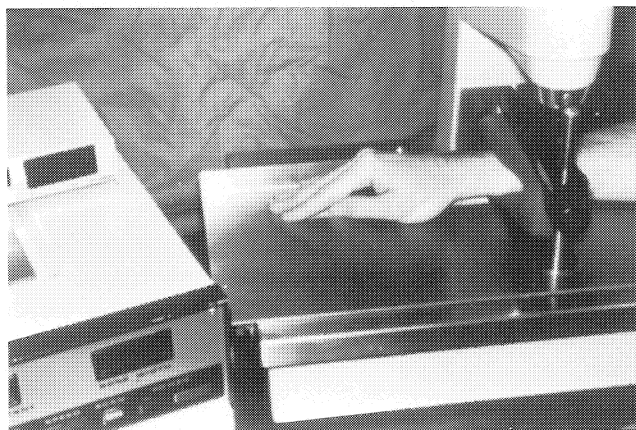


Figure 1. Photon absorptiometry. The Norland-Cameron absorptiometer is shown. Their radioactive source is placed below the forearm and the detector above.

measuring bone mineral content because it is highly accurate and precise. A monochromatic photon source is used (¹²⁵I with 27 Kev energy) coupled with NaI scintillating crystal as a detector. The technique is most suitable for use in the extremities, usually the

radius, at the junction of the proximal two-thirds with the distal one-third. The radiation dose to the forearm is minimal (5 mR) and to the body almost negligible, since there is virtually no scatter.⁶

Combined Cortical Thickness^{7,8}

This is a simple method to measure bone mass in the follow-up of patients with demineralizing bone disease and it is backed by a large body of normative data. It is easy to detect endosteal and periosteal cortical resorption with this technique; however, it is not sensitive to intracortical resorption (cortical porosity) which is manifested radiographically with intracortical tunneling.

Photodensitometry^{9,10}

This is among the earliest methods employed to quantitate bone mineral content. It basically utilizes the degree of film whitening (or blackening) produced after the part has been radiographed. A standard aluminum wedge is radiographed at the same time with the part (Figure 2). The density on the film is measured by a photodensitometer. Some European authors prefer to quantitate the amount of silver on the exposed film by chemical assay.

Neutron Activation¹¹

This is an accurate method for measuring total or partial body mineral content; however, the technique requires a readily available neutron source. Shielding of neutrons is difficult and radiation dose to the patient is high.

Iliac Histomorphometry¹²

This is an invasive technique and therefore is not widely used, since it involves obtaining an iliac bone biopsy for every bone mass determination.

The first three techniques are probably the most popular. However, all three utilize the cortical bone in the peripheral skeleton, which does not necessarily reflect the status of the bone mineral content in the axial skeleton where clinical problems are most apt to occur.¹³ Studies on bone mineral in subjects on bed rest¹⁴ and astronauts in weightless states^{15,16} reveal that the

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Figure 2. Photodensitometry. The hand is radiographed on a cardboard cassette. A standard aluminum wedge is placed between the thumb and the index finger and a fixed radiographic technique is used on all patients.

peripheral cortical bone loss is not always commensurate with the degree of negative calcium balance. A recent study comparing peripheral to axial bone loss in oophorectomized women clearly demonstrates an accelerated bone mineral loss in the spine compared to the peripheral skeleton.¹⁷ Cann et al. conducted a study on monkeys which also supports these findings.¹⁸

Trabecular bone has a much larger surface area per volume compared to cortical bone. It has been shown that the turnover rate of trabecular bone is about eight times that of cortical bone and therefore is quite sensitive to early metabolic changes.^{19,20}

The technologic explosion in the field of diagnostic radiology has stimulated investigators to evaluate the possibility of using computerized tomography in measuring bone mineral content in the spine.^{13,21,22} The spine is ideally suited for detecting early mineral changes in metabolic bone disease since 75% of its composition is trabecular bone.

With the earlier scanners three major technical problems emerged when researchers began measuring bone

density in the spine: (a) positioning of the patient in a standard reproducible fashion; (b) precision of the technique; and (c) accuracy.

