UNIVERSITY OF WASHINGTON
Department of Orthopaedics
1997 Research Report

Foreword

Making a Difference

The cover of this year's research report shows Vincent van Gogh's portrait of his physician, Dr. Paul Gachet (1828-1909). Gachet was a doctor who specialized in homeopathy, a psychiatrist, an engraver, a Darwinian, and a consistently helpful and generous patron and friend to all those artists with whom he came into contact. In spite of his best efforts, however, he was unable to make a difference in his patient's serious depression: Gachet took Vincent van Gogh into his house at Auvers-sur-Oise in 1890, and it was there that the artist committed suicide.

As orthopaedic surgeons we are much more fortunate than Gachet: we have wonderful opportunities to make a difference in the comfort and function of our patients. Never before have we had such powerful tools at our disposal for stabilizing fractured bones, restoring mobility to damaged joints, and improving the effectiveness of muscles, nerves and tendons. As is always the case, more power means more responsibility. We have the obligation to document the positive difference we make for our patients with the tools now at our hands. What is interesting about orthopaedic surgery is that, as in painting, it matters who holds the tool. Paints, brushes, canvas, drills, reamers, implants do not successes make. The surgeon (the artist) is the method!

This issue of the Research Report features a number of articles focusing on the measurement of the difference that individual orthopaedic surgeons make. In order for a surgeon to know the difference he or she makes with a specified procedure for a specific diagnosis, it is essential to know not only the outcome of that procedure, but also the status of the patient before surgery - the ingo. If both the outcome and ingo are measured using the same tools, the surgeon can measure his or her efficacy as the difference between the two. Because individual surgeons want to know their personal efficacy, our emphasis is on simple measurement tools that can be applied efficiently in the context of busy practices. Such information enbles us to assure our patients (1) that their ingo is similar to others on whom we have done the procedure in the past and (2) that the procedure has been efficacious for similar patients in our hands.

One of our featured articles, Assessing Patient Outcomes in Orthopaedic Surgery; Issues and Techniques, is authored by Marc Swiontkowski. Because of his dedication and expertise in the science of outcomes research, Marc has been appointed Deputy Editor for Outcomes Research of the Journal of Bone and Joint Surgery. He and his investigative team recently received the prestigious OREF Clinical Research Award for their development of a musculoskeletal function assessment tool. The OREF also awarded Doug Harryman a grant for a multipractice study of the effectiveness of treatment for rotator cuff tears.

Clinical efficacy articles in this Report concern the reversal of tetraplegia with immediate reduction of spinal dislocations, prosthetics for limb deficiency, and the management of stiff shoulders and elbows. A pair of articles characterize the ingo of (1) patients with musculoskeletal tumors and (2) patients with different shoulder diagnoses. Other clinical research reports the mechanical effects of limb length discrepancy and the prediction of chondrosarcoma behavior.

Basic science articles concern the biochemistry of cartilage, the reversible deformation of articular cartilage under load, and the ability of surgery to change the contour and stability the glenoid articular surface. Finally, two articles feature new research methodologies, one enabling real time animation of musculoskeletal joints and the other holding promise for the imaging of molecules using magnetic resonance force microscopy.

The strength and breadth of these and the many other investigative programs in our Department bear witness to the excellence and energy of the staff, residents, faculty and others who make ours one of the premier Orthopaedic Departments in the country. To all these and to the individuals whose generous contributions have helped make this research possible, we express our most profound gratitude. A special thanks to Susan DeBartolo and Fred Westerberg for their editorial assistance in the preparation of this research report. Thanks for helping us make a diffference!

Best wishes,

Frederick A. Matsen III, M.D.
Chairman

*Visit the Department of Orthopaedics WWW Home Page: http://www.orthop.washington.edu/ for information regarding faculty, training programs, research and common bone and joint problems.

Fibronectin Lacking the ED-B Domain is a Major Structural Component of Tracheal Change

Daniel J. Stechschulte, Jr., M.D., Ph.D., Jiann-Jiu Wu, Ph.D., and David R. Eyre, Ph.D.

Fibronectin is a highly-conserved, dimeric glycoprotein found in high concentrations in plasma and widely distributed in low concentrations in the extracellular matrix of tissues. The protein is the product of a single gene, but multiple splicing variants are expressed that show tissue specificity. Three exons (IIIA, IIIB and V) can be alternatively spliced to give different fibronectin isoforms. We report here that fibronectin is a remarkably abundant component of the extracellular matrix of bovine tracheal cartilage, increasing with age to more than 20% of the tissue dry weight. This matrix form of fibronectin is inextractable by 4M guanidine HCl, indicating that it is a covalently cross-linked structural component. By protein sequence analysis, the main molecular form of fibronectin in bovine tracheal cartilage was shown to lack the ED-B domain encoded by exon IIIB.

Introduction

Fibronectin is a widely distributed glycoprotein, abundant in plasma and in small amounts in most extracellular matrices. It functions as an adhesion molecule, with a key role suspected in various cellular processes including migration, morphogenesis, differentiation, and tissue repair. Evidence of altered fibronectin expression has also been reported for a range of tissues and pathologic conditions that include osteoarthritis and rheumatoid arthritis.

The fibronectin molecule is a disulfide-bonded homodimer of 250 kDa subunits. More than 90% of the protein sequence consists of three types of repeating domains referred to as types I, II, and III homologies. Multiple forms of fibronectin result from alternative splicing of at least three exons in the primary RNA transcript of the single fibronectin gene. Two of these exons encode type III elements referred to as ED-A (exon IIIA) and ED-B (exon IIIB), which are either wholly included or excluded. The third variable region, III-CS (exon V), can be included in total or in part. The pattern of fibronectin RNA splicing exhibits tissue specificity. Hepatocytes, for example, synthesize plasma fibronectin which excludes both ED-A and ED-B domains, whereas most other tissues produce cellular fibronectins which include either one or both of these domains.

The extracellular matrix of cartilage consists primarily of collagens and proteoglycans, with lesser amounts of non-collagenous proteins. Although grossly similar to articular cartilage in this respect, hyaline cartilages of the respiratory tract are distinguished by their unique profile of non-collagenous matrix proteins. Most prominent is cartilage matrix protein (CMP), a disulfide-bonded 148 kDa homotrimeric molecule first identified as a major, insoluble component of mature bovine tracheal cartilage. Lesser amounts of CMP were present in nasal septum, auricular, epiphyseal, and xiphisternal cartilages.

In attempting to define the mechanism of CMP crosslinking in tracheal cartilage, we found that fibronectin is also a major structural component of the extracellular matrix, reaching 20% or more of the tissue dry weight in older animals. From sequence analysis of fibronectin fragments extracted proteolytically from the tissue, we also show that the predominant fibronectin isoform in bovine tracheal cartilage lacks the ED-B domain.

Experimental Procedures

Source and preparation of tissue. Bovine tracheae from cattle of three age groups (calf, 2-year, and 5-year animals) were obtained at slaughter and immediately frozen and stored at -20˚C prior to analysis. Soft tissue and perichondrium were carefully removed, and the individual tracheal rings were minced on ice, ground to a fine powder under liquid nitrogen (Spex mill), and then extracted with 4M guanidine HCl, 0.05M Tris/HCl, pH 7.5, at 4˚C for 24hr.

CNBr and Trypsin digestion. Cyanogen bromide (CB) and trypsin digestions were carried out on portions of the washed residue. Conditions for trypsin digestion were 1% trypsin (w/w) in 0.2M NH_4HCO_3 at 37˚C for 24hr. Supernatant and washings were combined, lyophilized, and weighed, and the trypsin-insoluble residual tissue was weighed. CB digestion was carried out in 70% (w/v) formic acid under argon at room temperature for 24hr. with a CB concentration of 2.5 mg CB per mg dry weight of tissue. To separate collagenous peptides from noncollagenous peptides, the CB digest of bovine tracheal cartilage (20mg) was extracted 5 times with 1 ml of 1% (v/v) trifluoroacetic acid (TFA) at 60˚C for 2 min. The TFA soluble material was separated by microcentrifugation (Eppendorf). The pellet and pooled supernatants were lyophilized separately and weighed.

SDS-PAGE and N-terminal sequence analysis. Both the TFA-soluble and insoluble components were analyzed by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) and also transblotted onto polyvinylidene difluoride (PVDF) membrane for microsequence analysis. Edman N-terminal sequence analysis of phenylthiohydantoin (PTH) amino acids was performed on a gas-phase protein microsequencer (Porton 2090E) equipped with on-line high performance liquid chromatography (HPLC) analysis using the manufacturer's standard program.

Peptide chromatography. A 47 kDa CB peptide of fibronectin was purified by molecular-sieve HPLC. Two columns (Toso-Haas G3000SW, 7.5 mm X 60 cm) were coupled in series and eluted with 2M guanidine HCl, 0.05 M Tris HCl, pH 6.8, monitoring for absorbance at 220 nm. The isolated peptide was desalted by dialysis and digested with endoproteinase Asp-N (sequencing grade, Boehringer Mannheim). The digest was fractionated by reverse-phase HPLC. Individual peptide yields were

estimated from the integrated absorbance (220 nm) profile and PTH-amino acid recoveries on sequence analysis.

Results and Discussion

The pool of acid-insoluble material from CB-digested tracheal cartilage, which proved to consist primarily of non-collagenous protein fragments, increased with age for the three age groups analyzed to 57% of the digest (i.e., of the 4M guanidine-insoluble tissue dry weight) from a 5- year-old cow (Table 1). The trypsin-soluble pool of tracheal cartilage, which was extracted without heat denaturing the collagen in order to assess the content of non-collagenous matrix proteins by another method, also increased with age to 59% of the 4M guanidine-insoluble dry weight. In contrast, articular cartilage from the 5-year animal yielded only 12% of its 4M guanidine-insoluble dry weight as trypsin-soluble material when treated similarly.

Figure 1 compares the SDS-PAGE profiles of the TFA-soluble and TFA-insoluble fractions from CB-digested 5-year bovine tracheal cartilage. The TFA-soluble fraction showed the typical profile of type II collagen CB-peptides (Figure 1, lane 1). The identity of each peptide band was confirmed by protein microsequencing after blotting to PVDF membrane (sequence data not shown). The TFA-insoluble material gave an electrophoretic profile totally different from that of the acid soluble fraction. Protein microsequence analysis identified all the major protein bands from 5-year tracheal cartilage as CB-peptides of bovine fibronectin (Figure 1). Microsequence analysis from SDS-PAGE transblots of the trypsin extract of tissue showed that all major protein bands were tryptic peptides of either bovine fibronectin or bovine CMP (data not shown).

Based on the recovered dry weights of the various tissue fractions and the yields of protein bands on electrophoresis estimated by their staining intensities and sequencing results, fibronectin accounted for about 20% of the total dry weight of tracheal cartilage from the 5-year animal. This conservative estimate includes taking into account the material initially extracted by the 4M guanidine-HCl, which for the 5-year animal was less than 10% of the tissue dry weight as determined by dialysing, freeze-drying and weighing the extract.

The 47 kDa CB peptide that would contain the ED-B domain if present was purified by molecular sieve HPLC (Figure 2) and then digested with endoproteinase Asp-N. On the basis of the digest's elution profile on reverse-phase HPLC, individual Asp-N peptides were selected for microsequence analysis (Figure 3). Amino-terminal sequence results on each peak are shown in Table 2. Of particular interest is the peptide giving the DTIIPAVPPPT sequence (Table 2 and peak D5, Figure 3) . Compared to the published cDNA predicted sequence, this peptide clearly does not contain an ED-B domain, indicating that tracheal cartilage fibronectin lacks ED-B (Figure 4). The presence or absence of the other variable domain, ED-A, could not be established from these analyses. The findings are in agreement with a recent report demonstrating that fibronectin mRNA from canine tracheal cartilage was 100% ED-B negative.

Fibronectin is present in normal articular cartilage in low concentration. The splicing pattern of fibronectin mRNA from chick cartilage is reported to change during chondrogenesis. In mesenchymal tissue of the developing limb of the embryo, fibronectin mRNA includes both ED-A and ED-B, but later in chick cartilage only ED-B is present. In contrast, fibronectin mRNAs from chick muscle and tendon contain ED-A and lack ED-B, leading the authors to speculate that cartilage expresses an unusual form of fibronectin. Here, we show clearly at the protein level that the predominant fibronectin splicing variant in bovine tracheal cartilage lacks the ED-B domain. This may reflect the expression of a splicing variant that is peculiar to respiratory tract cartilages or is indicative of a plasma origin.

The surprising finding is that fibronectin increases with age to account for 20% of the dry weight of tracheal cartilage in the most mature animal. At this level, fibronectin rivals type II collagen in content, and it may be the most prominent structural protein of the tissue. Certainly, in combination, fibronectin and the 148 kDa cartilage matrix protein exceed the mass of collagen in the older tissue. The results are consistent with previous observations on cultures of tracheal cartilage, which synthesized fibronectin and deposited most in the matrix in contrast with articular cartilage explants which released most to the medium. The findings are also comparable to the behavior of CMP, which was shown to increase in content in bovine tracheal cartilage with age in parallel with a decrease in the protein's extractability in 4M guanidine HCl. It would appear, therefore, that both fibronectin and CMP become major structural components of adult respiratory tract cartilages. This is in sharp distinction to articular cartilage which contains very small amounts of fibronectin and CMP.

The cross-linking mechanism responsible for the inextractability of fibronectin and CMP in mature tracheal cartilage is uncertain. However, it is well documented that transglutaminase is responsible for the covalent cross-linking of plasma fibronectin to fibrin during blood clotting. A key site of transglutaminase action in plasma fibronectin has been identified as the glutamine at the third residue from the amino-terminus. Transglutaminase will also cross-link plasma fibronectin to native type I or type III collagens *in vitro* . It seems reasonable to suspect, therefore, that fibronectin becomes cross-linked in tracheal cartilage to collagen fibrils and/or other matrix proteins through transglutaminase-mediated reactions. CMP may accumulate and become cross-linked by the same mechanism. The biological significance is unknown, but profound effects on the material properties of the tissue of such a large pool of interfibrillar protein can be expected.

Acknowledgments

We thank Kae Pierce for her expert assistance in the preparation of this manuscript. The work was supported by grants AR36794 and AR37318 from the National Institutes of Health.

Reccommended Reading

Hynes, R.O. (1990) *Fibronectins*, Springer-Verlag, New York.

Ruoslahti, E. (1988) *Ann. Rev. Biochem.* 57, 375-413.

Wurster, N.B., and Lust, G. (1982) *Biochem. Biophys. Res. Commun.* 109, 1094-1101.

Homandberg, G.A., Meyers, R., and Xie, D-L. (1992) *J. Biol. Chem.* 267, 3597-3604.

Miller, D.R., Mankin, H.J., Shoji, H., and D'ambrosia, R.D. (1984) *Connect. Tissue Res.* 12, 267-275.

Chevalier, X. (1993) *Semin. Arthritis Rheum.* 22, 307-318.

Vartio, T., Vaheri, A., Von Essen, R., Isomaki, H., and Stenman, S. (1981) *Eur. J. Clin. Invest.* 11, 207-212.

Scott, D.L., Wainwright, A.C., Walton, K.W., and Williamson, N. (1981) *Ann. Rheum. Dis.* 40, 142-153.

Carsons, S., Lavietes, B.B., and Diamond, H.S. (1989) in *Fibronectin* (Mosher, D.F., ed.), pp. 327-361, Academic Press, San Diego.

Petersen, T.E., Thogersen, H.C., Skorstengaard, K., Vibe-Pedersen, K., Sahl, P., Sottrup-Jensen, L., and Magnusson, S. (1983) *Proc. Natl. Acad. Sci. USA* 80, 137-141.

Petersen, T.E., Skorstengaard, and Vibe-Pedersen, K. (1989) in Fibronectin (Mosher, D.F., ed.), pp. 1-24, Academic Press, San Diego.

Kornblihtt, A.R., Umezawa, K., Vibe-Pedersen, K., and Baralle, F.E. (1985) *EMBO J.* 4, 1755-1759.

Hynes, R.O. (1985) *Ann. Rev. Cell Biol.* 1, 67-90.

Tamkun, J.W., Schwarzbauer, J.E., and Hynes, R.O. (1984) *Proc. Natl. Acad. Sci. USA* 81, 5140-5144.

Schwarzbauer, J.E., Tamkun, J.W., Lemischka, I.R., and Hynes, R.O. (1983) *Cell* 35, 421-431.

Hirano, H., Yamada, Y., Sullivan, M., DeCrombrugghe, B., Pastan, I., and Yamada, K. (1983) *Proc. Natl. Acad. Sci. USA* 80, 46-50.

Schwarzbauer, J.E., Patel, R.S., Fonda, D., and Hynes, R.O. (1987) *EMBO. J.* 6, 2573-2580.

Kornblihtt, A.R., Vibe-Pedersen, K., and Baralle, F.E. (1984) *EMBO J.* 3, 221-226.

Kornblihtt, A.R., Vibe-Pedersen, K., and Baralle, F.E. (1984) *Nucleic Acids Res.* 12, 5863-5868.

Vibe-Pedersen, K., Kornblihtt, A.R., and Baralle, F.E. (1984) *EMBO J.* 3, 2511-2516.

Norton, P.A., and Hynes, R.O. (1987) *Mol. Cell. Biol.* 7, 4297-4307.

Bennett, V.D., Pallante, K.M., and Adams, S.L. (1991) *J. Biol. Chem.* 266, 5918-5924.

Heinegård, D.K., and Pimentel, E.R. (1992) in *Articular Cartilage and Osteoarthritis* (Kuettner, K.E., Schleyerbach, R., Peyron, J.G., and Hascall, V.C., eds.), pp. 95-111, Raven Press, New York.

Paulsson, M., and Heinegård, D. (1981) *Biochem. J.* 197, 367-375.

Paulsson, M., and Heinegård, D. (1982) *Biochem. J.* 207, 207-213.

Eyre, D.R., and Muir, H. (1975) *Biochem. J.* 151, 595-602.

Laemmli, U.K. (1970) *Nature* 227, 680-685.

Towbin, H., Staelin, T., and Gordon, J. (1979) *Proc. Natl. Acad. Sci. USA* 76, 4350-4354.

Bogaert, R., Wilkin, D., Wilcox, W.R., Lachman, R., Rimoin, D., Cohn, D.H., and Eyre, D.R. (1994) *Am. J. Hum. Genet.* 55, 1128-1136.

Eyre, D.R. (1987) *Methods Enzymol.* 144, 115-139.

Wu, J.J., and Eyre, D.R. (1984) *Biochemistry* 23, 1850-1857

Zhang, D-W., Burton-Wurster, N., and Lust, G. (1995) *J. Biol. Chem.* 270, 1817-1822.

Burton-Wurster, N., and Lust, G. (1984) *Biochim. Biophys. Acta* 800, 52-58.

Larsson, T. (1989) Doctoral Dissertation, University of Lund, pp. 16-19.

Paulsson, M., Inerot, S., and Heinegård, D. (1984) *Biochem. J.* 221, 623-630.

Tamaki, T., and Aoki, N. (1981) *Biochim. Biophys. Acta* 661, 280-286.

Mosher, D.F., Schad, P.E., and Kleinman, H.K. (1979) *J. Clin. Invest.* 64, 781-787.

McDonagh, R.P., McDonagh, J., Petersen, T.E., Thogersen, H. C., Skorstengaard, K., Sottrup-Jensen, L., Magnusson, S., Dell, A., and Morris, H.R. (1981) *FEBS Lett.* 127, 174-178.

Footnotes

The abbreviations used are: CMP, cartilage matrix protein; CB, cyanogen bromide; TFA, trifluoroacetic acid; SDS-PAGE, sodium dodecyl sulfate-polyacrylamide gel electrophoresis; PTH, phenylthiohydantoin; HPLC, high performance liquid chromatography; PVDF, polyvinylidene difluoride.

Figure Legends

Figure 1. SDS-PAGE of the CNBr-digest of bovine tracheal cartilage. The acid-soluble (lane 1) and acid-insoluble (lane 2) fractions were run on a 12.5% gel. The acid-soluble pool shows the typical CB-peptide pattern of type II collagen (31). The acid-insoluble pattern is quite distinct with the major CB fragments being shown to be derived from bovine fibronectin. The results of amino-terminal sequence analysis of individual transblotted bands are shown.

Figure 2. Molecular sieve HPLC purification of the 47 kDa CB peptide of fibronectin. A sample (2 mg) of the acid insoluble fraction of the CNBr-digest of tracheal cartilage was dissolved in 4M guanidine HCl, 0.05M Tris-HCl, pH 6.8 and eluted from serial molecular sieve columns (Toso-Haas TSK-gel

G3000SW, 7.5mmx60 cm, two columns in series) at a flow rate of 0.5 ml/min., collecting 0.5 ml fractions. The eluent was 2M guanidine HCl, 0.05M Tris-HCl, pH 6.8. Fractions marked by the bar were desalted and analyzed by 12.5% SDS-PAGE (inset). Fractions 57-63, containing the 47 kDa CB peptide of fibronectin, were pooled for further analysis.