Positioning is important in obtaining precise measurements. The same exact area should be scanned every time in order to obtain comparable results when following patients over a long period of time. This problem was resolved for the most part when the fourth generation scanners were developed with the capability of generating a computerized radiograph (commonly called a pilot scan)(Figure 3). The pilot scan permits us to position the patient properly and to localize the part

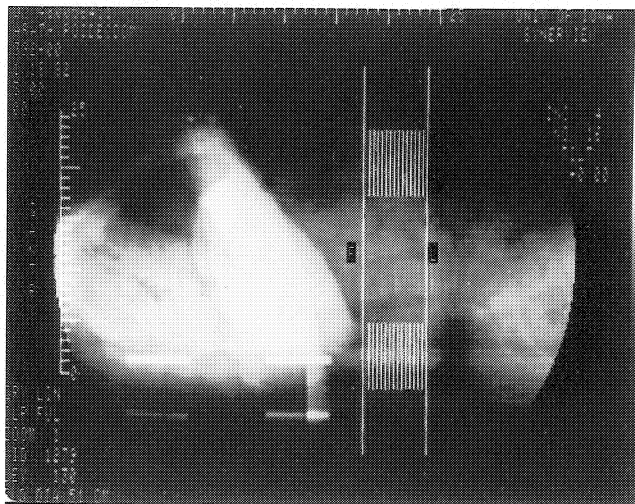


Figure 3. A pilot scan showing the plan for tomographic sections of L₂ and L₃. The same exact area could be scanned in future follow-up of the patient's disease.

of a vertebra to be scanned without difficulty. Scanning the endplates (cortical bone) can be avoided and follow-up scans of the same exact area are now feasible.

Precision problems are due to the diversity of CT or Hounsfield numbers which reflect the x-ray absorption coefficient of the scanned region. These numbers vary from one machine to another and from scan to scan on any particular machine. There is short-term variation in CT numbers occurring from minute to minute and long-term variation where appreciable drifts are noted in the CT numbers. The factors affecting this drift include the software, hardware, x-ray tube, detector problems, and fluctuations in the electrical current. To overcome this a phantom was devised which contains bone and soft tissue equivalent solutions (Figure 4). The phantom is therefore affected with the CT number fluctuations to the same degree as the part scanned. The phantom consists of five tubes which contain standardized solutions of K₂HPO₄, water, and ethanol (fat equivalent)(Figure 5). K₂HPO₄ has been chosen as the mineral equivalent standard because it has x-ray attenuation properties



Figure 4. The mineral calibration phantom has five tubes embedded within it. The tubes contain standardized solutions of K_2HPO_4 , water, and a fat-equivalent solution of ethanol. To fit under the patient it is designed in the shape of a crescent.

similar to calcium hydroxyapatite. The relationship between the CT numbers and the different concentrations of K_2HPO_4 solutions is linear; therefore the mineral content of bone can be expressed in units of K_2HPO_4 concentration equivalent. This scheme allows us to follow changes in bone mineral over time without assessing the actual quantity of mineral in the bone, which seems to be sufficient for the majority of clinical situations.

The problem of accuracy is immediately evident when viewing Figure 6. The CT technique attempts to average the density of a large area of the medullary space which consists mainly of trabecular bone and fat. These two substances have markedly different CT numbers and different x-ray attenuation coefficients. An important physical property of bone relates to its ability to absorb more x-rays at lower beam energies; this is not true of fat. Using this principal, investigators discovered that scanning a vertebra with dual energies (80 kvp and 120 kvp) could assist in determining accurately the mineral content of bone.²²

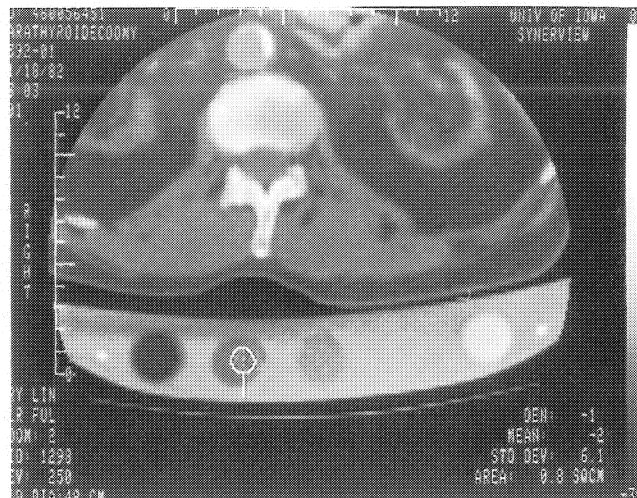


Figure 5. A CT scan through the L_2 vertebra. The mineral calibration phantom is under the patient. The different densities in the embedded tubes are demonstrated.