Figure 3. *Reverse-phase HPLC fractionation of the endoproteinase Asp-N-digested 47 kDa CB peptide of fibronectin*. The purified CB peptide (Figure 2) was digested with endoproteinase Asp-N (1:100 w/w) in 0.1M NH_4HCO_3 10% (v/v) acetonitrile at 37˚C for 16 hr. The digest was eluted from a C8 column (Brownlee Aquapore RP-300, 25 cmx4.6 mm) with a linear gradient (0-40%) of solvent B in A over 60 min. at a flow rate of 1 ml/min. Solvent A was 0.1% trifluoroacetic acid (v/v) in water, and solvent B was 0.085% trifluoroacetic acid (v/v) in acetonitrile-n-propanol (3:1, v/v). The determined amino-terminal sequences of the endoproteinase Asp-N-derived peptides found in peaks D1-D12 are given in Table 2.

Figure 4. *Amino acid sequence of the domain of bovine fibronectin (11) corresponding to the 47 kDa CB peptide* (See Figure 1, lane 2, upper band.). Endoproteinase Asp-N cleavage sites are indicated by arrows. The Asp-N peptide expected to contain the ED-B domain is underlined. The sequence of peptide D5 (Figure 3 and Table 2) is that predicted for the plasma form of fibronectin, which lacks the ED-B domain.

Table 1

Age-related increase in the yield of non-collagenous matrix proteins from bovine tracheal cartilage. Yields of matrix proteins from tissue previously extracted by 4 M guanidine HCL, pH 7.5, were estimated by two different methods shown to select for non-collagenouse components. Thus, the recovered dry weights of the acid insoluble fraction of a CNBr digest of tissue and of a trypsin soluble fraction from another tissue aliquot were expressed as % of total digest weights.

Animal age	CNBr digest Acid insoluble fraction	Trypsin digest Soluble fraction
4 mo.	6%	11%
2 yr.	37%	26%
5 yr.	57%	59%

Table 2

Amino-terminal sequences of the endoproteinase Asp-N *derived peptide*s. The purified 47 kDa CB peptide of fibronectin was digested with endoproteinase Asp-N and fractionated by reverse-phase HPLC. Peptides in peaks D1-D12 (Fig. 3) were identified by N-terminal sequence analysis and can be located in Fig. 4. It should be noted that endoproteinase Asp-N cleaves peptide bonds primarily at the amino side of aspartic acid, and to a lesser extent of glutamic acid residues. Peptides from both such cleavage sites were identified.

Peak		Sequence
D1	1191	EEVVH
D2	1221	DDKESVP
D3	1171	DITGYRITTTP
	967	DAPTNLQFINE
D4	1241	DLRFT
D5	1230	DTIIPAVPPPT
D6	896	WTPPESPV
	1132	DAPIVKKV
	1204	ENLSPGLE
D7	1171	DITGYRITTTPT
D8	1156	DTGVL
D9	909	DVIPVNLPGEHGQ
	1132	DAPIVKKVVTPLS
D10	909	DVIPV
	932	EVTGL
D11	1197	DQSS(C)TFENLSPG
	1156	DTGVLTV
D12	932	EVTGLSPGVTYHFKVF

Articular Cartilage Deforms Reversibly Under Load

JOHN M. CLARK, M.D., PH.D.

The most remarkable property of articular cartilage may be its durability. Joint surfaces are very smooth and they seem not to wear, and unless injured, a joint will usually last a lifetime. Although the chemical composition and material properties of cartilage have been extensively studied, no one knows what lends cartilage this unique capacity.

Most research on the function of cartilage has been done on small fragments of tissue rather than intact joints. When whole joints have been studied they were placed into material testing machines using jigs which artificially restrain the joint motion. We have developed a simple technique for loading knees using a simulated quadriceps extension force acting on the patella. A bar blocks knee extension, so the condition is analogous to standing on a bent knee (Figure 1). This method has several advantages, for example, the joint can be left sealed and stresses are distributed to the ligaments normally.

We have used this model to examine the structure of rabbit knee joints under load. The joints were loaded with a quadriceps force of 1.5 to 4.0 times the rabbit body weight and, after a specified time interval, frozen using supercooled isopentane. "Freeze-substitution fixation" was used to preserve the cartilage in its loaded state. In this technique the tissue is fixed while frozen so that it retains its shape when prepared for microscopy.

In earlier studies, we have used scanning electron microscopy to show that collagen fibers in the tibial plateau articular cartilage are very orderly in the center of the plateau (Figure 2). Using the loading/freeze-fixation technique we can examine what happens to these cartilage fibers in loaded knees. In loaded knees, the femoral condyle makes a dent in the tibial plateau, the size of which corresponds to the size and duration of the load. In the loaded regions, the vertical collagen fibers both crimp and bend over (Figure 3). Our model also allows the joint to be moved as a muscle load is applied. If a joint is moved for thirty minutes under load, the total amount cartilage compression is only one fifth of that which occurs if the joint is held still for the same period.

Our loading model can also be used to study the mechanics of the knee. In the Harborview Biomechanics Lab, we built a version of the loading device which uses a microprocessor to control the applied loads and simultaneously record data from the joint (Figure 4). Two types of information were collected:

Using highly accurate displacement gauges, we plotted movement of the tibia towards the femur and in effect, measured the compression of the loaded joint. We found that when a load is applied, the joint compresses and then returns to its resting position when the load is removed. The total amount of compression is increased by cutting the meniscus and—interestingly—simply by making an opening in the joint capsule.

The other measurement taken was joint contact pressure. We used pinhead-sized pressure gauges and inserted them into rabbit and dog knees. The pressures measured were directly proportional to the applied loads. When we applied simulated quadriceps muscle forces large enough to extend the knee against the animals' own weight (muscle forces of up to 80 lb. in a rabbit) the measured joint pressures were precisely in the range which others have predicted for weight-bearing joints.

Although our loading technique is simple, it provides a highly accurate way to study what happens to a loaded joint. Our biomechanical testing shows that the simulated quadriceps pull produces joint pressures and compression similar to those predicted by others. Using the technique, we have been able to produce the first micrographs of cartilage in loaded joints. Prior to this, most theories predicted that the cartilage collagen was somehow loaded in tension, but our result demonstrates that the fibers actually buckle from linear compression.

We are now using this technique to study what happens to the lubricating joint fluid in loaded knees. Our long term objective is to study the effects of joint motion and removal of the meniscus.

RECOMMENDED READING:

Clark, Variation of Collagen Fiber Alignment in a Joint Surface: A scanning electron microscope study of the tibial plateau in dog, rabbit, and man. J Orthopaedic Research, 9:246-257, 1991.

Norman, Clark, Notzli: The relationship of Quadricep Extension Force to joint contact pressures in intact knees, Trans Ortho Res Society, 43:648, 1997.

Notzli, Clark, Norman: The surface of Articular Cartilage of Intact Rabbit Knees, Trans Ortho Res Society, 43:462, 1997.

Figure One:
Method for loading the knee. The femur is fixed and the quadriceps pull is simulated by hanging a weight from a cable attached to the patella. The knee extension is blocked by a bar, but the tibia can translate and rotate freely, so forces are distributed to the knee without artificial constraint.

Figure Two:
a) Our model of cartilage collagen organization in the tibial plateau. In the plateau center the collagen fibers are straight and vertical. Therefore, changes caused by loading will be easily detected there.
b) Model of loaded cartilage showing fiber bending.

Figure Three:
a) SEM micrograph of cartilage collagen fibers in the unloaded tibial plateau.
b) SEM micrograph of cartilage collagen fibers in the loaded knee bent over by loading.

Figure Four:

Plot of joint compression vs. time with cyclical loading. Note the prompt return to normal after load removed.

Posterior Glenoplasty Changes the Effective Glenoid Shape and Mechanical Stability of the Shoulder

Michael H. Metcalf, M.D., David G. Duckworth, M.D., Seok-Beom Lee, M.D., John A. Sidles, Ph.D., Kevin L. Smith, M.D. and Frederick A. Matsen, III, M.D.

Although posterior instability accounts for only 2 - 4% of all shoulder dislocations, the future rate of surgical treatment is high. A variety of surgical treatments have been attempted, including: posterior Bankart repair, staple capsulorrhaphy, capsular plication, infraspinatus advancement, posteroinferior capsular shift, transposition of subscapularis, biceps tendon transfer, fascia lata reconstruction, extracapsular and intraarticular bone blocks and humeral osteotomy. However, none yields consistently good clinical results.

Posterior glenoplasty has been proposed as a procedure for managing recurrent posterior instability. Independently, in 1961, Scott and Kretzler began performing similar glenoplasty techniques on different patient populations. Both credited earlier work done in acetabuloplasties for congenital dislocations of the hip as the motivation for their technique.

251 cases of posterior glenoplasty have been presented in the literature. Of the 236 cases where post-operative stability was known, 187 (79%) of the shoulders were stable. In individual series, the percent rendered stable ranged from 31 to 100%. Reported complications of posterior glenoplasty include intra-articular fractures, late glenohumeral arthritis, avascular necrosis, anterior instability, joint contractures, subcoracoid impingement and complete osteotomy.

On one hand this operation has been characterized as "technically simple ... recommended without restriction or contraindication for any operable patient with recurrent posterior dislocation," on the other hand, it has been said to be "an operation reserved for a small percentage of patients with posterior instability and done only by experienced shoulder surgeons."

The objectives of our experiment were (1) to identify the variables under control of the surgeon in performing a posterior glenoplasty and (2) to determine, in a cadaver model, the effects of posterior glenoplasty on the effective shape of the glenoid and on the mechanical stability of the glenohumeral joint.

Materials and Methods

We characterized the effective glenoid shape of each preparation using the glenoidogram, the lateral displacement of the head plotted as a function of the distance the head translated from the glenoid center. For each direction of translation, a characteristic slope was determined by constructing a line tangent to the steepest part of the glenoidogram (Fig. 1).

We characterized the mechanical stability of each preparation in terms of the stability ratios, the translating force necessary to dislocate the head while a fifty Newton compressive load was applied. By convention, the stability ratios are expressed as the ratio of the dislocation force to the compressive load.

Glenoidograms and stability ratios were measured in eight directions before and after a posterior glenoplasty performed by a standardized technique. We identified nine variables under surgeon control in the performance of a posterior glenoplasty (not including the soft tissue aspects of the surgery). These are listed in Table 1 along with the values we assigned to each in this experimental protocol.

Results

Glenoid shape

The effective glenoid depth was increased an average of 2.5 millimeters, 3.2 millimeters and 1.9 millimeters for the inferior, posteroinferior and posterior directions respectively ($p < .001, .001, .005$) (Fig. 2). There was no evidence of intra-articular fractures (Fig. 3A - B).

Mechanical Stability

The average stability ratio increased significantly following glenoplasty in the posteroinferior direction from 0.47 to 0.81 ($p < .0001$). The average stability ratio was slightly, but statistically significantly decreased in

Table 1
Surgeon-Controlled Variables in Posterior Glenoplasty

	Variable	Value in our protocol
1	Area of the glenoid elevated	Posteroinferior quadrant
2	Distance of cut from posterior joint surface	One centimeter
3	Angle of cut relative to glenoid surface	Parallel
4	Depth the osteotome is inserted	Half the distance across the glenoid face
5	Number of times the osteotome is levered open	Four
6	Bone graft donor site	Posterior acromion
7	Width of base of wedge-shaped bone	Five millimeters
8	Depth to which the graft is inserted	Just inside posterior glenoid cortex
9	Osteotome type	One inch straight

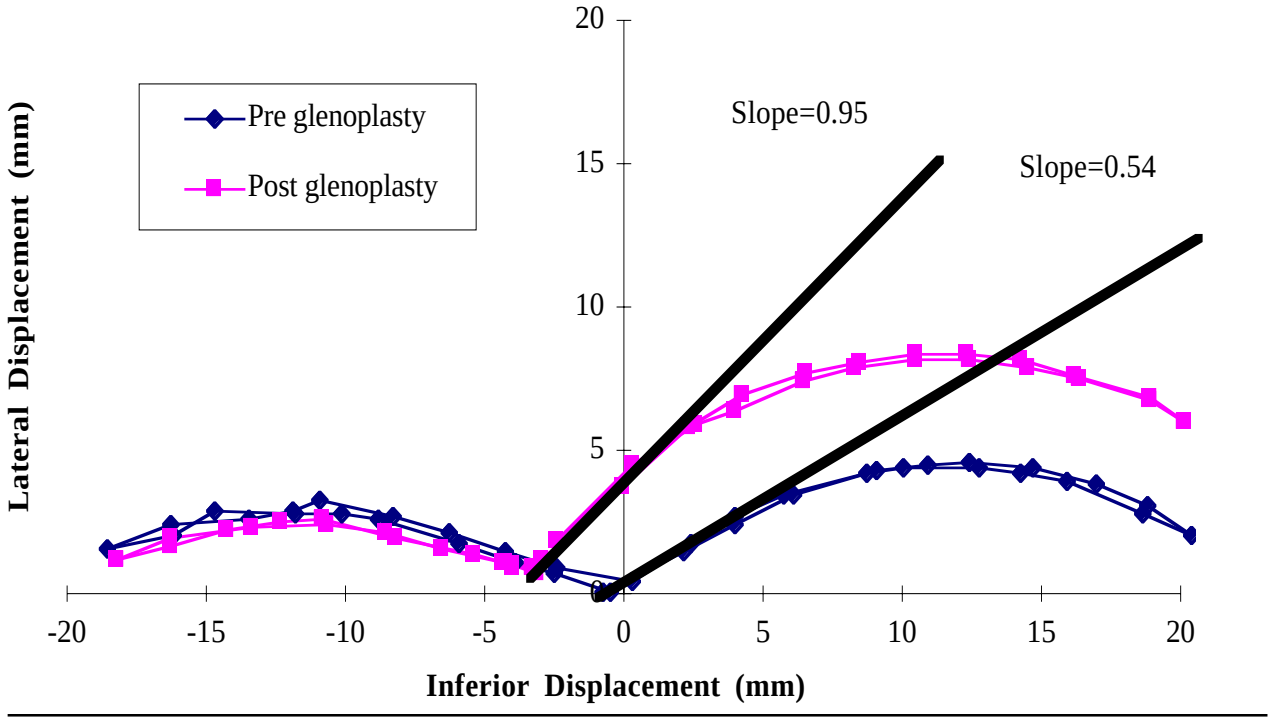


Figure 1: Representative glenoidograms and maximal slopes before and after glenoplasty.

the anterior and anteroinferior directions (Fig. 4). There was no significant change in the other directions.

Slope

The average maximum slope of the posteroinferior glenoidogram prior to glenoplasty was 0.55, which correlated with a mean stability ratio of 0.47 (corr. coeff. = 0.83, $p < .01$). After glenoplasty, the average slope increased to 0.83, which correlated with a mean stability ratio of 0.81 (corr. coeff. = 0.94, $p < .0005$). The slope of the steepest part of the glenoidogram was well correlated with the stability ratio.

Discussion

This investigation demonstrates that posterior glenoplasty increases the effective depth and the mechanical stability of the posterior inferior glenoid. The results confirm a close relationship between the shape of the glenoid, as reflected by the glenoidogram, and the mechanical stability, as reflected by the stability ratio.

The procedure we employed is similar to that described in most reported clinical series. Like Scott, we used a one inch straight osteotome. Other authors have used a reciprocating saw to make the cut and an osteotome to open it.

Previous authors place the cut five to ten millimeters to the glenoid lip. We chose ten millimeters.

The depth of osteotomy varies from one-half the anteroposterior dimension to completely through the anterior cortex. Scott recommends advancing the osteotome until it could be opened 1/2 to 3/4 inch. We elected to insert the osteotome one-half the anteroposterior dimension of the glenoid.

Both Scott and Kretzler recommend advancing the osteotome with a series of openings to achieve a greater sculpting of the glenoid lip. This is intended to create a series of small fractures which do not extend to the joint surface. We used four sequential openings in our glenoplasties.

Published drawings of posterior glenoplasty show the cut extending from the inferior point on the glenoid up to the superior glenoid tubercle. We found this difficult to accomplish safely, even in a cadaver preparation, due to the position of the scapular spine. Because most posterior instability is in the posteroinferior direction, we centered our osteotomy on this area of the glenoid.

Perhaps the greatest danger when performing a posterior glenoplasty lies in entering the joint with the osteotome, creating a floating wedge of bone, which may lead to avascular necrosis or early arthritis. Several authors recommend directing the cut medially to the glenoid face to avoid penetrating the articular surface. In the laboratory, we were able to make a cut parallel to the joint surface.

Some authors recommend that the bone graft be 1.0 to 1.9 centimeters. A graft this large may be more than

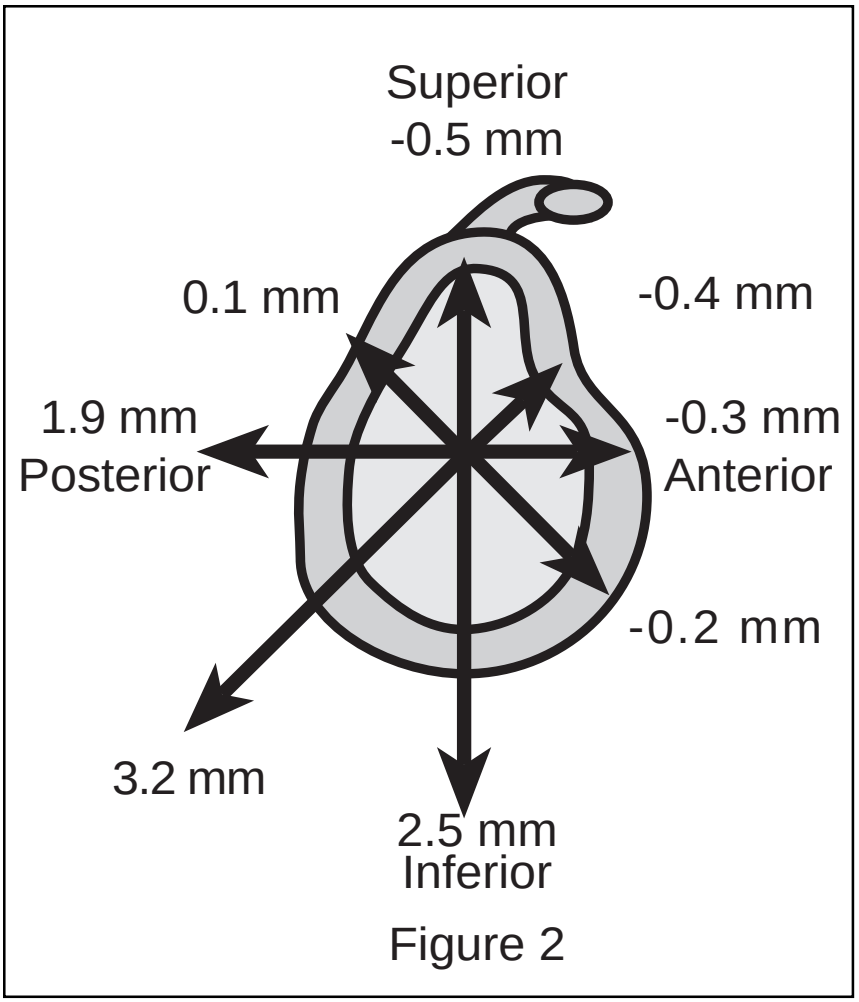


Figure 2

needed for augmenting stability, and may carry a substantial risk of fracturing the glenoid or of abutment of the head against the coracoid. We selected a graft of five millimeters in width. Our data show that this size of graft can substantially change the glenoid contour and increase the stability ratio; it shifted the glenoid center an average of 2.2 millimeters anteriorly and 1.8 millimeters superiorly.

The published donor sites for the bone graft include the posterior acromion, the spine of the scapula, and the iliac crest. We chose a graft from the posterior acromion because it is always within the surgical field.

This report has identified some of the variables in posterior glenoplasty which are under the control of the surgeon. There are other important variables having potentially major effects on the mechanical result which are not under surgical control. These may include the material properties of the bone, the preoperative shape of the glenoid surface, and the size and quality of the posterior glenoid labrum. Even in the carefully controlled conditions of the laboratory, the magnitude of the effects of a standardized glenoplasty varied. Inserting a five millimeter graft in the kerf created by a 1.5 millimeter osteotome increased the effective glenoid depth from two to four millimeters. We suspect that this variability may be due, at least in part, to varying material properties of the bone.

In conclusion, this study demonstrates that posterior glenoplasty can alter the shape of the glenoid and the mechanical stability of the glenohumeral joint. Clinical research will be required to determine the place of posterior glenoplasty in the management of posterior glenohumeral instability, as well as the optimal values for the nine surgeon-controlled variables described here.

Recommended Reading

Bell RH, Noble JS: An appreciation of posterior instability of the shoulder. Clin Sports Med 10:887-899, 1991.

Gerber C, Ganz R, Vinh TS: Glenoplasty for recurrent posterior shoulder instability. Clin Orthop 216:70-79, 1987.

Hawkins RJ, Koppert G, Johnston G: Recurrent posterior instability (subluxation) of the shoulder. J Bone Joint Surg 66-A:169-174, 1984.

Hernandez A, Drez D: Operative treatment of posterior shoulder dislocations by posterior glenoplasty, capsulorrhaphy, and infraspinatus advancement. Am J Sports Med 14:187-191, 1986.

Kretzler HH Jr., Scott DJ Jr.: Posterior glenoid osteotomy for posterior dislocation of the shoulder. In Shoulder Surgery. Bayley I. and Kessel, L., (eds.). Springer-Verlag, New York, pp. 95-97, 1980.

Norwood LA, Terry GC: Shoulder posterior subluxation. Am J Sports Med 12:25-30, 1984.

Scott DJ Jr.: Treatment of recurrent posterior dislocations of the shoulder by glenoplasty. Report of three cases. J Bone Joint Surg 49-A:471-476, 1967.

Legends

1 Representative glenoidograms and maximal slopes before and after glenoplasty.

2 Representation of change in effective glenoid depth resulting from posteroinferior glenoplasty. (Distance between the tip of the arrow and the edge of the glenoid corresponds to degree of change.)

3 Effect of glenoplasty on the effective glenoid depth. Oblique AP views showing the glenoid surface both (A) before and (B) after glenoplasty.

4 Representation of change in the stability ratio resulting from

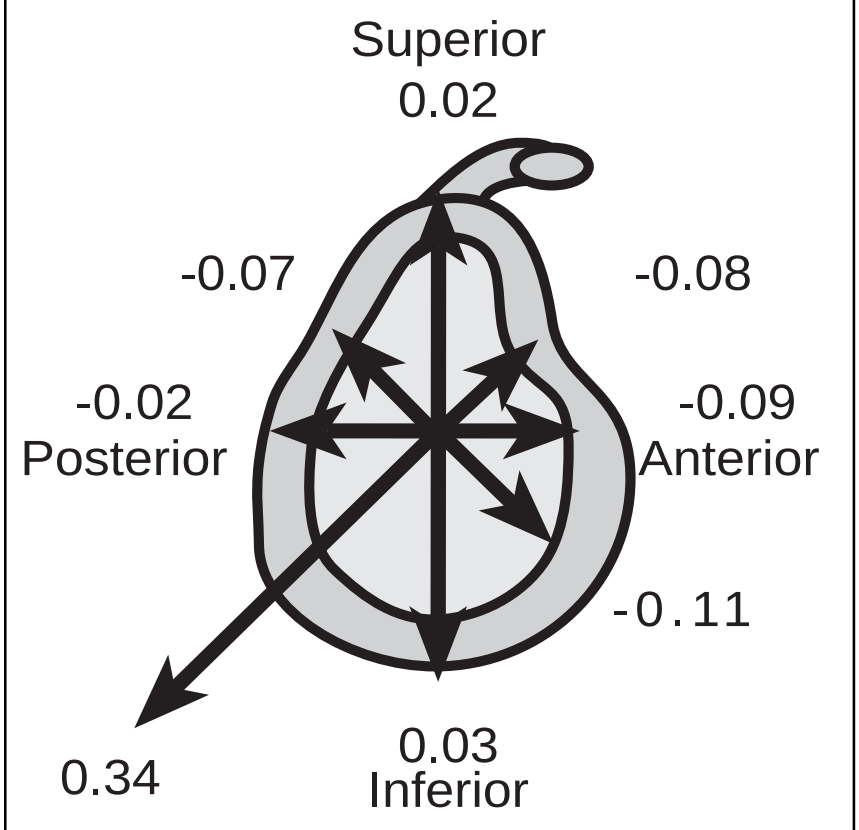


Figure 4

posteroinferior glenoplasty. (Distance between the tip of the arrow and the edge of the glenoid corresponds to degree of change.)

	Superior					Anterosuperior					Anterior				Anteroinferior	
	Inferior					Posteroinferior					Posterior				Posterosuperior	
Specimen	Pre[ε]	Post[ψ]	Diff.[ϕ]	Pre	Post	Diff.	Pre	Post	Diff.	Pre	Post	Diff.	Pre	Post	Diff.	Pre
Post	Diff.	Pre	Post	Diff.	Pre	Post	Diff.									
59 yo ♂, left	6.1	4.9	-1.2	3.9	4.4	0.5	1.4	1.0	-0.4	3.2	3.6	0.4	5.7	8.2	2.5	4.4
7.6	3.2	2.2	3.7	1.5	3.5	2.9	-0.6									
59 yo ♂, right	8.6	8.1	-0.5	6.2	5.7	-0.5	2.6	2.2	-0.4	3.3	3.3	0.0	4.0	8.1	4.1	4.0
8.6	4.6	3.4	6.5	3.1	5.6	5.9	0.3									
69 yo ♀, left	4.5	4.2	-0.3	3.2	2.3	-0.9	3.3	3.0	-0.3	4.8	4.5	-0.3	4.9	5.9	1.0	3.0
4.0	1.0	1.9	2.2	0.3	2.6	2.4	-0.2									
74 yo ♀, left	6.1	6.3	0.2	3.7	3.8	0.1	2.1	2.3	0.2	4.0	4.3	0.3	4.5	6.6	2.1	3.4
6.4	3.0	2.4	4.2	1.8	3.9	4.2	0.3									
70 yo ♂, left	5.9	5.3	-0.6	3.6	3.3	-0.3	1.3	1.5	0.2	2.1	2.1	0.0	3.5	7.0	3.5	3.8
8.6	4.8	2.3	5.6	3.3	2.6	3.0	0.4									
70 yo ♂, right	4.3	4.3	0.0	3.0	2.5	-0.5	2.1	2.1	0.0	5.0	4.6	-0.4	6.1	8.3	2.2	4.6
8.4	3.8	3.2	5.9	2.7	1.4	2.1	0.7									
78 yo ♀, left	3.0	2.2	-0.8	2.4	1.3	-1.1	2.3	0.7	-1.6	3.6	2.5	-1.1	4.3	6.4	2.1	3.1
5.3	2.2	1.1	1.7	0.6	1.2	1.0	-0.2									
MEAN	5.5	5.0	-0.5	3.7	3.3	-0.4	2.2	1.8	-0.3	3.7	3.6	-0.2	4.7	7.2	2.5	3.8
7.0	3.2	2.4	4.3	1.9	3.0	3.1	0.1									
SD	1.8	1.8	0.5	1.2	1.5	0.6	0.7	0.8	0.6	1.0	1.0	0.5	0.9	1.0	1.0	0.6
1.8	1.3	0.8	1.9	1.2	1.5	1.6	0.4									

[ε] Effective glenoid depth prior to glenoplasty (in millimeters)

[ψ] Effective glenoid depth after glenoplasty (in millimeters)

Real Time Animation of Musculoskeletal Joints: An Example Using the 6 Bone Hindfoot Complex

Allan F. Tencer, Ph.D., Randal P. Ching, Ph.D., Richard M. Harrington, M.S., Bruce J. Sangeorzan, M.D.

The motions of many joints of the skeleton are multiplanar, making them difficult to visualize, yet understanding normal and pathologic kinematics is vital to diagnosis, treatment, and rehabilitation. Traditional methods for describing joint motions, typically those found in textbooks, explain motions in terms of separate planar displacements, as single axes in defined directions, as physical models, or as graphical or tabular data.

With the advent of faster computer processors and with the availability of accurate systems to measure 3 dimensional motions, the ability now exists to represent the spatial motions of objects in real time. With new publishing media such as the CD-ROM or the World Wide Web, it is possible to present joint motions in a form which is readily understandable, as 3 dimensional objects moving in space. This report provides some information on the techniques used to produce 3D real time animations and provides some 2D views, showing the motions of the four joint complex of the hindfoot. Video clips can be viewed on the Department of Orthopedics WWW home page (http://www.orthop.washington.edu/).

Methodology

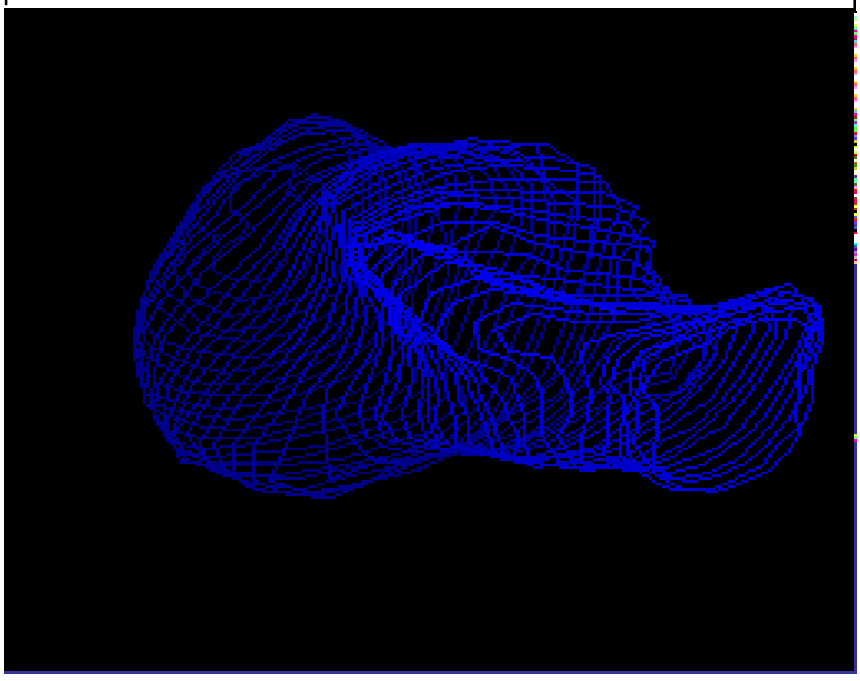
The methodology consists of first developing a spatially and geometrically accurate 3 dimensional model of the bones of the joint of interest, then transferring it to the modeling software, and finally producing the animation. The following describes these steps in more detail, with reference to a model of the hindfoot.

Development of the model

A normal appearing cadaveric foot was selected based on visual and radiographic inspection. The receivers of an electromagnetic motion tracking system (Polhemus Fastrack, Colchester, VT) must be rigidly attached to each bone whose motion is to be tracked. To place the pins, holes were drilled into the talus, calcaneus, navicular, and cuboid, filled with methylmethacrylate and a fenestrated carbon fiber placed into each. Pin positions were chosen so as not to disrupt the normal motions of the joints. Acrylic brackets were mounted to each pin and simulated receivers fixed to each bracket. A simulated transmitter of the electromagnetic sensor was placed on the tibial shaft. In addition, the position of the joints of the foot should be rigidly locked to allow a starting position for the motion measurement to be consistently defined. This assembly allows the bone position and geometry and motion tracker positions to be accurately defined in space from a CT scan.

This assembly was placed into a CT scanner, oriented with the toes facing approximately along the axis of the table and the tibial shaft vertical. A CT scan was taken, with cuts at 1.5 mm intervals. The CT scan data was then downloaded to a laboratory computer. Each slice was decompressed (Decomp, written by Dr. Ching), then loaded into image analysis software (NIH Image 1.47, National Institutes of Health, Bethesda, MD) and the perimeter of each bone in a slice identified by an edge detection routine. The perimeter coordinates file for each bone was then opened in custom software (Polylines, written by Dr. Ching) which defines an equal number of vertex points on each perimeter. This is required in order to construct a shell object connecting the perimeters. In addition, the coordinates of the origin of each receiver and the transmitter of the motion tracking system were determined from the CT slices and recorded. The perimeter model of each bone was opened in software (Rotator 3.5) and inspected, see Figure 1, before being saved in .DXF (drawing exchange file) format. The separate bone models were then transferred to a high speed graphics computer (Indigo^2 High Impact, Silicon Graphics, Mountain View, CA) where they were converted into a proprietary file format for use

Figure 1: A set of perimeters derived from image analysis of the CT scan of a calcaneus before assembly into a shell model.



with a graphics and animation software package (Soft Image, v 3.5, Microsoft Corp., Montreal, Que., Canada). The final step consisted of opening each bone model in Soft Image, skinning the perimeter ribs and adding texture.

Animation procedure

Animation is based on input from the motion tracker system. The system can be sampled by the Indigo[2] through its serial port at a rate which can provide image refresh at 15-20 frames per second, for the four moving bones, each object being modeled by about 600 polygons. This is a sufficient rate of capture to create smoothly moving objects in REAL TIME when the motions being tracked are of moderate speed (about 1 second per motion cycle). Using more simple models or a fewer number increases the rate of speed at which objects can be tracked accurately. Extensive calibration of the motion tracker showed input data errors to be quite low (usually under 1%) and crosstalk small (less than 3%), except in particular directions of motion, which can be avoided when setting up the experiment. Figure 2 shows the complete system with a specimen in place.

Figure 2: The complete setup, with the foot on the left , four sensors in position (at ends of cables) and the computer monitor showing 3 views of the model.

A Preliminary Example

As an example of the capability of the system, two views, from anterior to posterior, of the hindfoot joint complex moving in pronation and supination, are shown. The clips suggest several interesting aspects, although the complete accuracy of some motions are still being assessed. The cuboid appears to move almost as one with the calcaneus. The navicular rotates on the head of the talus while the cuboid swings lateral to the navicular with pronation or inferior to it with supination. A small amount of talar motion was also present because the foot was not loaded when it was displaced.

This system will be used to study midtarsal motion as well as the effect of defined lesions and surgical procedures. Similar analyses of motion of the upper extremity and the atlanto-occipital-axial complex are being developed. It is clear that this system is a powerful tool for visualizing musculoskeletal joint motion.

It is anticipated that this system will facilitate our understanding of normal and pathological joint motion as well as the cinematic effects of treatment.

Magnetic Resonance Force Microscopy

John A. Sidles, Ph.D.

Magnetic resonance force microscopy (MRFM) is a new medical research technology that was first conceived in 1992 by Department of Orthopaedics faculty member John Sidles.

The goal of MRFM technology is to provide the medical research community with new and incredibly powerful microscopes - microscopes powerful enough to image individual molecules within living cells.

The UW MRFM Research Group is a world leader in developing MRFM technology. It is jointly led by faculty members John Sidles of the Department of Orthopaedics and Joe Garbini of the Department of Mechanical Engineering.

The mission of the MRFM Research Group is easy to state - we are working to create a molecular imaging technology that is:

(1) non-destructive,

(2) fully three-dimensional,

(3) with single-atom spatial resolution,

(4) of individual molecules within cells.

The pace of medical research will be greatly speeded if these goals can be achieved. We particularly look forward to applying MRFM technology in the study of difficult-to-treat disorders relating to orthopaedics, like diabetes, arthritis, musculoskeletal tumors, the repair and healing of cartilage injuries, and HIV disease.

What Scientific Challenge Does MRFM Address?

Figure 1 illustrates the gap between what medical researchers can see with present microscope technology, and what medical researchers would like to be able to see. The top-left frame is an electron micrograph showing HIV viruses (the round objects) entering a human immune cell (the gray area at lower right in the frame). The magnification of this image is near the practical limit of electron microscopy.

What would medical researchers see if they had a technology which could image even smaller structures than viruses, so that details of the cell-virus interaction were visible? To show what they would see, we will enlarge the orignal HIV image three times. At each enlargement we add (by the magic of computer photography) some of the many molecules that medical researchers would like to image directly, but cannot see with their present instruments.

The frame at upper right shows the first six-fold enlargement. The micrograph has been made translucent

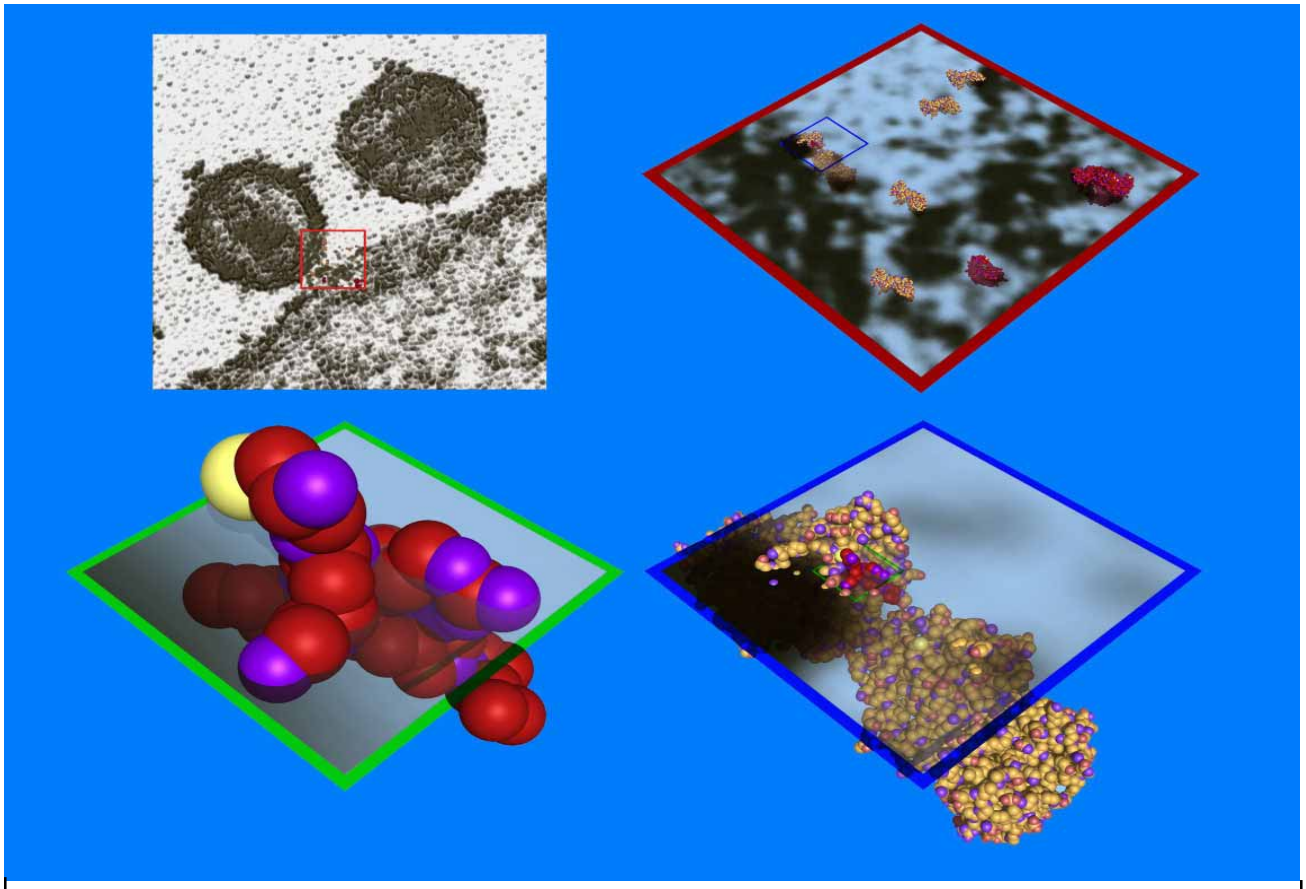


Figure 1: An illustration of the gap between what medical researchers can see with present technology and what they would like to see.

and rotated on its side, and several HIV-related proteins have been composited into the image. The protein images were created from crystallographic data downloaded from the Brookhaven Protein Data Bank.

The two proteins inside the lymphocyte (at lower right within the frame) are HIV protease and HIV reverse transcriptase. These are the two HIV proteins whose structure is best-understood from x-ray crystallography. A barely visible dot bound to the protease molecule is a new drug being tested for its ability to inhibit protease. The four elongated molecules spread in a diagonal line along the lymphocyte cell membrane are CD4 molecules. CD4 is a membrane-bound protein that helps lymphocyte cells recognize each other.

The outer envelope of the HIV virus includes a protein called GP120 which has a strong binding affinity for CD4. This binding is thought to allow the entry of HIV into the human immune system. If a structure for GP120 were available, we would have included images of GP120 in the form of an array of molecules around the outer envelope of the HIV viruses. Unfortunately, GP120 is very difficult to crystallize, and so no structure is presently available. Instead, we have included a mouse antibody bound to a fragment of GP120. This binding represents our best current understanding of the structural mechanism by which antibodies neutralize HIV viruses in the bloodstream.

A further 6X magnification shows the neutralizing antibody in greater detail (lower right frame). The antibody is bound to a synthetic fragment of GP120 (darker-colored). Note how GP120 fragment is tightly bound to a complementary-shaped crevice in the antibody; this three-dimensional "lock-and-key" binding is how antibodies neutralize foreign proteins. The black blob at upper left which partially obscures the antibody molecule is the residual resolution of the original electron micrograph.

The final 6X magnification (lower left frame) shows the GP120 fragment in isolation. The shape of GP120 represents a three-dimensional "key" to which designers of drugs and vaccines must find a three-dimensional "lock". The net magnification of this final frame, relative to the original micrograph, is a factor of 6x6x6 = 216.

The goal of the UW MRFM Research Group is to allow medical researchers to directly image <u>all</u> the structures which are visible in Figure 1. If this can be achieved, we will have solved one of the biggest challenges in modern applied physics and engineering.

How Does MRFM Technology Work?

Figure 2 shows a typical MRFM apparatus. A cantilever with a magnetic tip on the end scans over a sample (in this case, the same sample as illustrated in the previous figure). The force between the magnetic tip and the spins in the sample is modulated by a radio field generated by the large copper coil. In response to this changing force, the cantilever begins to vibrate up and down. This vibration is detected by a laser beam which illuminates the cantilever.

Everything shown in the figure fits comfortably into a volume of less than one cubic millimeter. Thus MRFM experiments are always assembled by hand, under a microscope. Overall, an MRFM device has about the same size and complexity as a laser printer — provided the laser printer operates at liquid helium temperature in a high vacuum!

Figure 3 shows, in accurate scale, the magnetic interaction between an MRFM device's magnetic tip and a nearby molecule. The magnetic tip is the large ball at the top of the illustration; it is 300 Angstroms in diameter. Fifty Angstroms below the tip is a GP120 fragment bound within a crevice of the larger antibody molecule (this is the same antibody/GP120 complex as was shown in the first illustration).