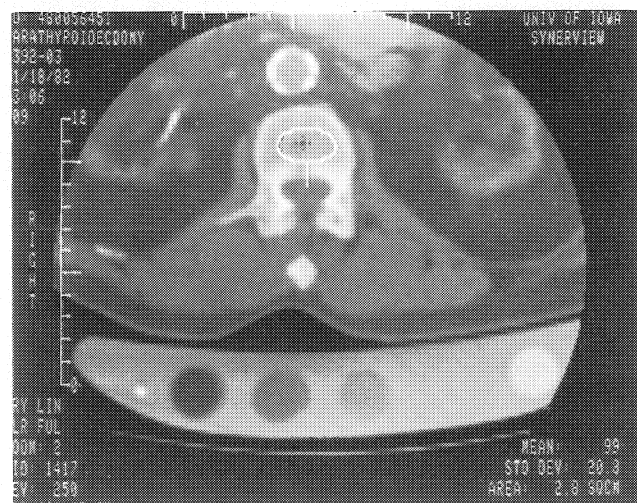


Figure 6. The mean density of the medullary space is being measured within the outlined ellipse. The cortical margins are excluded from the measurement.

Recent work has shown that quantitative CT for bone mineral analysis can be achieved with less than one-tenth the dose (100-125 mR) required for imaging the spine (1-3 R). It is now evident that the CT numbers are not affected by the noisy image resulting from dose reduction.²³

Conclusion

The increased use of CT technology will facilitate the diagnosis and follow-up of demineralizing bone diseases. The ease, precision, and accuracy by which bone mineral content is now being measured should guarantee the widespread application of quantitative CT for metabolic bone diseases.