MRFM achieves three-dimensional imaging by a slice-selection "trick" that is also used in conventional magnetic resonance imaging. The basic idea is that spins that are very close to the MRFM tip find themselves a strong magnetic field — a field that is too strong for spin resonance. These too-close spins therefore generate no force signal. Similarly, spins that are too far from the tip are in a weak magnetic field — too weak for spin resonance — and these spins also generate no signal. The only spins that generate a signal are the spins within a sensitive slice (the transparent dish), where the field strength allows resonant spin interactions. Under MRFM conditions the slice thickness can be an Angstrom or less. By scanning this sensitive slice through a sample, three-dimensional reconstructions can be obtained. Conventional magnetic resonance imaging works in a similar manner, except that the slices are roughly one million times thicker.

The forces generated by individual spins are extremely tiny, of order 10^{-17} Newtons, which is roughly one million times less than the forces detected in a typical force microscope experiment. This force is to the weight of a feather as the weight of a feather is to the weight of Hoover Dam! The main technical challenge in MRFM research is the detection of these extremely tiny forces.

What is the Present Status of MRFM?

Since 1992, our UW MRFM Research Group has made great progress toward the goal of single molecule imaging. Our most recent MRFM instrument has enough sensitivity that single-molecule imaging should be achievable, in the special case that the molecules in the sample are labeled with what are called "spin labels" (spin labels are molecules that are specially-designed to have unpaired electrons).

If successful, these experiments will take magnetic resonance imaging to its ultimate limit: one spin in one voxel. This would be a breakthrough experiment, but at present it is impossible to say when this breakthrough will be achieved: it could happen in one month, one year, or next century. This uncertainty is a fact of life in medical research.

Just as important as "breakthrough" MRFM experiments are steady improvements in MRFM sensitivity, device design, and theoretical understanding. Up to the present time, every MRFM experiment and every MRFM device have performed according to theoretical expectations. If this continues in the future, then single-molecule MRFM imaging will become a reality in the next few years.

Several other MRFM Groups have come into being — at IBM Almaden Laboratories, Los Alamos, NIST, the Army, Cal Tech, and in Europe. Our UW Group remains the <u>only</u> MRFM

group that is affiliated with a School of Medicine and that is exclusively devoted to medical research. This reflects the origins of MRFM, which was conceived by Dr. Sidles specifically as a tool in the service of medical research.

What is the Future of MRFM Research?

The highly-regarded textbook "Molecular Biology of the Cell" describes why instrumentation research is crucial to the overall progress of medical research:

Cells are small and complex. It is hard to see their structure, hard to discover their molecular composition, and harder still to find out how their various components function. What we can learn about cells depends on the tools at our disposal, and major advances in cell biology have frequently sprung from the introduction of new techniques.

from Alberts et al., "Molecular Biology of the Cell" (1994, 3rd edition, chapter 4, page 139)

Developing a major new biomedical technologies requires years of hard work by a community of researchers. For example, of ten major instrumentation technologies reviewed by Alberts et al. (op cit.), none were developed in less than twenty five years, none were developed by just one person or group, and none were achieved by a single "breakthrough". We expect that MRFM will develop according to this same paradigm. Table 1 summarizes our vision of the future of MRFM.

If the goals of MRFM research can be achieved, researchers will be able to determine the structure of individual biological molecules with the same ease and comprehensive power with which they presently determine individual gene sequences, using a device which sits on a tabletop, and which has roughly the same part count and complexity as a laserprinter.

How Will People's Lives Be Affected By MRFM?

The medical research community is presently preparing a comprehensive database of the human genome (this is the well-known Human Genome Project). We anticipate that MRFM technology will eventually enable the creation of a similar structural database, a database cataloging the structure of all human biological molecules. The "Human Structural Biology Project" that we envision will complement and extent the power of the Human Genome Project.

Knowing more about the structure of biological molecules will help orthopaedists develop cures for diseases which at present we can only diagnose (like diabetes, rheumatoid arthritis, cartilage injury, and tumors). Hopefully, a few decades in the future, all of the above diseases and many more will be entirely curable — contributing to this goal is the main motivation for MRFM research.

The overall mission of the UW MRFM Research Group is thus the same as the mission of the National Institutes of Health: *"to uncover new knowledge which will lead to better health for everyone".*

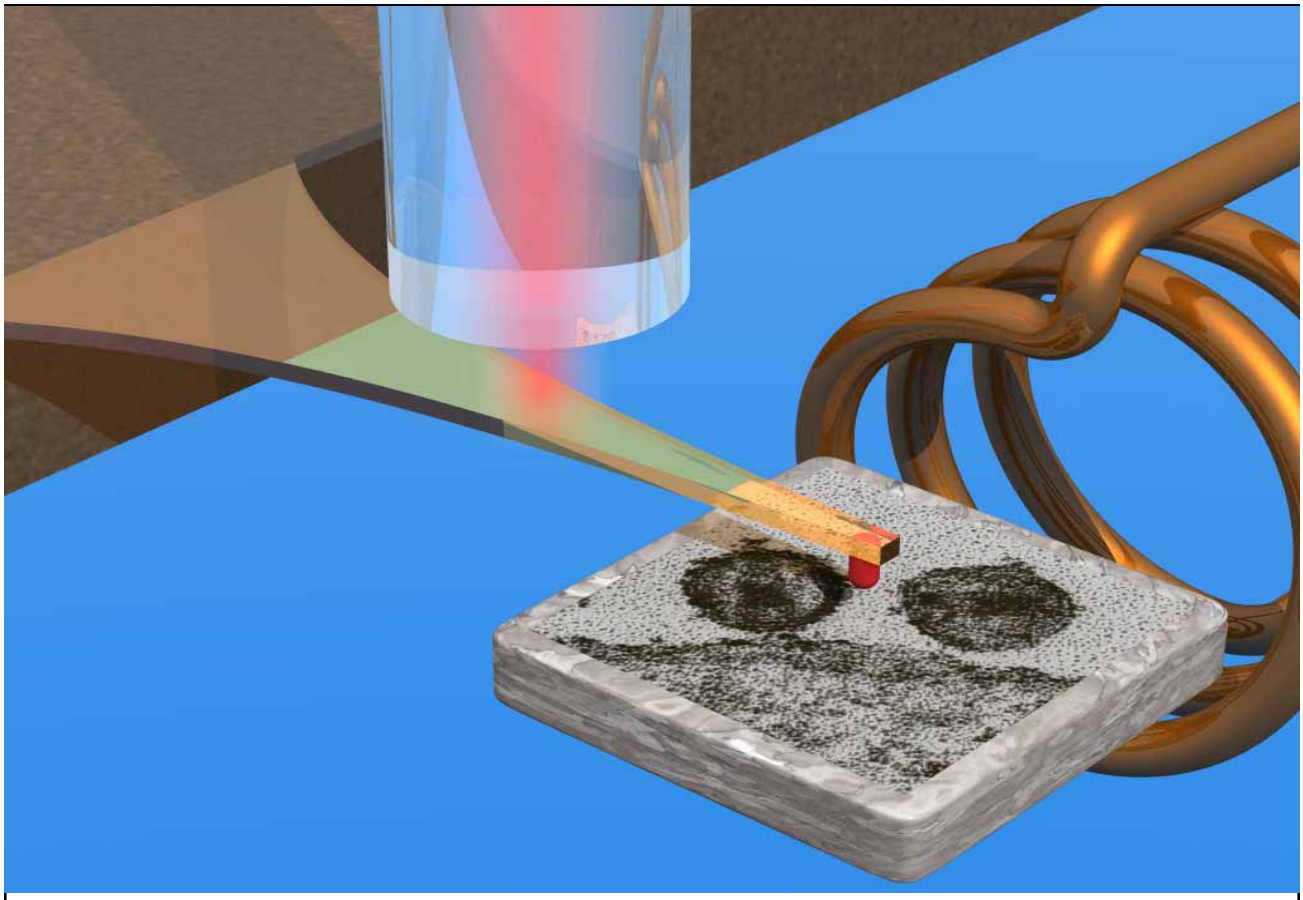


Figure 2: A typical MRFM apparatus. A cantilever with a magnetic tip scans over a sample as a radio field is generated by a large copper coil.

Table 1: Major Steps in the Development of MRFM Technology: Past, Present, and Future

Past Major Steps

1982 **Binnig and Rohrer** demonstrate that scanning probe microscopy can achieve atomic resolution, and thus span the 1-100 Angstrom imaging gap.

1992 First successful MRFM experiment, achieved by researchers **John Sidles** of the University of Washington and **Dan Rugar** and **Nino Yannoni** of IBM Almaden Research Laboratories

Present Major Step

199X First detection and imaging of **single electron** moments.
(This is the experiment that is presently being attempted by our UW MRFM Research Group, and independently by the IBM MRFM group led by Dan Rugar.)

Future Major Steps

200X First detection and imaging of **single proton** moments.
(Protons signals are smaller than electron signals, so this will be a major experiment.)

200X First determination of a **protein structure** from microscopic examination of a single protein molecule *in situ*, and deposition of this structure in the Protein Data Bank.

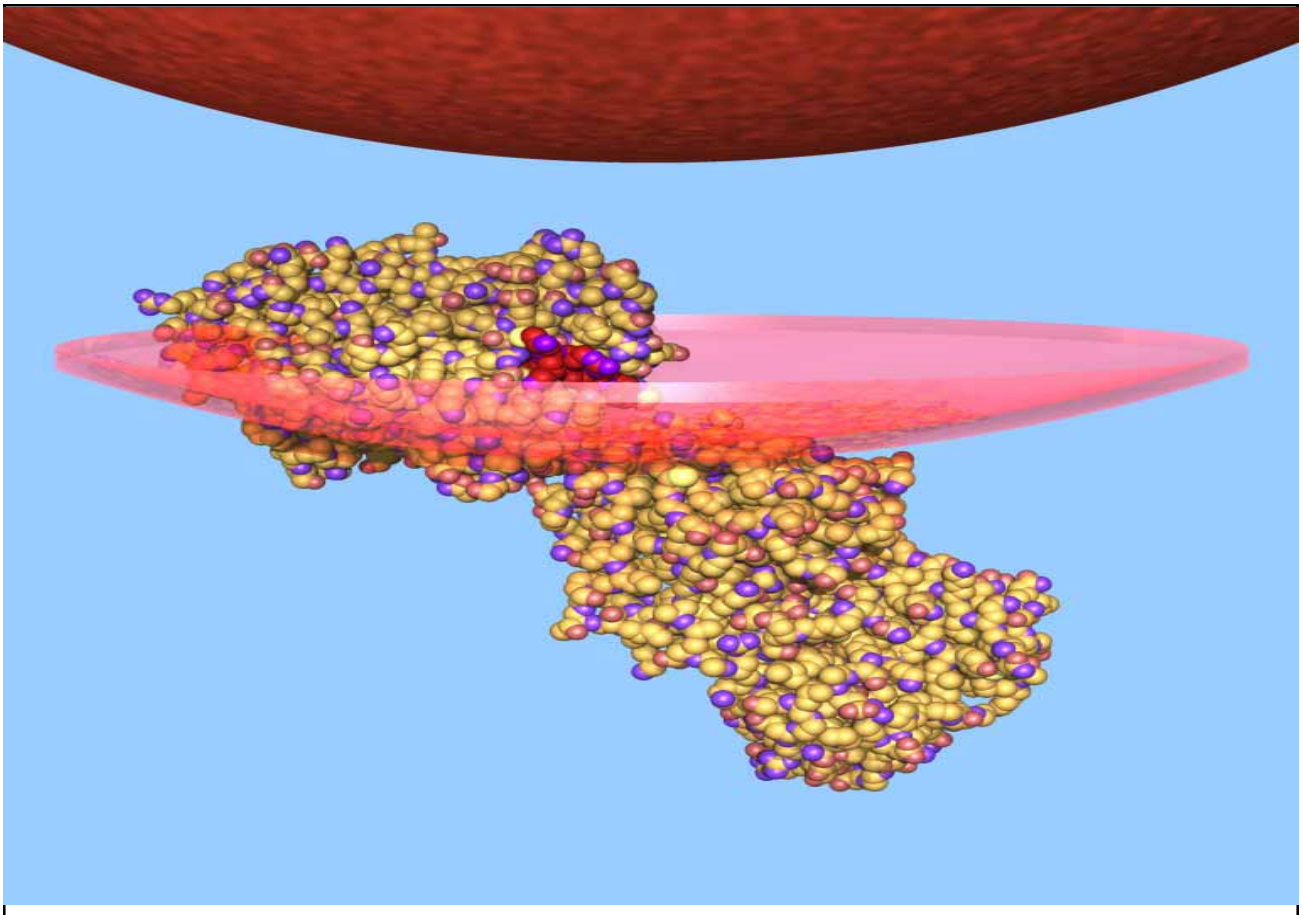


Figure 3: The magnetic interaction between a MRFN device's magnetic tip and a molecule.

Acknowledgments

We thank Prof. Jim Koehler of the University of Washington Department of Biological Structure for supplying this photomicrograph.

Specifically, the original image is enlarged by three successive powers of six, to yield a final image (at lower left) that spans 16 Angstroms on a side.

The protein images were created from crystallographic data publically available as Protein Data Bank entries 1CID, 1GGI, 1HNI, and 7HVP. For further information see the Protein Data Bank web page at "http://pdb.pdb.bnl.gov/index.html".

To fit all the components of an MRFM device into one picture, we have taken some liberties with scale. The magnetic tip and the sample are shown about 50 times larger than they really are. Also, the cantilever is drawn too thick ... the cantilever thickness should be only ~1/1000 of the length.

The format of this Table is borrowed from Alberts et al. (op cit.), see for example Tables 4-1 through 4-9 and Table 7-1 of Albert's textbook for a historical review of other major biomedical technologies.

Assessing Patient Outcomes in Orthopaedic Surgery; Issues and Techniques

MARC F. SWIONTKOWSKI, M.D.

The "end-result" concept was introduced by Codman in the 1920's. This Massachusetts General Hospital staff Orthopaedist felt that each hospital and the surgeons that worked there should be evaluated based on the functional improvements they provided their patients. Traditionally, orthopaedic clinical research has focused on the results of treatment from the surgeon's perspective. This has resulted in a major void in our literature - a lack of evidence to base treatment decisions and recommendations upon.

To evaluate the result of treatment from the perspective of the physician, the patient and the payer, several types of "end results" or outcomes must be assessed. Clinical outcomes, functional outcomes , patient satisfaction and cost must be addressed. Clinical outcomes include ROM, strength, radiographic results, joint stability, etc.- issues all orthopaedic surgeons are all familiar with. Most Orthopaedic specialty societies have addressed these issues and have come up with standardized formats for collecting these clinical data. Functional outcomes are assessed with patient-completed questionnaires that deal with all realms (or domains) of human function. These include ADL's, pain, role function, work activities, etc. In order for the questionnaire to assess these issues accurately, it must be validated. Finally, brief patient satisfaction questionnaires have been developed which assess the patients' satisfaction with the process of care - phone responsiveness, ease of making appointments, interaction with the treating physician, etc. Cost is self-explanatory and is the major driver for treatment decisions in the managed care environment.

Development and Testing of Patient-Oriented Functional Assessment Tools

Questions that are reflective of patient function cannot simply be developed based on clinical experience. Questionnaires developed in this fashion (by orthopaedic surgeons generating questions which they feel are relevant to patients) miss many important functional issues of great importance to patients. Guyatt has described the steps in the development of a functional assessment questionnaire.

-Item development: The patient population to be evaluated must be described and then functional issues of concern to this group selected from interviewing patients and clinicians experienced in treating them or alternatively, selected from a literature and published questionnaire review. The former process is more expensive and time consuming but is preferable because it limits the risk of missing functional issues of relevance to patients. Items are generally written for an eighth grade reading level.

-Item reduction: By frequency and importance of item endorsement in a sample patient cohort or by statistical methods such as factor analysis.

-Format selection: Scaled responses vs. endorsed statements vs. visual analog scales (VAS). Endorsed statements are easiest for patients (yes this is true for me or no it is not). Scaled (Likert) responses yield more sensitivity but are more difficult for patients. VAS are the most sensitive but produce data handling problems.

-Pretesting: Administration with an interviewer present to discover poorly worded or confusing items.

-Reproducibility and responsiveness: Reproducibility is evaluated by reviewing the variability in responses in relation to the variability in clinical status determined at the time the questionnaire is completed. Responsiveness is the measure of the questionnaires' ability to detect clinically important changes even if they are small. This is addressed by a "test-retest" exercise where the same patients complete the questionnaire twice in a short interval where no clinical change has taken place. The second exercise involves administering the questionnaire twice at a minimum three month interval after a clinical intervention of known efficacy.

-Validity: Face validity is assessed by clinician review, construct validity is assessed by developing hypotheses about how the scores should change between and within subjects and comparison with already validated instruments. Criterion validity is addressed by comparing scores with objective tests and clinician evaluations of the same group of patients.

Validated Questionnaires for Use With Musculoskeletal Conditions

-SF-36: A 36 item self-administered questionnaire developed by Ware et al. It takes 5-7 minutes to complete and has been used with increasing frequency to assess musculoskeletal function.

-SIP: The Sickness Impact Profile is a 136 item endorsed statement questionnaire which takes 20-25 minutes to complete; it was developed by Bergner et al and has been used to assess function for patients with extremity injury.

-WOMAC: This questionnaire was developed and validated for use in arthritis patients at the University of Western Ontario by Bellamy et al.

-MFA: A 100 item endorsable statement questionnaire which takes 15 minutes for the patient to complete and has demonstrated increased sensitivity over the SF-36 and SIP for extremity conditions. It was developed by Martin et al and can be used for all extremity conditions including arthritis.

-AAOS Instruments: Four regional instruments are under validation testing at this time. The four will be Spine, Upper and Lower Extremity and Pediatrics. Because of the larger number of items for each region it is expected that these instruments will have greater sensitivity than the above more general health status instruments.

-Condition Specific Instruments: Questionnaires have been developed and tested for specific musculoskeletal conditions such as carpal tunnel syndrome. These will, of course, have

the greatest sensitivity in evaluating the conditions for which they were developed.

The issue of which questionnaire to use is an important one. This question can only be answered when the specifics of the outcomes assessment project are known. If the project is to assess functional outcomes of a specific condition where there is a validated instrument- that instrument should be used, as with carpal tunnel syndrome. If the individual surgeon is assessing outcomes for several procedures all of which are in the upper extremity, then the AAOS upper extremity instrument (also known as the DASH- disabilities of the shoulder arm and hand) would be a good choice. If there are multiple Orthopaedic surgeons in a group who would like to assess outcomes for several musculoskeletal conditions in both upper and lower extremities as well as the spine, the MFA would be a good choice. Finally, if the individual practices in a group practice environment where physicians are assessing clinical outcomes for multiple medical conditions, the SF-36 would be a wise choice. When selecting an instrument to use, practicality is an important consideration. One should select the shortest validated instrument available when assessing outcomes in the clinical setting. For greater sensitivity, in funded research projects, longer instruments may be a better choice.

Recommended Reading

Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt L: Validation study of WOMAC: A health status instrument for measuring clinically-important patient relevant outcomes following total hip or knee arthroplasty in osteoarthritis. *J Orthop Rheumatol* 1988, 1:95—108.

Bergner M, Bobbitt RA, Kessel S, Pollard We, Gilson BS, Morris JR: The Sickness Impact Profile: conceptual formulation and methodology for the development of a health status measure. *Ann Rev Public Health* 1976, 8:191—210.

Guyatt GH, Kirshner B, Jaeschke R: Measuring health status: what are the necessary measurement properties? *J Clin Epidemiol* 1992, 45:1341—1345.

Patrick DL, Bergner M: Measurement of health status in the 1990's. *Ann Rev Public Health* 1990, 11:65—83.

Ware JE, Sherbourne CD: The MOS 36 item short-form health survey (SF-36). *Medical Care* 1992, 30:473—483.

Tetraplegia Can Be Reversed With Immediate Reduction in Cervical Spinal Dislocations

Sohail K. Mirza, M.D., Jens R. Chapman, M.D., Paul A. Anderson, M.D., M. Sean Grady, M.D., and David Newell, M.D.

Complete tetraplegia following cervical spine injuries is associated with a prognosis of minimal neurologic recovery. We report three patients who paralysis below the level of injury following a cervical spine fracture dislocation who made full neurologic recovery after closed reduction within two hours of injury. Neurologic recovery following complete tetraplegia is reviewed. We recommend immediate closed reduction with cervical traction for patients presenting with these injuries.

Introduction

Recent studies of the pathophysiology of spinal cord injury in animal models and clinical trials of early treatment interventions in patients with a spinal cord injury provide the basis for a more optimistic outlook for patients sustaining acute traumatic tetraplegia. Gillingham reported on one patient with complete tetraplegia following a cervical fracture dislocation who showed some neurologic recovery with reduction of the cervical fracture within two hours of injury. He advocated early reduction of the spinal deformity. We report three patients with cervical spine dislocations and complete motor paralysis on initial post-injury examination who progressed to full motor recovery following immediate reduction of the cervical dislocation within two hours of the onset of their neurologic deficit.