Bibliography

- ¹Ardran, G.M.: Bone destruction not demonstrable by radiography. *Br. J. Radiol.*, 24:107-109, 1951.
- ²Barnett, E. and Nordin, B.E.C.: The radiological diagnosis of osteoporosis: a new approach. *Clin. Radiol.*, 11:166-174, 1960.
- ³Lachman, E.: Osteoporosis: the potentialities and limitations of its roentgenologic diagnosis. *Am. J. Roentgenol.*, 74:712-715, 1955.
- ⁴Cameron, J.R. and Sorenson, J.A.: Measurement of bone mineral in vivo: an improved method. *Science*, 142:230-232, 1963.
- ⁵Cameron, J.R., Mazess, R.B., and Sorenson, J.A.: Precision and accuracy of bone mineral determination by direct photon absorptiometry. *Invest. Radiol.*, 3:141-150, 1968.
- ⁶Griffiths, H.J. and Zimmerman, R.E.: The clinical application of bone mineral analysis. *Skeletal Radiol.*, 3:1-9, 1978.
- ⁷Garn, S.M., Poznanski, A.K., and Nagy, J.M.: Bone measurement in the differential diagnosis of osteopenia and osteoporosis. *Radiology*, 100:509-518, 1971.
- ⁸Virtama, P. and Mähönen, H.: Thickness of the cortical layer as an estimate of mineral content of human finger bones. *Br. J. Radiol.*, 33:60-62, 1960.
- ⁹Doyle, F.H.: Some quantitative radiological observations in primary and secondary hyperparathyroidism. *Br. J. Radiol.*, 39:161-167, 1966.
- ¹⁰Colbert, C., Mazess, R.B., and Schmidt, P.B.: Bone mineral determination in vitro by radiographic photodensitometry and direct photon absorptiometry. *Invest. Radiol.*, 5:336-340, 1970.
- ¹¹Harrison, J.E., McNeill, K.G., Meema, H.E., Fenton, S., Oreopoulos, D.G., and Sturtridge, W.C.: Partial-body calcium measurements by in vivo neutron activation analysis: comparisons with x-ray photodensitometry measurements of the radius. *J. Nucl. Med.*, 15:929-934, 1974.
- ¹²Jensen, P.S., Orphanoudakis, S.C., Baron, R., Lang, R., Rauschkolb, E.N., and Rasmussen, H.: Determination of bone mass by CT and correlation with quantitative histomorphometric analysis. *J. Comput. Assist. Tomogr.*, 3:847, 1979.
- ¹³Cann, C.E., and Genant, H.K.: Precise measurement of vertebral mineral content using computed tomography. *J. Comput. Assist. Tomogr.*, 4:493-500, 1980.
- ¹⁴Lockwood, D.R., Vogel, J.M., Schneider, V.S., and Hulley, S.B.: Effect of the diphosphonate EHDP on bone mineral metabolism during prolonged bed rest. *J. Clin. Endocrinol. Metab.*, 41:533-541, 1975.
- ¹⁵Smith, M.C., Jr., Rambaut, P.C., Vogel, J.M., and Whittle, M.W.: Bone mineral measurement-experiment M078. [In] *Biomedical Results from Skylab. NASA Report SP-377.* Johnston, R.S. and Dietlein, L.F. (eds.) Washington D.C., U.S. Govt. Print. Off., 1977, Chapt. 20, pp. 183-190.
- ¹⁶Whedon, G.D., Lutwak, L., Rambaut, P.C., Whittle, M.W., Smith, M.C., Reid, J., Leach, C., Stadler, C.R., and Sanford, D.D.: Mineral and nitrogen metabolic studies, experiment M071. [In] *Biomedical Results from Skylab. NASA Report SP-377.* Johnston, R.S. and Dietlein, L.F. (eds.) Washington, D.C., U.S. Govt. Print. Off., 1977, Capt. 18, pp. 164-174.
- ¹⁷Cann, C.E., Genant, H.K., Ettinger, B., and Gordan, G.S.: Spinal mineral loss in oophorectomized women. Determination by quantitative computed tomography. *JAMA*, 244:2056-2059, 1980.
- ¹⁸Cann, C.E., Genant, H.K., and Young, D.R.: Comparison of vertebral and peripheral mineral losses in disuse osteoporosis in monkeys. *Radiology*, 134:525-529, 1980.
- ¹⁹Weissberger, M.A., Zamenhof, R.G., Aronow, S., and Neer, R.M.: Computed tomography scanning for the measurement of bone mineral in the human spine. *J. Comput. Assist. Tomogr.*, 2:253-262, 1978.
- ²⁰Orphanoudakis, S.C., Jensen, P.S., Rauschkolb, E.N., Lang, R., and Rasmussen, H.: Bone mineral analysis using single-energy computed tomography. *Invest. Radiol.*, 14:122-130, 1979.
- ²¹Bradley, J.G., Huang, H.K., and Ledley, R.S.: Evaluation of calcium concentration in bones from CT scans. *Radiology*, 128:103-107, 1978.
- ²²Genant, H.K. and Boyd, D.: Quantitative bone mineral analysis using dual energy computed tomography. *Invest. Radiol.*, 12:545-551, 1977.
- ²³Cann, C.E.: Low-dose CT scanning for quantitative spinal mineral analysis. *Radiology*, 140:813-815, 1981.

JUVENILE AMPUTEES: CLASSIFICATION AND REVISION RATES

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Introduction

The care of the juvenile amputee presents special problems for the physical therapist, prosthetist, and orthopaedist. Optimal surgical treatment and prosthetic fitting demand careful planning and frequent clinical and radiographic followup, as growth alters the size and shape of the residual limb. Disproportionate growth of the bone and soft tissue may result in bony overgrowth, which as stated by Lambert,¹ represents the most common unfavorable sequela of the surgical treatment of the juvenile amputee. Parents of these children and third party payers often request information from medical personnel concerning the anticipated nature and frequency of surgery and prosthetic modification due to bony overgrowth. Ideally, a classification of the juvenile amputee by type, age and amputation level, and an analysis of patients with such classifications, would help to answer these questions.

Aitken,² Lambert and Pellicore³ described bony overgrowth in the juvenile amputee as appositional bone growth independent of epiphyseal growth. Aitken⁵ documented the order of overgrowth frequency as: humerus, fibula, tibia, femur, and tibia/fibula, and Pellicore³ reported similar findings, with exception of the tibia, which was most frequently affected. Pellicore demonstrated that, in addition to the specific bone involved, age at amputation and transection through bone may influence recurrence of bony overgrowth. Both authors concluded that prevention of overgrowth can best be accomplished by joint disarticulation. If the bone pierces the skin, the treatment of choice is bony excision and soft tissue closure (Figure 1). Many children with acquired amputations need revision, particularly of the humerus and fibula. True congenital amputations which need revision, although rare, have been reported by Lambert and Aitken.⁷ They did not describe these cases.