These cases support arguments for early correction of spinal canal compromise in patients with cervical spinal cord injuries. They illustrate clinical evidence of an early "window of opportunity" in some patients with spinal cord injuries in which their neurologic deficit may be improved or reversed with rapid intervention and correction of spinal column deformity. Some authors have cautioned about the risk of disc herniation in patients with bilateral facet dislocation and advocated pre-reduction MR imaging. Delay in early reduction in patients with evident cord injuries, however, may entail permanent loss of an opportunity for early intervention and improvement in their neurologic impairment.

Case Reports

Case 1: SG

An 18 year old female high school student fell from uneven bars during gym practice, sustaining a hyperflexion injury to her neck. On arrival of the paramedics, she complained of neck pain, numbness in her lower extremities, and inability to move her lower extremities. Examination in the emergency room ninety minutes following the injury showed neck tenderness with a palpable step-off and C7 motor and sensory level complete tetraplegia. ASIA Motor Index Score was 38, Pin Prick Score 34, Light Touch Score 34, and an Frankel Impairment Level A. She had intact rectal tone, and no sacral sensation, no motor function below T1.

The initial lateral cervical radiograph showed bilateral facet dislocation between the sixth and seventh cervical vertebrae. Dexamethasone IV (10mg) was administered and cervical traction Gardner-Wells tongs applied. Closed reduction was performed with progressive weights. She had return of sensation in both lower extremities and motor function in the right lower extremity with traction at 35 lb. at 2 hours and twenty minutes following the injury. Reduction was achieved with 70 lb. of traction at 3h post injury. Examination following reduction showed intact sensation to L5 dermatome bilaterally, return of perianal sensation, and trace motor function in the proximal right lower extremity.

Myelography and CT scan following reduction showed no canal compromise. The patient underwent posterior C6-C7 wiring and fusion fourteen days following the injury. She was discharged 24 days following the injury, at which time she her neurologic status had evolved into a Brown-Sequard Syndrome. At the time of discharge she had fully recovered right lower extremity motor function with ipsilateral diminution of pin prick sensation, but had left lower extremity motor deficit with preservation of pin prick sensation. At follow-up evaluation 3 months post injury she had fully recovered left lower extremity motor function with persistent mild dysesthesia remaining in the right lower extremity. Ten years following the injury she is working full time as a physical therapist with no apparent neurologic deficit.

Case 2: VB

A 60 year old male writer slipped and fell on stairs at home. He noted pain in the neck area and complained of a tingling sensation in both upper extremities to the paramedics. Examination in the emergency room twenty minutes following the injury showed neck tenderness with a palpable hematoma, left triceps 4/5 weakness and decreased pin prick and light touch in the left C7 dermatome. ASIA Motor Index Score was 99, Pin Prick Score 111, Light Touch Score 111, and an Impairment Level E.

The initial lateral cervical radiograph showed bilateral facet fracture-dislocation at the C6-7 level. Two hours and fifty-five minutes following the injury, the patient began to complain of weakness in both upper and both lower extremities. Examination showed complete C6 level tetraplegia. ASIA Motor Index Score was 14, Pin Prick Score 20, Light Touch Score 20, and Frankel Impairment Level A. Methylprednisolone was started immediately. Garner-Wells tongs were applied and traction initiated fifteen minutes following the onset of tetraplegia. Reduction was achieved at 102 lb. at one hour and fifteen minutes following the onset of tetraplegia (four hours and fifteen minutes following the

injury). Examination following reduction showed full return of sensation throughout and return of motor function in both upper and both lower extremities, with some weakness in wrist extension, grip, finger abduction, and hip flexion bilaterally.

Myelography and CT scan following reduction showed anterior thecal sac compression with cord deformity at the C6-C7 level, consistent with herniated nucleus pulposus or hematoma at that level. The patient underwent anterior decompression with removal of an extruded disc fragment at the C6-C7 level followed by fusion and internal fixation with a Morscher plate. The patients neurologic status remained essentially unchanged post-operatively with persistent mild upper extremity weakness bilaterally. He was discharged eight days following the injury. Follow-up four months following the injury showed full neurologic recovery.

Case 3: RP

A 43 year old male forklift operator sustained a crush injury to his left head and neck from a 1000 lb. falling crate. He did not loose consciousness. On arrival of paramedics, he complained of tingling throughout but was able to move all extremities. En route to the emergency room he noted weakness in both upper extremities and both lower extremities. Examination in the emergency room twenty minutes following the injury showed neck tenderness with a palpable step-off, a C5 motor level and a C7 sensory level with sacral sensory sparing. ASIA Motor Index Score was 12, Pin Prick Score 70, Light Touch Score 70, and an Impairment Level B. He had intact rectal tone but no motor function below C7.

Initial lateral cervical radiograph showed bilateral facet dislocation at C5-6. Gardner-Wells tongs were applied and closed reduction performed with progressive weights, serial radiographs, and slight neck flexion and rotation. Reduction was achieved within 90 minutes following the injury with 45 lb. traction. Over the subsequent three minutes, the patient had full return of neurologic function with the exception of persistent paresthesia in the C7 distribution and grade 3/5 triceps weakness bilaterally.

Myelography and CT scan following reduction showed no canal compromise. The patient underwent posterior C5-C7 wiring and fusion five days following the injury. He was discharged 16 days following the injury with continued paresthesias in the C7 distribution and 4/5 triceps weakness. At one year and three year follow-up, the patient had complete neurologic recovery with resolution of the sensory disturbance, return of triceps strength, and return to full time employment.

Discussion

The patients reported all presented with complete loss of motor function below the level of injury on initial examination. All three of the patients showed immediate improvement during the initiation of cervical traction (case 1) or with reduction of the cervical dislocation (case 2 and case 3). Cervical traction was initiated within 105 minutes in all patients and reduction was achieved in less than 140 minutes following the injury. One patient did not receive steroids but still had full motor recovery.

Brunette reported on one patient sustaining a complete cervical spinal cord injury with C4 neurologic level on initial examination who recovered full motor strength in the lower extremities at the time of discharge three weeks post-injury. This patient sustained a C3-4 fracture dislocation that was reduced with Gardner - Wells tongs traction at 90 minutes post injury. This report was the first in our review to clearly demonstrate the excellent capacity for recovery following a spinal cord injury despite a complete motor deficit on initial presentation.

Frankel et al. reported on 218 patients with cervical injuries. Their report included 123 patients with initially complete neurologic lesions. None of these patients recovered full motor function. A small number of theses patients, however, showed some useful motor function return below the level of the lesion. The article does not specify whether this signified root recovery below the lesion or return of lower extremity motor function. Gillingham reported briefly on one patient with an initially complete cervical lesion who was treated with traction within two hours of injury and reduced in six hours who recovered some motor function in his toes. He attributed the result to early institution of steroid treatment and reduction. Shrosbee reported on 302 cervical fracture dislocations. He reported that 16% of patients with complete injuries "showed significant neurologic recovery." Again, distinction was not made whether this represented return of root function or lower extremity motor function. The tables in the report show no patients recorded as Frankel grade A making full motor recovery. Neurologic status in each group, however, was not clear and no follow-up was mentioned in their report. Kiwerski reported on 308 patients with traumatic injuries of the cervical spinal cord and noted that 18% of the patients with complete spinal cord injuries showed improvement in neurologic status. The degree of motor recovery is not specified; however one table in their report shows that 7/221 were able to ambulate with a crutch or stick.

Eismont et al. reported on six cases of neurologic deterioration after reduction of cervical spine dislocation secondary to extrusion of an intervertebral disc. They strongly advocated imaging studies prior to reduction in any patient with a neurologic deficit to assess the injured disc. They recommend anterior discectomy prior to reduction if a disc prominence is noted. Rizzolo et al. reported MRI findings of disc disruption in 23/55 patients with cervical spine injuries and recommended an MRI prior to treatment to assess for this problem in patients with a deteriorating neurologic status or an incomplete cord injury. The report showed no correlation of this finding to neurologic recommended MRI prior to reduction and anterior discectomy if the study showed disc herniation. The study, however, presented no evidence to indicate a worse outcome with closed reduction or a better result with anterior discectomy and fusion. Robertson and Ryan reported three patients with neurologic deterioration following closed reduction. All three patients recovered following removal of herniated disc tissue. They recommended that neurologic deterioration following reduction should be investigated for possible compression by disc tissue. Cotler et al. in a prospective study of 24 patients reported successful closed reduction in all patients with no patients showing

neurologic deterioration following reduction. Time from injury to reduction was not reported, although most patients were reduced on the day of injury. Lee et al. reviewed 210 patients with cervical spine dislocations who underwent reduction with rapid traction. The minimum time from injury to reduction was 12 hours. No patient showed neurologic deterioration and early reduction was associated with improved neurologic recovery. They concluded that early reduction was safe and effective and should not be delayed to obtain complex imaging studies.

The patients presented in this report demonstrate that complete motor neurologic deficit on initial examination following a spinal cord injury does not necessarily predict a poor neurologic recovery. These patients have been described as being in a state of spinal shock. Assessment of sacral sparing and rectal tone may be unreliable in alert and cooperative patients; it may impossibly inaccurate in an uncooperative patients or patients with impaired mental status. This diagnostic uncertainty about the actual underlying neurologic status should not delay definitive treatment measures. There is no rational justification for delaying reduction in a patient with a cervical fracture dislocation who presents with a complete motor deficit. Concerns of further neurologic deterioration are irrelevant in a patient with a complete motor deficit. Reports of further neurologic deterioration in patients with some preserved motor function on initial examination are rare and are counterbalanced with more numerous reports of no neurologic deterioration following early closed reduction. A patient with an intact neurologic exam and persistent mal-alignment of the cervical spine, in contrast, presents a very different clinical situation. Neurologic deterioration is very much the overriding concern in such a patient, and further diagnostic measures should be pursued to prevent possible compromise of the space available for the cord with reduction maneuvers. These patients should be maintained in cervical traction for protection and an MRI scan performed to rule out disc herniation prior to cervical reduction measures.

Conclusions

Full neurologic recovery is possible after cervical spinal cord injuries presenting as complete tetraplegia on initial examination. There may exist a window of opportunity within the first few hours following a spinal cord injury in which it may be possible to significantly improve or reverse the neurologic deficit. Rapid closed reduction with traction is safe and effective. Patients presenting with a neurologic deficit following a cervical spine fracture dislocation should be reduced as quickly as possible. Complex imaging studies such as MRI should not delay reduction in patients already manifesting a neurologic injury. The benefit of early reduction and spinal re-alignment appear to outweigh the risks.

Recommended Reading

Bracken MB, Shepard MJ, Collin WF, et al.: A Randomized, controlled trial of methylprednisolone or naloxone in the treatment of acut spinal cord injury. NEJM 1990; 322:1405-1411.

Delamarter RB, Sherman JE, Carr JB: Spinal Cord Injury: The pathophysiology of spinal cord damage and subsequent recovery following immediate or delayed decompression. Presented at annual meeting of the CSRS. December 1-4, 1993.

Brunette DD, Rockswold GL: Neurologic Recovery following Rapid Spinal Realignment for Complete Cervical Spinal Cord Injury. J Trauma 1987; 27(4):445-447.

Frankel HL, Hancock DO, Hyslop G, Melzak J, Michaelis LS, Ungar GH, Vernon JDS, Walsh JJ: The value of postural reduction in the initial management of closed injurioe of the spine with paraplegia and tetraplegia. Paraplegia 1969; 7:179-192.

Gillingham J: Letter. J Neurosurg 1976; 44:766-7.

Shrosbee RD: Neurologic sequelae of reduction of fracture dislocations of the cervical spine. Paraplegia 1979; 17:212-221.

Kiwerski J, Weiss M: Neurologic improvement in Traumatic Injuries of the Cervical Spinal Cord. Paraplegia 1981; 19():31-37.

Eismont FJ, Arena MJ, Green BA: Extrusion of an Intevertebral Diac Associated with Traumatic Subluxation or Dislocation of Cervical Facets. JBJS-A 1991; 73A(10):1555-1559.

Rizzolo SJ, Piazza MR, Cotler JM, Balderston RA, Schaefer D, Flanders A: Intervertebral Disc Injury Complicating Cervical Spine Trauma. Spine 1991; 16(6):S187-S189.

Doran SE, Papadopoulos SM, Ducker TB, Lillehei KO: Magnetic Resonance imaging documentation of coexistent traumatic locked facets of the cervical spine and disc herniation. J Neurosurg 1993; 79:341-345.

Robertson PA, Ryan MD: Neurologic Deterioration after Reduction of Cervical Subluxtation. JBJS-B 1992; 74B(2):224-7.

Cotler JM, Herbison GJ, Nasuti JF, Ditunno JF, An H, Wolff BE: Closed Reduction of Traumatic Cervical Spine Dislocation using traction weights up to 140 Pounds. Spine 1993; 18(3):386-390.

Lee AS, MacLean JCB, Newton DA: Rapid traction for reduction of cervical spine dislocations. JBJS-B 1994; 76B(3):352-356.

The Biomechanical Effects of Lower Limb Length Discrepancy Upon Gait in Children

Kit M. Song, M.D.

Considerable attention has been given to operative intervention for correction of lower limb length inequality and to forecasting leg length discrepancies at maturity, but little information has been published about the biomechanical and clinical consequences of limb length inequality. Anecdotal associations of back pain, knee dysfunction, and hip osteoarthritis to lower limb length inequality have been made, but only one previously published work has examined the biomechanical alterations in gait resulting from an acquired leg length discrepancy. There has been widespread acceptance that discrepancies of two centimeters or more at maturity should be treated, but the rationale for this recommendation is poorly defined.

It was the purpose of this study to evaluate the effects of varying degrees of leg length discrepancy (LLD) upon the gait of otherwise healthy children. We wished to characterize gait patterns, describe compensatory strategies used for progressively larger discrepancies, and to see if a threshold discrepancy exists above which there are significant biomechanical alterations in gait which might serve as a rationale for treatment.

Materials and Methods

We studied thirty-five children. The criteria for inclusion were: age older than 7 years; a measurable leg length discrepancy, less than ten degrees of angular difference between their long and short limb in any plane, less than ten degrees difference in total range of motion of the hip, knee, and ankle in any plane, and neurologically and cognitively normal. We excluded any child who had complained of pain or who had undergone an operative procedure in the preceding six months. All children were recalled. We subjected each child to a detailed physical examination and functional questionnaire, an orthoroentgenogram for assessment of LLD, an instrumented gait analysis using a VICON 3 dimensional gait system, force plate analysis, and CYBEX isokinetic muscle testing of the hip, knee, and ankle. We then evaluated the kinematic and kinetic data looking for statistical correlations of changes in each variable with the degree of LLD. Calculations for the total mechanical work of each limb were made by integrating and summing the area under the hip, knee, and ankle power curves in all planes. We also plotted the trajectory of the body center of mass in the sagittal plane. We visually identified compensatory strategies used by the children and then reviewed the kinetic and kinematic data for objective criteria to reclassify the strategies used.

Results

There were thirteen females and twenty-two males with an average age of 12.9 years. The absolute LLD ranged from 0.6 cm to 11.1 cm with the per cent discrepancy being 0.8% to 15.8% of the length of the long limb. The etiology of the LLD was idiopathic for nine children, congenital short femur for six, fibular hemimelia for five, tibial bowing for four, femur fracture for four, and Aitken type A proximal femoral focal deficiency for three children. We found that there were significant differences between the long and short limb for almost all kinematic, kinetic, CYBEX and cadence variables, but that there was not a correlation between the degree of LLD and the differences between the short and long limbs for any of these variables. Persistent pelvic obliquity during gait was seen in eight children and an increased range of pelvic obliquity was seen in nine children, but the range and degree of pelvic obliquity did not correlate with the degree of LLD. Four compensatory strategies were identified. These were toe-walking on the short limb, increased flexion of the long limb, circumduction of the long limb, and vaulting over the long limb. We could identify objective kinematic and kinetic criteria to define toe-walking and increased flexion and had interobserver agreement of these strategies 100% of the time. Only children who toe-walked had a significant ($p<0.0001$) increase in mechanical work being done by the long leg. No other group had a significant difference in mechanical work between the two limbs. Similarly, only toe-walkers had a significantly greater translation of the body center of mass than normal controls. The threshold discrepancy for the 95% confidence limit for toewalkers was 5.5% discrepancy. We had seven children who used no visible compensatory strategy. The average LLD for this group was 2.2% discrepancy.

Discussion

It is estimated that up to 70% of asymptomatic normal adults will have some degree of LLD with 45% having discrepancies greater than 5 mm, 30% discrepancies from 1 cm to 2.5 cm, 4% discrepancies from 2 cm to 2.5 cm, and 0.7% as large as 4.5 cm. Recommendations for treatment have ranged from any discrepancy to more than five centimeters, but the rationale for these recommendations is poorly defined.

Anecdotal associations of back pain, long leg hip osteoarthritis, and "long leg arthropathy" with knee pain have been made, but a true association has never been established. Pelvic obliquity with relative uncovering of the femoral head has been postulated as a possible mechanism by which these anecdotally observed problems might occur. Our study found that relatively few individuals with LLD have measurable pelvic obliquity while walking and that there was no correlation between the degree of LLD and the degree of pelvic obliquity. Although pelvic obliquity can occur in association with LLD, we believe that this is not a common finding and that the majority of otherwise normal individuals develop compensatory strategies which

maintain a level pelvis during gait. It appears that these compensatory strategies are able to equalize the mechanical work done by the two limbs until the strategy of toe-walking on the short limb is used. At this point, significantly more mechanical work is performed by the long limb and increased translation of the body center of mass occurs. The threshold discrepancy for incorporation of this strategy was 5.5% discrepancy in our study.

The results of this study are limited to children with long term discrepancies. We cannot say whether or not the compensatory strategies employed by our subjects will be used by them as adults. We believe that the lack of differences in mechanical work between the long and short limbs for the majority of our subjects suggests that the compensatory strategies selected provide an efficient gait pattern that will serve them well long term. It is possible that the use of compensatory mechanisms causes alterations in the firing patterns of muscles which may lead to abnormal stresses, but do not lead to an overall difference in the mechanical work of a limb. The results of this study are not intended to apply to adults with an acutely acquired LLD. We believe that they would probably have a more difficult time developing compensatory strategies compared to this population of children with long standing LLD.

In summary, we found that children with LLD utilized a variety of compensatory strategies during gait. Pelvic obliquity during gait was not a common finding and is not the most likely cause of hip osteoarthritis or back pain in LLD patients. Small discrepancies averaging 2.2% of the length of the long limb invoked the use of no compensatory strategies. Significant differences in the mechanical work performed by the long versus the short leg and increased center of mass displacement were not found until a threshold discrepancy of 5.5% was reached. Clinically, this degree of discrepancy involved the use of toe walking as a compensatory strategy. Further clinical and biomechanical studies will help to define the degree of leg length inequality which would justify treatment.

Recommended Reading:

Beaty J: Limb Length Discrepancy. In *Campbell's Operative Orthopedics*, edited by A. H. Crenshaw. Ed. 8th, vol. 3, pp. 2126-2158. St. Louis, Mosby, 1992.

Kaufman KR, Miller LS, Sutherland DH: Gait Asymmetry in Patients with Limb-Length Inequality. *Journal of Pediatric Orthopedics*, 16:144-50, 1996.

Moseley CF: Leg-Length Discrepancy. In *Lovell and Winter's Pediatric Orthopedics.*, edited by R. T. Morrissey. 3rd ed., vol. 2, pp. 767-815. Philadelphia, J.B. Lippincott, 1990.

Effects of Musculoskeletal Neoplasms on Patient Self-Assessment of Health Status and Function: An Investigation Into the Practicality and Effectiveness of the SF-36 Standardized Self-Assessment Questionnaire

James D. Bruckner, M.D., Ernest U. Conrad III, M.D., and Jonathan Cluett, B.S.

Musculoskeletal neoplasms present an enormous variety of clinical conditions, including benign soft-tissue and bone tumors and tumor-like conditions, malignant soft-tissue and bone tumors, and metastatic tumors. Each of these broad categories of musculoskeletal neoplasia are further subdivided into smaller groups based on histologic subtype, each of which has unique clinical features. The treatment required for any particular type of musculoskeletal neoplasm depends upon the age of the patient, the location of the tumor, and the stage of the lesion. Treatment may include observation, neoadjuvant chemotherapy, radiation therapy, wide excision or amputation.

Many different schemes have been devised to assess the outcome of treatment for musculoskeletal neoplasms. Unfortunately, many of these assessment schemes are very complicated and difficult to reliably apply across the broad spectrum of clinical presentations of these tumors. Furthermore, while newer evaluation systems have recognized the value of functional results, many fail to adequately address the patient's own assessment of their wellness or health status before and after treatment.

The SF-36 is a widely used general, health-status questionnaire that has been repeatedly demonstrated to provide a convenient and practical assessment of the effectiveness of management of more common musculoskeletal disorders. It has been used to demonstrate the health status of controlled populations, as well as populations with defined medical and psychological conditions. To date, it has not been used to document the health status of patients with musculoskeletal neoplasms. This investigation will apply the SF-36 to the measurement of the effect of musculoskeletal neoplasms on self-assessed health status and function. It will also attempt to identify which clinical characteristics are most closely correlated with deficits in health status.

Methods

Eighty-five consecutive patients referred to the University of Washington Musculoskeletal Tumor Service for evaluation and treatment of bone and soft-tissue tumors were prospectively studied. Data collected included the patient's name, hospital record number, age, gender, diagnosis, ICD-9 designation, tumor size, clinical presentation, stage, and anatomic site.