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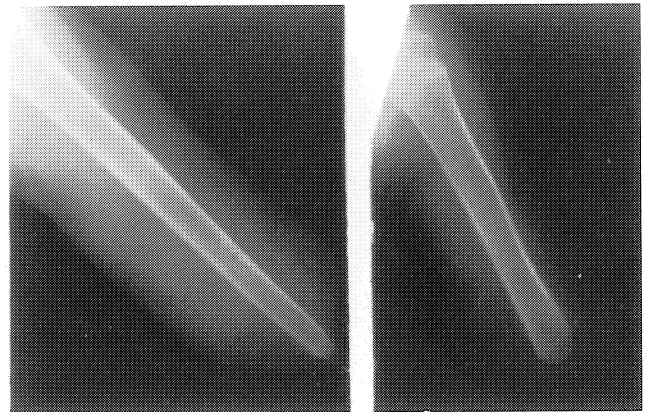


Figure 1. A Pre and Post Operative X-ray of a Humerus.

Method

Juvenile amputees were identified in two ways: by computer search of the University of Iowa medical records from 1965 to 1981; or from the Congenital Hand Project, which extended from 1960 to 1980. The charts of all patients were reviewed. The analysis included only those patients who underwent initial amputation or first revision prior to skeletal maturity. We documented the following: age at amputation, etiologic factors, bones involved, level, and the nature and number of operations involving bone. The data were tabulated and graphed for analysis.

Results

One hundred and twenty patients with major limb deficiencies or amputations prior to skeletal maturity were classified according to the following 5-category system:

Type	Description	No. of Cases
1	Acquired amputations (infection, trauma, etc.).	26
2	Congenital amputations through long bones.	8
3	Congenital deficiencies surgically converted by amputation through bone	3

Continued

Type	Description	No. of Cases
4	Congenital deficiencies surgically converted by disarticulation.	4
5	Congenital deficiencies treated non-surgically with prostheses.	79
Total Number of Cases		120

The distinction between Type 2 and Type 5 amputations is important. Type 2 includes true congenital amputations through long bones and results from such causes as constriction ring syndromes (Figure 2). Type 5 includes terminal transverse deficiencies, in which vestigial appendages are usually present (Figure 3).



Figure 2. A Type 2 BK Amputation, Secondary to Constriction Ring Syndrome.

Type 1 cases ranged at amputation from 2 months to 14 years. Humeral overgrowth occurred most frequently and necessitated as many as 6 revisions, resulting in 14 procedures on 4 patients. The fibula was revised in 3 cases, the tibia/fibula twice, and the tibia once. Revisions were not necessary for amputations acquired after age 12. Only 1 of 7 skeletally mature patients, who had a below knee acquired amputation at age 10, required



Figure 3. A Classic Congenital BE, with Vestigial Hand.

revision. His tibia and fibula were revised separately at ages 15 and 16 respectively.

Type 2 cases are true congenital amputations through the long bones. We excluded classic terminal transverse below-elbow deficiencies with vestigial hands or nubbins, and all other congenital limb deficiencies not through the long bones. We included proximal focal femoral deficiencies (PFFD), phocomelias and amelias in Type 5. Of the 8 Type 2 cases, 7 underwent at least 1 revision. One fibula was revised 5 times, and 2 humeri were revised twice. One patient (Figure 4) had bilateral PFFD and bilateral above-elbow amputations, one longer than the other. In 20 years, he underwent 2 revisions on the right above elbow amputation and no revisions on the left.

Four out of 5 above-elbow deficiencies needed revision indicating that the humerus does overgrow in the so-called congenital amputation (Table 5). The humerus, the most common bone involved, required 6 revisions in 4 patients. Two tibia/fibulae were revised a total of 4 times: 3 in 1 case and 1 in another.