The SF-36 is a 36 item, short-form survey which measures the following generic, health-status factors::

Limitation in physical functioning due to health (physical function.).

Limitation in social activities due to physical or emotional health (social function.).

Limitation in usual role (work and daily) activities due to physical health (physical role function.).

Limitation in usual role activities due to personal or emotional problems.

-General mental health

-Vitality

-Bodily pain (comfort)

-Perceptions of general health

The SF-36 also includes an additional general, health rating item - Reported Health Transition - which is not used to score any of the above eight scales but which provides information about changes in health status during the year prior to the patient's entry into the study.

The initial SF-36 questionnaires were distributed to the patients and completed prior to physician-patient contact.

Questionnaire data from this study group were compared to age and gender matched control data derived from three separate populations-based health status surveys, which included individuals suffering from various chronic health deficits representative of a "control" population. Statistical interpretation of data was carried out using single sample, paired t-test, and Spearman rank correlations.

Results

The 85 patients in this pilot study were referred for the evaluation of musculoskeletal tumors between February and July 1995. There were 44 females and 41 males. Their mean age was 51. Overall, neither gender nor age showed any significant relationship to health status. Fifty-six patients had malignant and 29 benign tumors. Fourty-nine had soft-tissue and 36 bone tumors.

Table 1

SF-36 variable	control mean	subject mean	p-value
Physical function	83	56	<.0001
Social function	89	65	<.0001
Physical role function	77	39	<.0001
Emotional role function	85	70	.0008
Mental health	76	70	.0032
Vitality	62	51	.0001
Comfort	77	48	<.0001
General health	72	64	.0010

Table 1 compares population control and subject means for each SF-36 variable. These data show that our patients had statistically significantly lower mean scores than age and sex matched controls in all SF-36 domains (P<.05).

Table 2

SF-36 variable	control mean		subject mean		p-value	
	Malignant	*Benign*	*Malignant*	*Benign*	*Malignant*	*Benign*
Physical function	81	87	54	59	<.0001	<.0001
Social function	88	90	61	74	<.0001	.0051
Physical role function	75	83	34	50	<.0001	.0006
Emotional role function	84	87	70	70	.0101	.0316
Mental health	77	76	69	72	.0019	.2130
Vitality	61	63	49	55	.0007	.0917
Comfort	76	78	48	49	<.0001	<.0001
General health	71	75	61	66	.0040	.0710

Table 2 compares health-status deficits for patients presenting with benign and malignant tumors. Patients with benign tumors had significant deficits in five of eight domains, while patients with malignant tumors had significant deficits in all domains (P<.05).

Table 3

SF-36 variable	control mean		subject mean		p-value	
	Bone	*Soft-Tissue*	*Bone*	*Soft-Tissue*	*Bone*	*Soft-Tissue*
Physical function	86	80	49	61	<.0001	.0005
Social function	90	88	57	71	<.0001	.0002
Physical role function	82	74	30	47	<.0001	.0002
Emotional role function	88	84	60	77	.0004	.1811
Mental health	76	76	67	73	.0063	.1652
Vitality	63	61	44	56	<.0001	.1522
Comfort	79	75	39	56	<.0001	<.0001
General health	74	71	58	66	.0011	.1462

Table 3 compares deficits for patients presenting with bone and soft-tissue tumors. Patients with bone tumors had significant deficits in all domains, while those with soft tissue tumors had significant deficits in four of eight domains.

Discussion

Our results indicate that patients with musculoskeletal neoplasms experience significant deficits in their self-assessed health status, compared to age and gender matched controls. These health status deficits have not been previously documented using the SF-36. The factors which seem to exert the greatest influence on these patient's perceived health deficits are the type and location of their tumor. Health-status deficits were most significant and numerous in patients with bone tumors and malignant tumors, who exhibited significant deficits in all eight generic health-status factors. Patients with soft-tissue tumors experienced significant deficits in four of eight; and patients with benign tumors, five of eight health-status factors.

This study documents the effectiveness of the SF-36 in documenting the health status deficits of patients with musculoskeletal neoplasms. We believe the SF-36 is a useful benchmark which can serve as a baseline in determining the effectiveness of treatment of musculoskeletal neoplasms.

Recommended Reading

Bombardier C, Melfi CA, Paul J, Green R, Hawker G, Wright J and Coyte P: Comparison of a generic and a disease-specific measure of pain and physical function after knee replacement surgery. *Medical Care (Philadelphia PA)* 33:AS131-44, 1995.

Kantz ME, Harris WJ, Levitsky K, Ware JE Jr., and Davies AR: Methods for assessing condition-specific and generic functional status outcomes after total knee replacement. *Medical Care (Philadelphia PA)* 30:MS240-52, 1992.

Katz JN, Harris TM, Larson MG, Krushell RJ, Brown CH, Fossel AH, and Liang MH: Predictors of functional outcomes after arthroscopic partial meniscectomy. *Journal of Rheumatology* 19:1938-42, 1992.

Matsen FA, Ziegler DW, and DeBartolo SE: Patient self-assessment for health status in glenohumeral degenerative joint disease. *Journal of Shoulder and Elbow Surgery, In press.* 1995.

Radosevich DM, Wetzler H, and Wilson SM: Health status questionnaire (HSQ) 2.0 Scoring comparisons and reference data, in Bloomington, MN: Health Outcomes Institute, 1994.

Ware JE, Snow KK, Dosinski M, and Gandek B: *SF-36 Health Survey, Manual and Interpretation Guide*. Boston, MA: The Health Institute, New England Medical Center, 1993.

Tumor-Related Proteins Can Help Predict the Behavior of Chondrosarcomas

HOWARD A. CHANSKY, M.D. AND ERNEST U. CONRAD III, M.D.

Chondrosarcomas are malignant tumors of cartilage that may arise de novo or within a preexisting benign cartilaginous lesion. They are the second most common primary sarcoma arising in the skeleton, exceeded in incidence only by osteosarcoma. These tumors most commonly occur in adults and represent a difficult problem for physicians, surgeons and pathologists in terms of predicting their clinical course, degree of malignancy and appropriate treatment. The treatment of this disease has remained purely surgical since as a group, chondrosarcomas are resistant to both radiotherapy and chemotherapy. Low grade lesions are treated by marginal or wide local excision while high grade lesions are treated with radical excision or amputation. Unfortunately up to 50% of the lesions arise in the pelvis and proximal femur. These locations present difficulties in obtaining wide surgical margins without resorting to amputation. Low grade lesions have cure rates up to 85% while the highest grade lesions have mortality rates on the order of 85%. Local recurrence rates are significant for all grades.

An effective grading system for chondrosarcomas is needed to provide patients with prognostic information. Such a grading system would suggest the best form of treatment for an individual tumor and permit accurate comparisons among the results of clinical trials. Unfortunately clinical, radiographic and histological criteria have not provided sufficient information for determining prognosis or guiding treatment. The grading system in current use relies on the histological appearance of the tumor cells, mitotic indices and cellular DNA content. Radiographic (cortical erosion, size) and clinical (pain, location) criteria are typically incorporated into the final grade. However, cellular differentiation and malignancy do not reliably correlate with the histomorphologic findings in cartilaginous neoplasms. It is often impossible to distinguish with certainty low grade from high grade sarcomas or even benign from malignant cartilage lesions. Chondrosarcomas present a therapeutic as well as a diagnostic challenge. Preoperative knowledge of the biological aggressiveness of a chondrosarcoma would greatly aid in optimal treatment.

The revolution in molecular biology has provided the clinician with very sensitive and specific tools with which to refine the characterization of sarcomas. Mutation of the p53 tumor suppresser gene and amplification of the mdm2 oncogene have been demonstrated in one-half to one-third of soft tissue and bony sarcomas. Both of these genes encode for proteins, which when abnormally expressed, permit the development of a malignancy through their adverse effects on the regulatory mechanisms of the cell cycle. Although there is not an exact correspondence between the underlying genetic changes and "overexpression" of the mdm2 and p53 proteins, detection of these proteins by immunostaining has been associated with a poorer clinical prognosis in some sarcomas. The Ki-67 monoclonal antibody is specific for a nuclear antigen that is expressed in proliferating cells and has also been used as a prognostic marker for certain neoplasms including osteosarcoma. We undertook this retrospective study to evaluate the prognostic value of immunostaining for these tumor-related proteins in chondrosarcomas of varying grades.

METHODS

We analyzed the hospital records, radiographs and archival tissue blocks from 20 patients with a histologically and radiographically confirmed diagnosis of a cartilage tumor and a minimum clinical follow-up of 2 years. The tumors had been graded using the classic criteria as grade 0 or benign (3 tumors), grade I (8), grade II (6), grade III (2) and dedifferentiated (1). Evaluation of the clinical data and the immunohistochemical (IHC) data were performed independently in a blinded fashion. The avidin-biotin peroxidase complex technique was used for immunohistochemistry, primary antibody. Slides of breast carcinoma tissue known to be p53, mdm2 and Ki-67 positive were used as positive controls. Normal mesenchymal tissue present within a subset of the specimens was also used as an internal negative control. Only nuclear staining was considered to be positive. The percentage of stained nuclei were counted in 5 high-powered fields for each specimen. Based upon the existing literature, overexpression (positive) was defined as staining of at least 10% of the nuclei for each antibody.

STATISTICAL ANALYSIS

Antigen overexpression was correlated with patient age and sex, tumor size, location, and grade and surgical margin using Pearson's correlation coefficient and one-way ANOVA. Kaplan-Meier disease-free survival curves were constructed and the significance of differences for each factor was estimated by the log-rank test. Subsequently, Cox multivariate analysis was used to determine which factors had independent prognostic significance. Statistical significance was defined as p-values less than 0.05.

RESULTS

Overexpression of Ki-67, mdm2 or p53 was correlated with increasing grade based upon classic histological criteria (see Table 1). Nuclear overexpression of either Ki-67 or p53 was also associated with reduced disease-free survival. There was 72% disease free survival (DFS) at 2 years for the group without Ki-67 overexpression versus 16% disease free survival in the Ki-67 overexpression group. The p53 negative group had a disease free survival of 73% while in the group that overexpressed p53 no patients were disease free at 2 years. None of the 11 patients who remained disease-free at 2 years were overexpressors of p53. Overexpression

of mdm2 was not correlated with decreased survival. Only p53 overexpression and tumor grade remained statistically significant predictors of prognosis after multivariate analysis.

Discussion

Very little is known about the pathogenesis of chondrosarcoma. Oncogenesis likely involves multiple genetic aberrations, resulting in both activation of oncogenes that override cellular growth regulatory controls, and inactivation of tumor suppresser genes that free cells from growth restraints. We undertook this study to determine whether immunochemical detection of three of these proteins, previously found to be overexpressed in sarcomas, could be of diagnostic and prognostic value. This study documents frequent grade-associated alterations of expression of the Ki-67, mdm2 and p53 tumor-related proteins by cartilage neoplasms. These changes appear to be predictive of clinical outcome. Overexpression of p53 implies a particularly poor outcome with no patients remaining free of disease after 2 years of clinical follow-up. 11 of 21 patients were disease-free at 2 years and none of these patients overexpressed the p53 tumor-suppresser gene. Ki-67 which is a general indicator of cellular proliferation was also strongly predictive of clinical outcome. Preoperative assessment of these proteins in biopsy specimens may provide the clinician with additional information with which to guide the generosity of surgical margins or the threshold for performing an amputation. This data justifies pursuing more specific molecular studies such as northern analysis and in situ hybridization to further understand the role of these genes in the pathogenesis of chondrosarcoma. Clinical correlation with long-term followup of additional patients will be needed to definitively assess the diagnostic, prognostic and therapeutic implications of immunohistochemical detection of tumor-related proteins.

Recommended Reading

Chansky HA, Cunningham R, Howlett AT, Gown A, Bruckner JD, Conrad EU: The prognostic value of tumor-related proteins in chondrosarcoma. Transactions, American Academy of Orthopaedic Surgeons. San Francisco, February 1997.

Chansky HA, O'Donnell R, Howlett AT, Conrad EU III: Common Bone Tumors. *In* Pediatric Surgery, 5th Edition, O'Neill JA, Rowe MI, Grosfeld JL, Fonkalsrud EW, Coran AG, (eds.), Mosby-Year Book, Inc., St Loius, MO, In press, 1997.

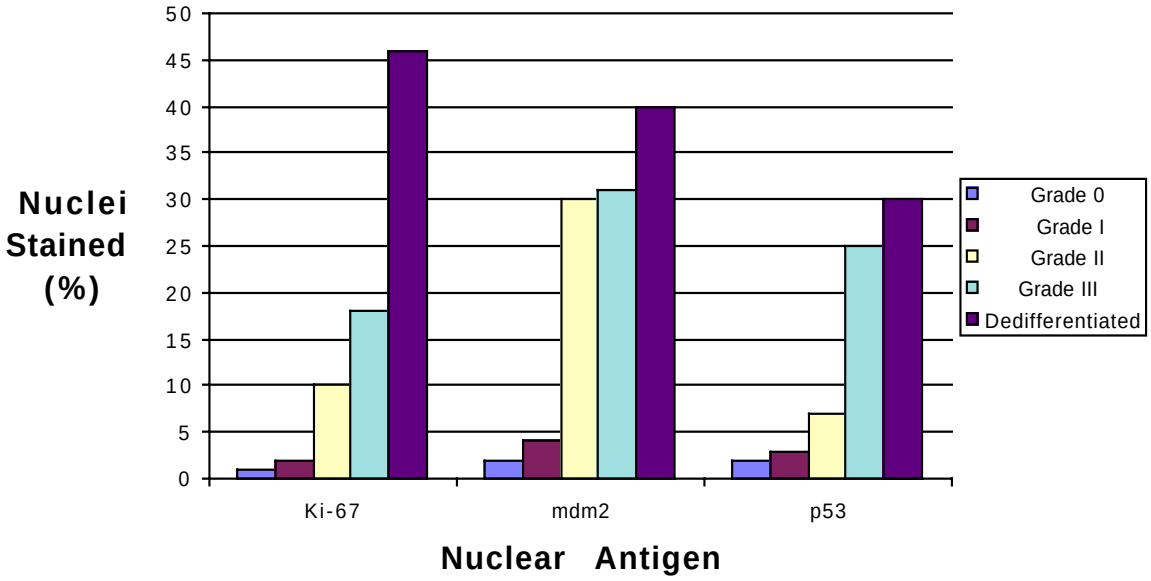
Cordon-Cardo C, Latres E, Drobnjak M, Oliva MR, Pollack D, Woodruff JM, Marechal V, Chen J, Brennan MF, Levine AJ: Molecular abnormalities of mdm2 and p53 genes in adult soft tissue sarcomas. *Cancer Res* , 54:794-799, 1994.

Evans HL, Ayala AG, Romsdahl MM: Prognostic factors in chondrosarcoma of bone. A clinicopathologic analysis with emphasis on histologic grading. *Cancer* ; 40:818-831, 1977.

Scotlandi-K, Serra-M, Manara-M-C, Maurici-D, Benini-S.Nini-G, Campanacci-M, Baldini-N: Clinical relevance of Ki-67 expression in bone tumors. *Cancer* . 75(3):806-14, Feb 1,1995.

Wadayama B, Toguchida J, Yamaguchi T, Sasaki MS, Kotoura Y, Yamamuro T: p53 expression and its relationship to DNA alterations in bone and soft tissue sarcomas. Br. J. *Cancer* ; 68:1134-1139, 1993.

Table 1: Nuclear Staining vs Tumor Grade



The Fasciculi of the Popliteus Contribute to Lateral Meniscal Stability

Peter T. Simonian, M.D., Thomas L. Wickiewicz, M.D., and Russell F. Warren, M.D.

The structural association between the popliteus and the lateral meniscus has been described. The frequency and consistency of these attachments has been debated. More importantly, the clinical relevance of these structures has not been clearly elucidated. It has been assumed that disruption of the fasciculi attachments between the popliteus and lateral meniscus will result in increased meniscal mobility; however, accurately predicting the amount of increased mobility, and whether it will result in mechanical symptoms to the patient is unclear. Further, parameters for clinical decision making based on lateral meniscal instability at the time of surgery have not been defined.

In an attempt to better understand the contribution of the antero-inferior and postero-superior popliteomeniscal fasciculi to lateral meniscus stability, we objectively evaluated the stability of the lateral meniscus before and after sequentially sectioning them. The biomechanical model attempted to account for the inherent limitations of arthroscopic evaluation of lateral meniscal stability.

Materials and Methods

Specimen setup

Seven fresh, cadaveric knee specimens, along with the distal half femur and proximal half tibia and fibula were obtained. The mean age of the donors was 71 years (50-87). The specimens originated from patients without skeletal diseases. No signs of bone or soft tissue disease were found at the time of dissection. All ligaments, capsular tissues, and the popliteus muscle and tendon were preserved. The remaining extraarticular soft tissues were removed to allow access to the knee joint, especially the popliteomeniscal region. All specimens had intact antero-inferior and postero-superior popliteomeniscal fasciculi.

A separate anatomic specimen of the lateral meniscus and popliteus tendon with intact antero-inferior and postero-superior popliteomeniscal fasciculi was sectioned in the frontal plane from posterior to anterior to demonstrate the relationships of these structures.

The proximal femur was locked into a holding clamp designed to fix the femur in a stationary position. This was achieved with an aluminum frame that surrounded the proximal portion of the femoral specimen and allowed placement of multiple transverse bicortical screws locking the specimen to the frame. The aluminum frame was then secured to a rigid surface with two C-clamps. This configuration prevented motion of the specimen.

The knee joints were then locked at ninety degrees of flexion with a skeletal fixator to reproduce knee positions between loading trials and to prevent tibial translation with loading.

Loading arrangement

A number 1, non-absorbable, polyester suture (Ethibond, Ethicon Inc., Somerville, NJ) was consistently placed from the central to the peripheral edge of the lateral meniscus at the level of the anterior border of the popliteal hiatus. Each intact meniscus was loaded through the suture with an anteriorly directed force of 10N for a set period of 60 seconds prior to measurement. The antero-inferior fascicle was sectioned and the lateral meniscus was loaded again with a 10N anterior force for 60 seconds. Additionally, the postero-superior popliteomeniscal fascicle was sectioned and the lateral meniscus was loaded again with a 10N anterior force for 60 seconds.

The magnitude and direction of this 10N, anteriorly directed, force is similar to that which can be applied at arthroscopy with a simple probe through an anterior portal. Applying the force for a period of 60 seconds prior to each measurement allowed a consistent amount of elastic deformation to occur in the system.

Meniscal motion measurement

Meniscal motion was measured on a perfect lateral radiograph utilizing a portable fluoroscope (OEC Mini 6600 Digital Mobile C-Arm, OEC Medical Systems, Salt Lake City, UT). A Kirchner wire marker was placed centrally in the tibial shaft between the tibial spines to provide a stationary reference marker. A 20 gauge needle was placed in the peripheral substance of the lateral meniscus, from superior to inferior at the level of the anterior border of the popliteal hiatus; the needle did not interfere with the loading suture. The shaft and tip of the needle were free from interference with any structures including the femoral condyle and the tibial plateau. The needle was placed perpendicular to the meniscus and parallel to the tibial marker. Images were obtained with the meniscus unloaded and loaded with the fasciculi intact, with the antero-inferior fascicle disrupted, and with both fasciculi disrupted. Permanent hard copies were printed from each of the fluoroscopic images using a graphic printer (Sony Video Graphic Printer UP-850, Sony Corp., Tokyo, Japan). This resulted in a total of six images per specimen. For each of these images, the distance was measured between the stationary tibial marker and the mobile meniscal marker. Care was taken not to move the specimen or fluoroscope between loading trials. Utilizing this method, each intact knee served as its own control for each of the disrupted states.

Statistical analysis of data

The difference of meniscal position between the loaded and unloaded states was calculated in the intact and disrupted trials; means and standard deviations were calculated for each condition. Differences between the states were analyzed with a one factor ANOVA - repeated measures test (Statview II, Abacus Concepts Inc., Berkeley, CA). Statistical significance for the Scheffe F-test was set at $p < 0.05$.

Results

Lateral meniscal motion - intact fasciculi

When the fasciculi were intact, the average lateral meniscal motion with a 10N load was 3.6 mm (standard deviation = 1.8 mm).

Lateral meniscal motion - disrupted antero-inferior fascicle

When the antero-inferior fascicle was disrupted, the average lateral meniscal motion with 10N load was 5.4 mm (standard deviation = 2.3 mm). The mean increase in motion from the intact state was 1.8 mm or 50%, which was significant ($p < 0.05$).

Lateral meniscal motion - disrupted antero-inferior and postero-superior fasciculi

When both fasciculi were disrupted, the average lateral meniscal motion with 10N load was 6.4 mm (standard deviation = 2.4 mm). The mean increase in motion from the intact state was 2.8 mm or 78%, which was significant ($p < 0.05$). The mean increase in motion from the single fascicle disruption state was 1.0 mm or 18%, which was significant ($p < 0.05$).

In each of these three proportions, the meniscus did not become locked with the application of the displacing force and spontaneously reduced to the original position when the meniscus was unloaded.