All Type 2 patients had at least 3 limbs involved and had at least simple syndactylies. This group appeared to respond differently than the classical limb deficiency patient or the patient with only 1 limb involved. Patients with congenital amputations of the humerus or fibula reacted much like Type 1 or Type 3, even though they appeared to have true congenital amputations.

Type 3 cases, in which surgical conversion of congenital limb deficiencies involved bone transection, were all at the below-knee level (Table 4). There were two congenital pseudarthroses of the tibia and fibula, and one congenital absence of the fibula. Type 1 amputations like Type 3, required bony revision. Two below-knee amputations required revision of the tibia,

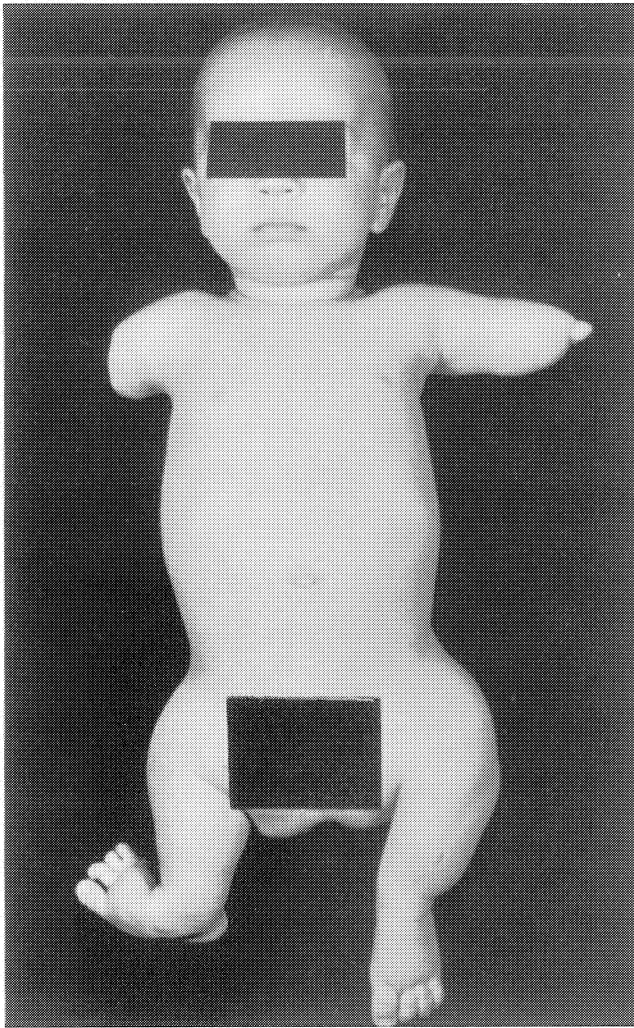


Figure 4. A Type 2 Congenital Quadramembral, who had Two Revisions of the Right Humerus.

one patient at age 12 and one at age 15, and one required revision of the fibula. All amputations were done prior to age 5, and predictably followed a course similar to Type 1.

Type 4 encompasses congenital deficiencies converted surgically by disarticulation. PFFD and single or double ray feet without a hindfoot are examples. Surgical conversion enhances prosthetic fitting without concomitant loss in function. No bony overgrowth occurred in this group.

Type 5 comprises the largest sub-group of these congenital deficiencies, those treated non-surgically by prostheses. Type 5 includes the classic terminal transverse below-elbow amputation which occurs more often in females.⁶ Vestigial hand or nubbins are usually present. In review of 33 unilateral cases with no other abnormalities, we found no case of bony overgrowth.

Type I by Level and Cause

Level	Cause
AE = 7	Farm Equipment = 11
BE = 4	Lawn Mower = 5
WD = 2	Infection = 6
BK = 13	Burn = 3
	Motor Vehicle = 1
<u>26</u>	<u>26</u>

Table 1
Type 1 by Level and Cause.

Number of Type I Amputation Revisions by Bone

	Number of Revisions					
	1	2	3	4	5	6
Humerus		●●		●		●
Fibula	●●	●				
Tib/Fib	●●					
Tibia	●					

Table 2
Number of Type 1 Amputation Revisions by Bone.