Discussion

Higgins, in 1895, reported that the posterior horn of the lateral meniscus is closely attached to the popliteus muscle. He and others believed these attachments protected the cartilage, pulling it from between bone structures of the knee during flexion. In 1950, Last reported on the popliteus and the attachments to the menisci. There have also been studies observing continuous attachment of the popliteus into the lateral meniscus. The occurrence and consistency of fasciculi attachments between the lateral meniscus and the popliteus tendon are debated. Cohn and Mains described the gross anatomical dissections of 10 fresh-frozen knee specimens, none of which had evidence of previous surgery. They reported that the superior border of the popliteal hiatus is the superior popliteomeniscle fascicle and the inferior border is the inferior popliteomeniscle fascicle. They emphasized that the anatomy of the popliteal hiatus is constant. Staubli and Birrer confirmed these anatomical consistencies. In 1989, Tria et al reported that 18 of 40 cadaver knees had an isolated insertion of the popliteus tendon to the lateral femoral condyle and with no connection to the lateral meniscus. Although the anatomy in this region can be variable, the knee specimens utilized for the present study had both intact antero-inferior and postero-superior fasciculi.

Thompson et al studied the normal excursion of the lateral meniscus has been studied with a three-dimensional reconstruction magnetic resonance image model. During flexion, the posterior excursion of the medial meniscus was 5.1 mm, while that of the lateral meniscus was 11.2 mm. The anterior horn segments were shown to be more mobile than the posterior horn segments bilaterally. Their model represents actual motion of the intact meniscus through a range of motion; however it is difficult to correlate this motion to what is seen during arthroscopic surgery. At arthroscopy, the meniscal stability is typically assessed with an anteriorly directed force, through a probe, with the knee in a flexed position. The motions observed of the intact lateral meniscus in the present study were 3.6mm, with a 10N anterior directed load with the knee fixed in the flexed position. The excursion of the lateral meniscus was less than half of that observed by Thompson et al. Because of the clear differences in methodology between these two studies, these measurements of lateral meniscal motion should not be directly compared.

The clinical significance of the popliteomeniscal attachments and lateral meniscal mobility has been questioned. Staubli and Birrer in 1990 described and illustrated the popliteus tendon and its fasciculi at the popliteal hiatus. They found that the superior and inferior popliteal fasciculi influenced motion of the lateral meniscus. They found an increase in "medial/lateral meniscal displacement" after disruption of these structures in the anterior cruciate ligament deficient knee. In this circumstance, they postulated that the resulting increased meniscal motion protected the meniscus from tears in the meniscal substance. They also felt that isolated lesions of the fasciculi would result in minimal increases in "meniscal play"; however, combined extended lesions of the popliteus unit may have a more profound effect on the lateral meniscus. They also noted that these injuries to these structures affected tibial femoral motion and stability.

Kimura et al in 1992 categorized fasciculi attachment of the popliteus to the lateral meniscus into two groups. They described type I coronary ligaments as those covering the entire popliteal tendon beneath the meniscus and type II ligaments as those with the popliteal tendon visible beneath the meniscus through defects of the coronary ligament. They observed cases with either type II or torn type I coronary ligaments resulted in increased lateral meniscus mobility, but stated that "no conclusion could be reached". Conclusions were lacking because the determination of increased meniscal motion was based on subjective measurements based upon probe palpation. Kimura et al reported operative outcomes on 27 patients with abnormal mobility in the posterior aspect of the lateral meniscus. They found that subtotal meniscectomy and meniscal repair groups did better than the partial meniscectomy group.

In the present study, each intact knee served as its own control to measure the increases in motion of the disrupted comparisons. The antero-superior fascicle seemed to lend a greater amount of control to meniscal motion. However this was the fascicle that was always cut first; it would have been more optimal to alternate the sequence of cutting the fasciculi. However for technical reasons, we had to cut the antero-inferior fascicle to gain access to the postero-superior fascicle. Therefore it is difficult to state that one fascicle controls motion significantly more than the other. Clearly both fasciculi make a significant contribution to meniscal stability. Interestingly, with lateral meniscal motion almost doubled after disruption of both fasciculi; however, the meniscus never became locked in the joint when loaded and always reduced spontaneously after the load was removed. In the clinical situation, the meniscus is subjected to many variable loads through normal activities and mechanical symptoms might be expected when meniscal motion is increased from disruption after

fasciculi.

Typically the stability of the lateral meniscus is evaluated with a probe at the time of arthroscopy from an anterior portal with an anterior to posterior force with the knee in a flexed position to allow access to this region. For this reason, the force applied to the meniscus in the present study was designed to mimic the force applied at arthroscopy. Although, this may not be the only direction of instability of the lateral meniscus after disruption of the fasciculi, it is useful to know the expected increase in motion during arthroscopic evaluation.

Recommended Reading

Cohn AK, and Mains DB: Popliteal hiatus of the lateral meniscus. Anatomy and measurement at dissection of 10 specimens. *Am J Sports Med,* 7: 221-6, 1979.

Fetto JF, Marshall JL, and Ghelman B: An anomalous attachment of the popliteus tendon to the lateral meniscus. Case report. *J Bone Joint Surg [Am],* 59: 548-9, 1977.

Higgins H: The popliteus muscle. *J Anat,* 29: 569-573, 1895.

Kimura M, Shirakura K, Hasegawa A, Kobayashi Y, and Udagawa E: Anatomy and pathophysiology of the popliteal tendon area in the lateral meniscus: 1. Arthroscopic and anatomical investigation. *Arthroscopy,* 8: 419-23, 1992.

Kimura M, Shirakura K, Hasegawa A, Kobayashi Y, and Udagawa E: Anatomy and pathophysiology of the popliteal tendon area in the lateral meniscus: 2. Clinical investigation. *Arthroscopy,* 8: 424-7, 1992.

Last RJ: The popliteus muscle and the lateral meniscus with a note on the lateral attachment of the medial meniscus. *J Bone Joint Surg [Br],* 32: 93-99, 1950.

Staubli HU, and Birrer S: The popliteus tendon and its fascicles at the popliteal hiatus: gross anatomy and functional arthroscopic evaluation with and without anterior cruciate ligament deficiency. *Arthroscopy,* 6: 209-20, 1990.

Staubli HU, and Rauschning W: Popliteus tendon and lateral meniscus. Gross and multiplanar cryosectional anatomy of the knee. *Amer J Knee Surg,* 4: 110-121, 1991.

Thompson WO, Thaete FL, Fu FH, and Dye SF: Tibial meniscal dynamics using three-dimensional reconstruction of magnetic resonance images. *Am J Sports Med,* 19: 210-5; discussion 215-6, 1991.

Tria AJ, Johnson CD, and Zawadsky JP: The popliteus tendon. *J Bone Joint Surg [Am],* 71: 714-716, 1989.

Early Surgical Release of Post-traumatic Elbow Contracture

Randall W. Viola, M.D. and Douglas P. Hanel, M.D.

Elbow stiffness commonly complicates elbow trauma. There are three factors which are thought to cause post-traumatic elbow stiffness. First, the high degree of articular congruity and conformity of the elbow joint predispose this joint to limited motion after articular injury. Second, the brachialis covers the anterior elbow capsule, predisposing it to post-traumatic peri-articular heterotopic ossification (HO). Third, mobilization after elbow injury is often delayed, because it is difficult to achieve rigid internal fixation of comminuted elbow fractures. Furthermore, elbow stiffness may occur in spite of both early aggressive motion and prophylactic measures.

Post-traumatic elbow stiffness is often disabling, as a wide range of motion is necessary for basic everyday activities. Morrey demonstrated that an arc of elbow flexion of 100 degrees, ranging from 30 degrees to 130 degrees, and an arc of forearm rotation of 110 degrees, ranging from 55 degrees of pronation to 55 degrees of supination, is necessary for an individual to perform 90% of his normal daily activities. Furthermore, peri-articular ossification may cause late ulnar neuropathy.

A variety of treatments have been used for post-traumatic stiff elbows. The most drastic, elbow fusion, causes severe functional impairment and should be considered only as a last resort. Total elbow replacement has a high complication rate, especially in post-traumatic arthritis. Excision of HO alone has been reported to provide good results; however, the timing of operative intervention in patients with elbow HO is thought to be critical. The desire to delay surgery until ectopic bone has become metabolically quiescent must be balanced against the risks of progressive soft tissue contracture, potential articular cartilage destruction, and prolonged infirmity. In the past, surgical release of the post-traumatic stiff elbow was not performed until the patient's bone scan and serum alkaline phosphatase were normal and the heterotopic ossification, as seen on plain radiographs, appeared mature. These prerequisites are typically met at twelve to twenty-four months post-injury and early intervention was thought to predispose to HO recurrence. Several recent reports suggest that good results may be obtained with early surgical release combined with postoperative non-steroidal anti-inflammatory drugs (NSAIDs) or radiation.

This study describes the results of early operative intervention, a short course of NSAIDs and intensive therapy in patients with post-traumatic stiff elbows.

Materials and Methods

A. Patient Selection

Sixteen patients (eighteen elbows) with post-traumatic elbow stiffness associated with HO have been managed with HO excision from 1992-1996.

B. Operative Indications

Our criteria for elbow contracture release were: (1) function-limiting elbow stiffness resulting from musculoskeletal trauma (2) radiographic union of fractures, (3) intact ulnohumeral joint articular surfaces, (4) HO in any stage of maturity on plain radiographs, and (5) stabilization of traumatic brain injury. Patients who reported either elbow-stiffness related disability or inability to perform activities of daily living (ADLs) and who were found to have less than 100 degrees of motion in the flexion-extension plane, less than 110 degrees in the pronation-supination plane, or a flexion contracture greater than 45 degrees were considered to have functionally limiting elbow stiffness. Patients were categorized according to Hasting's classification: class I (figure 1): no functional limitation, class IIA: limited flexion-extension, class IIB limited pronation-supination, class IIC limited flexion-extension and pronation-supination, and class III: elbow ankylosis preventing either flexion-extension or pronation-supination. Functionally limiting elbow stiffness was determined by patient history and physical exam. This study includes no burn patients.

C. Surgical Technique

Each surgery was individualized to restore full intraoperative elbow range of motion (ROM) by removing all HO as well as the anterior and posterior elbow joint capsule. Patients with ulnar nerve palsies underwent ulnar nerve transposition. If these procedures caused elbow instability, the elbow was stabilized by either ligament reconstruction or by a hinge-type external fixator for six weeks.

D. Postoperative Care

All patients were placed in elbow continuous passive motion (CPM) in the recovery room and this was continued for five days postoperatively. Splint, sling, and other forms of immobilization were strongly discouraged. However, after CPM was discontinued, night extension splinting was initiated for those patients with flexion contractures. Aggressive, unrestricted active and passive elbow ROM was initiated immediately postoperatively. Patients were instructed to complete elbow ROM exercises at least four times a day for at least six months. All patients were prescribed a five day course of indomethicin (25 mg po TID) and sulcralfate (1g po QID) postoperatively.

E. Patient Evaluation

Each case was analyzed by review of medical records, radiographs, physical examinations, and patient interviews. Active ROM was documented.

Results

The overall average preoperative flexion/extension arc was 38 ± 18 degrees, and the overall average preoperative pronation/supination arc was 75 ± 62 degrees. The average time from injury to contracture release was 31 weeks.

At an average follow-up of104 weeks (after contractrure release), the overall average postoperative flexion/extension arc was 117 ± 17 degrees, and the overall

average postoperative pronation/supination arc was 155 ± 24 degrees. Both the flexion/extension and pronation/supination arcs were significantly improved as assessed by the paired t test ($p < 0.05$). There were no operative complications; however, three postoperative complications occurred in two patients. These complications included a pin tract infection, aseptic capitellum resorption, and scar breakdown requiring free flap coverage. Of seven patients with ulnar neuropathy preoperatively, all resolved.

Table 1 lists the preoperative and postoperative flexion/extension and pronation/supination arcs of motion for all patient groups as a function of Hasting's classification.

Conclusions

Like other published series of elbow contracture releases, our report describes a mixed patient population. Yet, most patients were young adults (average age thirty years) with traumatic brain injuries (75%) who sustained significant elbow trauma (94%) and had their initial injury managed without HO prophylaxis (94%). Additionally, most were neurologically intact after their initial injury (88%) but many developed delayed ulnar nerve palsies (39%). The time from injury to HO excision was variable: fourteen of eighteen elbow contractures were released within thirty-one weeks post-injury. Figures 1A through 1G show both radiographs and clinical photographs of a typical case.

Elbow contracture release and/or ulnar nerve transposition improved elbow motion and resolved of ulnar neuropathy in all patients at two years of follow-up. Out of the eighteen elbows treated, sixteen achieved both flexion/extension and pronation/supination arcs greater than 100 degrees and 110 degrees, respectively.

We attribute these results to thorough operative resection of HO and capsule, submuscular ulnar nerve transfer, and an aggressive, unlimited postoperative active and passive motion. The focus of each release was complete resection of HO and capsule so that intraoperative ROM was as close to normal as possible. Furthermore, all elbows were stable postoperatively, due to either preservation of the collateral and annular ligaments, ligament reconstruction, or fixator stabilization. Although all patients were prescribed three to six weeks of indomethicin, follow-up interviews revealed that fourteen patients discontinued indomethicin after discharge on postoperative day five because of gastrointestinal side-effects. While the utility of Indomethicin in the prevention of HO reformation after HO resection has been well documented, we are unsure of its role in this series of patients.

The complication rate of post-traumatic elbow contracture release is high. In Morrey's series of twenty-six elbows, seven patients had eight complications. These complications included triceps avulsion, ulnar nerve paresthesias, deep infection, aseptic resorption of the distal humerus, and skin slough. In the current series of eighteen elbows, two patients had three complications.

Based on this retrospective data, early surgical release of the post-traumatic stiff elbow can restore elbow range of motion to a functional level. Although the complication rate was 11%, no patient sustained a neurovascular injury, 89% of patients achieved functional range of motion in both the flexion/extension and pronation/supination planes, and no patient developed instability. Furthermore, seven patients who developed late ulnar neuropathy had full recovery of ulnar nerve function after excision of HO and submuscular ulnar nerve transposition.

Recommended Reading:

Hastings H II, Graham TJ: The classification and treatment of heterotopic ossification about the elbow and forearm. *Hand Clinics*, 10: 417-437, 1993.

Husband JB, Hastings H: The lateral approach for operative release of post-traumatic contracture of the elbow. *JBJS*, 72A: 1353-1358, 1990.

Morrey BF: The elbow and its disorders. Philadelphia, WB Saunders, pp 73-91,1993.

Morrey BF: Post-traumatic contracture of the elbow. *JBJS*, 92A:601-618, 1990.

Wainapel SF, Rao PU, Wchepsis AA: Ulnar nerve compression by heterotopic ossification in a head-injured patient. *Arch. Phys. Med. Rehabil.*, 66: 512, 1985.

Outcome Assessment in Prosthetics and Orthotics

Douglas G. Smith, M.D., Kim Coleman, M.S. and David A. Boone, C.P.

There is growing recognition in the medical community of the importance of quantifying multidimensional patient outcomes following medical interventions. Health care providers are now being asked to demonstrate that what they do actually makes a difference in the patient's "outcome". However, little guidance as to what "outcomes" actually are, and the means to measure "outcomes" has been provided by those requesting the information. Investigators now understand that what the outcome is and how to measure it changes according to the specific medical intervention or condition being examined.

The concept of "outcomes" research is not new, and can be traced back to EA Codman, the Massachusetts Orthopaedic Surgeon, who in 1914 proposed that knowledge of the "end result" for patient management should be the measurement by which medical and surgical treatments be judged as worthy. In Prosthetics and Orthotics, in spite of intense research, we have a difficult time demonstrating that measurable differences exist between the wide range of available prostheses. Our patients say that differences exist, and providers often have very strong bias as to which components are "better", but clinically meaningful evidence beyond subjective opinion is sparse. Because there are large differences in the cost of prosthetic systems, and large differences in the compensation paid to a provider for providing these different systems, third party payers are asking for evidence that measurable differences do exist between these systems. In our opinion, there is a clear need to improve our measurements of "Outcomes" in Prosthetics and Orthotics. We need to expand the knowledge bases that guide decision making.

Traditional Measurements of "Outcomes"

Outcomes of amputation management have traditionally been presented in terms of clinical endpoints, physical measurements of gait or energy expenditure, and questionnaire based tools. Clinical endpoints such as wound healing, successful prosthetic fitting, or achievement of a minimal level of ambulation are all important measurements of the early success of surgery and rehabilitation. These clinical measurements have guided our treatment decisions for many years. However, these approaches are not sensitive tools for measuring the subtle but important differences between variations in surgical technique, rehabilitation programs, or prosthetic systems.

Physical measurements have also been a foundation in the study of human gait. Investigators have analyzed the individual components of the gait cycle and described in great detail measurements of joint kinematics, electrical activity of muscles, ground reaction forces, and the energy requirements of walking. The results of such studies are invaluable in piecing together our understanding of the intricacies of gait and its deviations. But while this approach has been fascinating in detail, it has been extraordinarily frustrating in complexity. These physical measurements have been extremely limited in routine clinical use, and definite links between specific measurements and a patient's overall functionality have not been well established. Also, because traditional physical measurements describe gait within a brief and often very controlled observation period in a laboratory setting, such measurements do not address the broader issues of what patients actually choose to do in the real world setting. We still know little about how much people actually walk during a day, and even less about how people vary their walking from hour to hour or from day to day. The differences between what a patient can do in the laboratory setting, and what a patient actually chooses to do in the real world are probably larger and more important than we realize. We believe that in amputations and prosthetics, the newer definition of "outcomes" will focus on what patients actually choose to do in the real world, blending physical capacity, motivation, comfort, satisfaction, and emotional issues.

Using improved questionnaire-based Health Assessment Tools is the third approach to measuring patient outcomes. During the last decade, many questionnaire-based Health Assessment Tools were developed and validated (Sickness Impact Profile, SF-36, Bartell Index, AIMS) in an attempt to better measure activity, emotional state, pain, mobility, cognitive ability, and health perception. Additional scales were developed and validated to measure patient quality of life, self efficacy, life stress and life changes. These standardized, measurement tools are a great improvement over previous outcome assessment. However, because they are designed to measure overall health status, these general tools can be very difficult to interpret for a specific disease or condition such as amputation. The tools are just not sensitive enough to distinguish the small, but important changes that we believe result from switching from a traditional to an advanced prosthetic design, or component.

An example to illustrate some of the benefits and limitations of these general Health Assessment tools comes from our study of twenty traumatic below-knee amputees using the SF-36. The SF-36 is a validated health assessment tool developed by the Medical Outcomes Study Group. Using the SF-36, we found little deviation of the twenty traumatic below-knee amputees from normalized patient scores in the five categories related to emotional problems, social functioning, mental health, energy/fatigue, and health perception. But, amputee's scores were significantly lower than those for a normalized, age-matched population in the categories of physical functioning, role limitations due to physical health,

and pain; reflecting the fact that real physical limitations do exist.

Although our results confirm that the SF-36 health status profile can document limitations in physical activity between amputees and non-amputees, the scales were designed for large populations, are not precise enough to determine small differences in activity level between individual amputees. For example, role limitation due to physical problems is measured on a scale of 0 - 100 in 25 point increments, and physical activity is measured on a scale of 0 - 100 in 5 point increments, both of which are far too coarse to provide useful statistical data for measuring subtle changes in activity for the small numbers of amputees available for our studies. Much more specific and discriminating is to evaluate its use in clinical trials, and assess whether it can successfully measure differences between various prosthetic systems.

Our pursuit of improved methods to objectively measure the activity of amputees, not in the laboratory setting but out in the real world during their daily activities, has led to the development of a small, self-contained device which is worn on the ankle and records the number of steps taken each and every minute for up to four weeks. The gait activity monitor (US Patent # 5,485,402) is easy to use, requires no intervention by the wearer, and can be set to continuously monitor a patient's ambulatory activity for up to one month. Accuracy at counting steps is 99% for counting steps during level walking and greater than 95% for counting steps on stairs and hills. Detailed activity profiles can be generated which provide objective information such as number of steps per day, minutes of total activity, minutes of activity at fast, medium, or slow step rates, minutes of inactivity, and peak performance.

To test the feasibility of using the gait activity monitor to detect differences in gait activity due to a change in prosthetic components, an active trans-tibial amputee was monitored for a week at a time under two conditions. First he wore his normal "dynamic limb" components which consisted of a Seattle™ Lightfoot and a Seattle™ Air Stance pylon. Then he was switched to a Otto Bock 30 mm aluminum pylon with titanium adapters and a Otto Bock SACH foot (the "rigid limb") and monitored for another week. He was not told what type of components he had received, only that he had been switched to different ones. When the subject returned to the lab, he stated that he had done more walking on the second limb. Analysis of the data showed a different story (Table 1). Despite feeling that he had walked more on the rigid limb, the data showed that during his normal weekdays he was actually more active with the dynamic limb. With the dynamic limb, he took 40.1% more steps per day and consistently achieved higher peak step rates. Further, he spent an average of 1.4 more hours a day being active, 65.5% more time in moderate intensity activity (20-40 steps/minute) and 11.1% more time in high intensity activity (over 40 steps/minute). His weekend data showed much more variability in both the levels and patterns of activity with both the rigid and dynamic limbs. Interestingly, the day he achieved the highest level of activity (11,227 steps) was with the rigid limb, since the weather permitted him to go golfing. This indicates to us that the rigid prosthesis did not ultimately limit his ability to function at a high level, but instead led him to make consistent daily choices to walk less during normal activities.