Total Number of Revisions by Type

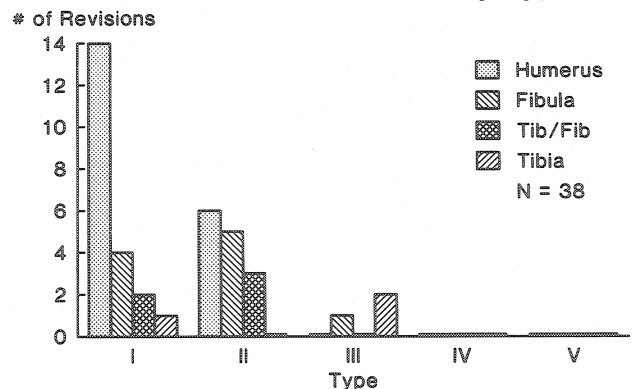


Table 3
Total Number of Revisions by Type.

Total Cases by Type and Level						
Level	Type					Total
	I	II	III	IV	V	
AE	7	5	0	0	0	12
BE	4	0	0	0	33	37
WD	2	0	0	0	0	2
AK	0	0	0	0	0	0
BK	13	2	4	0	0	19
AD	0	0	0	0	0	0
All Others	0	0	0	4	46	50
Total	26	7	4	4	79	120

Table 4
Total Cases by Type and Level.

Type II Congenital Amputations Through the Long Bones					
Level	F/U Years	Number of Revisions	Age, in Years, at Revision		
			Humerus	Fibula	Tib/Fib
AE	8	1	7		
AE	8	2	8, 10		
AE	3	1	2		
BK	14	3			2,4,14
(L)AE	20		3, 7		
(R)AE		2(R)			
BK	7	1			5
BK	9	5		1,3,6,7,9	

Table 5
Type 2 Congenital Amputations through the Long Bones.

Since no bony overgrowth occurred, we believe that these are true limb deficiencies, and therefore belong in our Type 5 classification.

Discussion

After analyzing juvenile amputees, we concluded that the proposed classification system has prognostic value. The known tendency of acquired amputations (Type 1) to require revisions is confirmed. Twenty-six patients underwent 21 revisions. The analysis indicates that congenital transverse amputations (Type 2) through long bones frequently require revision, occurring 14 times in 7 patients. This confirms the opinions of Aitken and Lambert.^{2,3} For prognostic purposes, the transverse congenital amputation (Type 2) should be considered an entity distinctly different from non-

surgically treated congenital terminal transverse deficiencies (Type 5), in which revisions were not required.

When congenital deficiencies were treated by amputation through long bones (Type 3), they followed a course similar to that of a congenital amputation through a long bone, changing from an entity in which revision was unlikely to one that was nearly predictable. If the congenital deficiency was surgically treated by disarticulation instead of amputation (Type 4), revision was not necessary, suggesting that when possible, disarticulation is the preferred surgical procedure.

This data and classification system provide guidelines by which other investigators may further explore the question of surgical revision in juvenile amputees, especially in patients with congenital amputations of long bones.

Conclusions

Surgical revision of the juvenile amputee is frequently necessary in both congenital and acquired cases. The younger the patient at the time of amputation, the more likely the need for revision. In our series, the humerus was most often revised, followed by the fibula, tibia/fibula, and tibia. The data indicate a frequent need for revision for bony overgrowth in true congenital amputations through the long bones, particularly through the humerus and fibula. It also supports the contention that through-bone amputations should not be done if disarticulation is possible.

Bibliography

- ¹Lambert, C.T.: Amputation surgery in the child. *Ortho. Clin. North Am.*, Vol. 3, No. 2:476, 1972.
- ²Aitken, G.T.: Overgrowth of the amputation stump. *Inter. Clin. Info. Vul.*, Vol. 1, No. 11:1-8, 1962.
- ³Pellicore, R.J.: Incidence of bone overgrowth in the juvenile amputee population. *Inter. Clin. Info. Vul.*, Vol. 13, No. 15:1-10, 1974.
- ⁴Lambert, C.T.: A different viewpoint on overgrowth. *Inter. Clin. Info. Vol.*, Vol. 5, No. 9:15-16, 1966.
- ⁵Aitken, G.T.: The child amputee. *Clin. Ortho.*, Vol. 3, No. 2:476, 1972.
- ⁶Shurr, D.G.: Terminal transverse congenital limb deficiency of the forearm. *Ortho. and Pros.*, Vol. 35, No. 3:22-25, 1981.