We also monitored the activity of 20 male diabetic patients using step count based gait assessment (mean age 65 years, range 48 to 80). The average number of steps per day for the 20 subjects was 3276. However the range (875 to 6502) and standard deviation (1574) reveal the large variation in ambulatory activity between these subjects. The percent of inactive time = 76.3% (SD 9.0), the percent of time spent walking at low levels of ambulation (0-15 steps/min) = 18.5% (SD 7.1), moderate activity (16-30 steps/min) = 4.3% (SD 2.7), and high activity (≥31 steps/min) = 0.9% (SD 0.8). SF-36 health assessment questionnaire was also administered to these 20 subjects, and scores for the eight categories calculated. The Pearson correlation coefficient was calculated for steps/day, % inactive time, % time at low activity, % time at moderate activity, and % time at high activity with the eight different scores of the SF-36. (Pearson "r" values shown in table). This data (Table 2) suggests the strongest correlation with physical functional, role physical, and bodily pain is with % time at high activity levels. We are fascinated by the variation in the correlation of other step count data with the individual SF-36 scores. We believe this should stimulate more research into understanding both objective assessment of activity and questionnaire based assessment tools.

Conclusions

We are encouraged by the results of our initial pilot data, and believe that both improved questionnaire based outcome tools, and improved physical measurements of activity are needed. We are hopeful that data such as this will be helpful in documenting "outcomes" for the various treatments that exist in Prosthetics and Orthotics, and results ultimately in continued advances for our patients.

Acknowledgments

Research Supported by:

Veterans Affairs, Depts. of RR&D, and HSR&D

Prosthetics Research Study

Prosthetics Outreach Foundation

University of Washington, Department of Orthopaedics

A Special Acknowledgment to: Gayle E. Reiber, Ph.D.; Marcia Legro, Ph.D., Michael del Agula ; and Linda Laing who have had tremendous impact on the ongoing development of the Prosthetics Evaluation Questionnaire.

Table 1

Pilot Work Evaluating Differences in Daily Activity of an Active Trans-Tibial Amputee with Two Different Prosthetic Limbs

Evaluation of Nine Common Mechanical Shoulder Disorders With the SF-36 Health Status Instrument

David G. Levinsohn, M.D. and Frederick A. Matsen III, M.D.

The purpose of this study is to demonstrate a practical method for documenting the perceived health status and function of patients presenting with one of nine defined shoulder disorders using a self-assessment questionnaire. The SF-36 was selected because it is widely used to assess patients' perceptions of different health conditions, such as arthritis, migraine headaches and endometriosis.

Materials and Methods

747 patients who met the necessary and sufficient diagnostic criteria for one of nine common shoulder disorders completed the SF-36 health status instrument. Diagnoses included osteoarthritis (OA) (n=159), secondary degenerative joint disease (SDJD) (n=40), traumatic instability (TUBS) (n=78), atraumatic instability (AMBRII) (n=52), full thickness rotator cuff tear (RCT) (n=133), partial thickness rotator cuff tear (PTRCT) (n=102), frozen shoulder (FS) (n=74), post-traumatic frozen shoulder (PTFS) (n=76), and rheumatoid arthritis (RA) (n=33).

The data from the SF-36 were analyzed using the scoring algorithm described by its authors to generate eight health status scores: physical role (PR), comfort (C), physical function (PF), emotional role (ER), social function (SF), vitality (V), general health (GH), and mental health (MH). For each scale, a score of zero was the most impaired and one-hundred was the most healthy response.

Age and sex matched expected SF-36 scores for each diagnosis were computed from the published data that utilized the same questionnaire for three separate population-based surveys: the Geisinger Health Plan Survey (1,760 subjects), the AT&T American Trans Tech "MASH" Trial (702 subjects), and the Northwest Area Foundation Health Survey (1,814 subjects). Statistical analysis was by the one sample t-test comparing SF-36 scores in the study group to the corresponding expected age and sex matched population means.

Results

The SF-36 scores separated by diagnosis are summarized in table 1 which shows the expected mean (standard deviation) for the age and sex matched general population, the mean (standard deviation) for the study group, the 95 % confidence interval for the study group, and the p-value obtained from the one sample t-test comparing the study group to the expected population mean. The percent of the expected general population age and sex matched mean SF-36 score for each diagnosis is shown in figure 1.

On the whole, patients with these shoulder conditions gave themselves particularly low scores with respect to their comfort and physical role function. Of these two parameters, physical role reflected more sensitively the patients disability. In general, the patients' perceptions of their mental health, vitality, and general health were similar to those of the population controls.

Patients with rheumatoid arthritis tended to have the lowest scores for all SF-36 variables compared to patients of other diagnostic groups. The traumatic instability group demonstrated the overall least perceived dysfunction compared to other groups. Analysis of the percent expected scores for related diagnoses (secondary degenerative joint disease and osteoarthritis, post traumatic frozen shoulder and frozen shoulder, rotator cuff tear and partial thickness rotator cuff tear, and traumatic instability and atraumatic instability) revealed a common pattern. For each pair there was one group with clearly more deficit with respect to at least seven of the eight SF-36 parameters: secondary degenerative joint disease more deficit than osteoarthritis, post traumatic frozen shoulder more deficit than frozen shoulder, rotator cuff tear more deficit than partial thickness rotator cuff tear, and atraumatic instability more deficit than traumatic instability.

Discussion

This study reveals that standardized documentation of the patient's perspective is practical in the context of a busy practice. This documentation reveals important aspects of an individual patient's condition that may not become apparent in a traditional clinical evaluation. With respect to mechanical shoulder conditions, the most common problems perceived by patients presenting for treatment are pain and inability to carry out their desired physical functions.

The wide dispersion of perceptions of health status and function suggests that these self-assessments may be useful in determining the selection and timing of treatment. Patients who perceive their health and function to be near the healthy end of the scale may merit consideration for conservative management which places their health and function at relatively small risk - even if their "objective" parameters suggest advanced disease. Alternatively, those who perceive poor comfort and function may be prepared to consider more risky treatment if such a plan is consistent with the remainder of their evaluation.

The type of pretreatment data presented here will serve as the "ingo" or baseline against which the post-treatment "outcome" can be compared to determine the treatment effectiveness in the hands of the specific provider. We are unaware that such data has previously been published. If standardized patient self-assessment is used as one of the cornerstones for documenting pretreatment severity and post treatment improvement, these results should be comparable among different practices.

Routine documentation of the patients' perspective of their health status and function can provide the basis for analyzing indications for different treatment approaches as well as for comparing indications and

effectiveness.

Recommended Reading

Gartland JJ: Orthopaedic Clinical Research: Deficiencies in experimental design and determinations of outcome. J Bone and Joint Surg 1988;70A:1357-1364.

Matsen FA III, Lippitt SB, Sidles JA, Harryman DT II: Practical Evaluation and Management of the Shoulder. W.B. Saunders, Philadelphia, PA, 1994.

Radosevich DM, Wetzler H, Wilson SM: Health status questionnaire (HSQ) 2.0: Scoring comparisons and reference data. Health Outcomes Institute, Bloomington, MN, 1994.

Ware JE, Snow KK, Kosinski M, Gandek B: In: SF 36 Health Survey, Manual and Interpretation Guide. The Health Institute, New England Medical Center, Boston, Massachusetts, 1993.

Williams A: Setting Priorities in Health Care: An Economist's View. J Bone and Joint Surg (Br) 1991;73-B:365-7.

Figure 1: Percent of age and sex matched expected SF-36 score (y-axis) separated by diagnosis (x-axis).

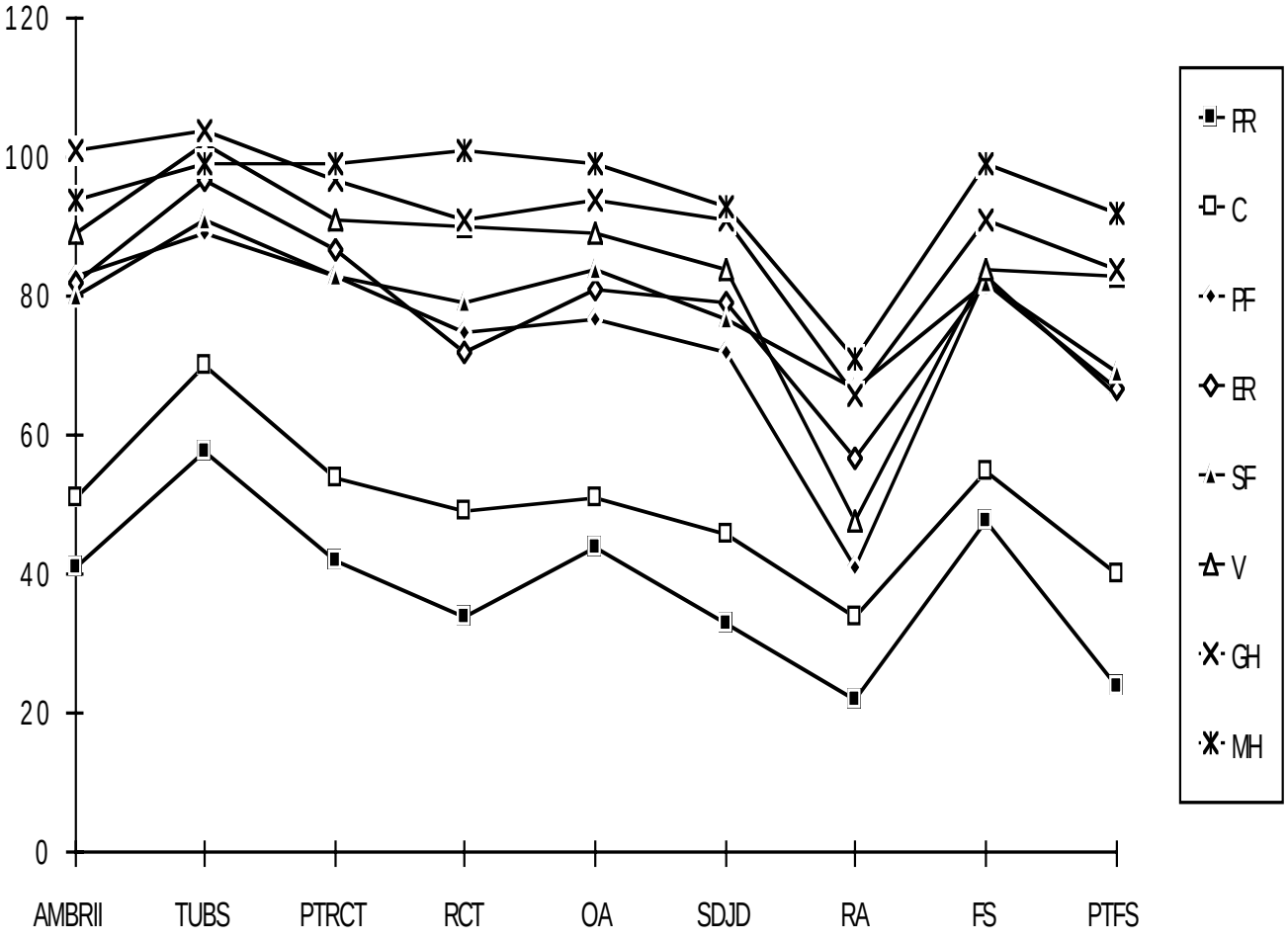


Table 1: SF-36 scores separated by diagnosis. For each diagnosis and SF-36 parameter there are 4 scores. Row 1 shows the expected mean and standard deviation for an age and sex matched general population. Row 2 shows the mean and standard deviation for the study group. Row 3 shows the 95 % confidence interval for the study group. Row 4 shows the p-value obtained from the one sample t-test comparing the study group to the age and sex matched general population mean (row 1).

	PR	C	PF	ER	SF	V	GH	MH
AMBRII	91 (26)	85 (21)	93 (17)	88 (30)	90 (19)	65 (22)	76 (19)	79 (20)
	37 (42)	43 (28)	77 (18)	72 (38)	72 (38)	58 (21)	77 (21)	74 (19)
	25-49	35-51	72 - 82	61 - 82	64 - 80	52 - 63	71 - 82	69 - 79
	<0.0001	<0.0001	<0.0001	0.0035	<0.0001	0.0116	0.8537	0.0713
TUBS	90 (25)	84 (20)	93 (15)	88 (28)	90 (18)	65 (20)	77 (18)	79 (19)
	52 (41)	59 (26)	83 (17)	85 (32)	82 (24)	66 (18)	80 (16)	78 (15)
	43 - 61	53 - 65	80 - 87	78 - 93	77 - 88	62 - 70	77 - 84	75 - 81
	<0.0001	<0.0001	<0.0001	0.4945	0.0063	0.5589	0.0728	0.5865
PTRCT	84 (31)	80 (22)	88 (18)	89 (27)	90 (18)	64 (21)	77 (17)	76 (19)
	35 (41)	43 (21)	73 (18)	77 (35)	75 (28)	58 (21)	75 (17)	75 (17)
	27 - 43	39 - 47	69 - 77	70 - 84	69 - 80	54 - 62	71 - 78	72 - 79
	<0.0001	<0.0001	<0.0001	0.0008	<0.0001	0.0054	0.1493	0.618
RCT	73 (42)	75 (27)	79 (25)	85 (35)	87 (24)	62 (24)	78 (18)	70 (24)
	25 (36)	37 (22)	59 (28)	61 (45)	69 (29)	56 (23)	71 (19)	71 (22)
	19 - 31	34 - 41	54 - 64	54 - 69	64 - 74	52 - 60	68 - 75	69 - 76
	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0035	0.001	0.1509
OA	70 (42)	75 (26)	77 (26)	83 (35)	86 (24)	62 (23)	78 (16)	68 (23)
	31 (39)	38 (22)	59 (25)	67 (42)	72 (26)	55 (22)	73 (19)	67 (19)
	25 - 37	35 - 42	55 - 63	61 - 74	67 - 76	50 - 57	66 - 72	70 - 76
	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0011
SDJD	78 (58)	78 (41)	83 (35)	86 (54)	88 (35)	63 (35)	78 (29)	73 (33)
	26 (36)	36 (17)	60 (24)	68 (42)	68 (23)	53 (23)	71 (18)	68 (21)
	15 - 38	31 - 41	52 - 68	54 - 81	61 - 75	46 - 60	61 - 75	65 - 77
	<0.0001	<0.0001	<0.0001	0.0087	<0.0001	0.0071	0.0038	0.469
RA	73 (69)	74 (44)	78 (22)	84 (59)	87 (39)	61 (39)	76 (31)	70 (39)
	16 (25)	25 (18)	32 (24)	48 (42)	58 (27)	29 (30)	50 (26)	50 (26)
	8 - 25	19 - 31	24 - 40	33 - 63	49 - 67	22 - 36	41 - 59	65 - 77
	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.7857
FS	79 (38)	78 (26)	83 (22)	87 (21)	89 (21)	63 (23)	77 (19)	73 (22)
	38 (39)	43 (19)	69 (19)	71 (39)	73 (27)	53 (21)	70 (20)	72 (21)
	29 - 48	38 - 47	64 - 73	62 - 80	68 - 80	49 - 59	67 - 77	65 - 75
	<0.0001	<0.0001	<0.0001	0.0007	<0.0001	0.0004	0.0488	0.2051
PTFS	85 (33)	81 (23)	89 (18)	88 (29)	90 (19)	64 (22)	77 (18)	76 (20)
	20 (34)	32 (18)	59 (22)	59 (46)	62 (32)	53 (24)	65 (19)	70 (19)
	12 - 27	28 - 36	54 - 64	49 - 70	55 - 69	47 - 58	66 - 74	60 - 69
	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0016	<0.0001

A Simple Home Program is Efficacious in the Management of Frozen Shoulder: A Prospective Study Using Patient Self-Assessment

David G. Duckworth, M.D., Kevin L. Smith, M.D., John A. Sidles, Ph.D., Barry Campbell, Sarah Jackins and Frederick A. Matsen III, M.D.

Frozen shoulder is a condition in which shoulder function is limited by restricted motion at the glenohumeral joint in the presence of normal joint surfaces. Ever since Codman stated in 1934 that frozen shoulder was "difficult to define, difficult to treat, and difficult to explain", frozen shoulder has been the subject of lively discussion within the orthopaedic literature.

Recent retrospective studies have reinforced an emerging consensus that most cases of idiopathic frozen shoulder substantially improve with non-operative treatment.

We undertook a prospective study of frozen shoulder patients with two objectives. First, we wished to document that frozen shoulder is associated with diminished function and health status as assessed by the patients themselves. This approach is in contrast to previous frozen shoulder studies which focus on the medical nature of glenohumeral motion. Our second objective was to define the extent to which the patients' perception of their shoulder function and health status changed with a simple home program.

Materials and Methods

This study concerned forty-one consecutive patients who met strict diagnostic criteria for frozen shoulder (Matsen et al). The average age of the patients was fifty-six years (range thirty-six to seventy-five). There were nineteen males and twenty-two females. Six patients had bilateral frozen shoulders; and in these cases one of the two shoulders was picked at random for inclusion in the study. Fifteen shoulders were on the right side, and twenty-seven were on the left side. There were four diabetic patients in the study.

Each patient completed the Simple Shoulder Test and the SF-36 self-assessment questionnaires at the time of presentation and sequentially after treatment was initiated. The average follow-up period was twenty-five months with a range from six to fifty months.

The SF-36 questionnaires were scored according to the algorithm of Ware et al which yields eight health status scores: physical function, social function, physical role function, emotional role function, comfort, vitality, mental health, and general health perception. Scores potentially range from zero to one hundred, with zero the least healthy and one hundred the most healthy.

Treatment consisted of a simple program of education and home stretching exercises, emphasizing flexion, external and internal rotation, and cross body reach.

Results

Deficits at the Time of Presentation

The initial Simple Shoulder Test scores indicated that patients with idiopathic frozen shoulder perceived substantial compromise of self-assessed shoulder function. Less than half of the patients were able to sleep on the side, tuck in a shirt, place eight pounds on a shelf, throw overhand, or wash the back of the opposite shoulder (Table 1).

With respect to self-assessed health status, patients perceived pronounced deficits in physical role function and

		percent "Yes"	confidence interval §	p-value†	percent "Yes"	confidence interval	p-value*	change in "Yes"¥	confidence interval
1	Arm comfortable at side	71%	(56,85)	<0.001	95%	(88,100)	0.003	24%	(09,40)
2	Sleep on side	12%	(02,23)	<0.001	78%	(65,90)	<0.001	66%	(51,81)
3	Tuck in back of shirt	39%	(23,55)	<0.001	88%	(78,98)	<0.001	49%	(30,68)
4	Place hand behind head	51%	(35,67)	<0.001	88%	(78,98)	<0.001	37%	(20,54)
5	Place coin on shelf	68%	(53,83)	<0.001	90%	(80,98)	0.005	22%	(07,37)
6	Place 1 pound on shelf	71%	(56,85)	<0.001	83%	(70,93)	0.058	12%	(00,25)
7	Place 8 pounds on shelf	24%	(11,38)	<0.001	56%	(40,70)	0.002	32%	(13,51)
8	Carry 20 pounds at side	63%	(48,79)	<0.001	66%	(50,80)	0.743	2%	(-13,17)
9	Toss underhand	54%	(38,70)	<0.001	73%	(60,88)	0.019	20%	(03,36)
10	Throw overhand	15%	(03,26)	<0.001	46%	(30,63)	<0.001	32%	(15,48)
11	Wash back of shoulder	15%	(03,26)	<0.001	76%	(63,88)	<0.001	61%	(44,78)
12	Allow regular work	56%	(40,72)	<0.001	78%	(65,90)	0.018	22%	(04,40)

§ 95% confidence intervals for the estimated mean (binomial distribution)
†p-value that the SST answers at initial presentation are no worse than controls (binomial distribution)
*p-value that the SST followup scores are unchanged relative to initial presentation (binomial distribution)
¥ Percent of patients changing "No" to "Yes" (favorable response) minus percent changing "Yes" to "No" (unfavorable response)

Table 1: Initial and follow-up shoulder function scores as reflected by the Simple Shoulder Test.

	SF36 Score	control scores¥	SF36 scores at initial presentation			SF36 scores at followup			Response to treatment	
			mean score	confidence interval §	p-value†	mean score	confidence interval	p-value*	change in score	confidence interval
1	Physical function	84	72	(67,77)	<0.001	81	(75,88)	<0.001	10	(05,15)
2	Social function	91	76	(67,85)	0.002	87	(80,94)	0.005	11	(04,19)
3	Role function: physical	80	44	(31,57)	<0.001	74	(62,87)	<0.001	30	(17,44)
4	Role function: emotional	90	76	(64,87)	0.016	79	(67,91)	0.797	02	(-11,15)
5	Mental health	76	71	(65,77)	0.107	74	(68,80)	0.288	03	(-03,08)
6	Vitality (energy/fatigue)	62	56	(49,62)	0.060	63	(55,70)	0.057	07	(00,14)
7	Comfort (bodily pain)	77	46	(40,52)	<0.001	71	(63,78)	<0.001	25	(17,33)
8	General health	72	73	(67,80)	0.619	69	(62,76)	0.116	-05	(-10,01)

¥ mean SF36 scores of an age-matched and sex-matched control population
§ 95% confidence intervals (t-test)
†p-value that initial scores do not differ from scores of age-matched and sex-matched controls (t-test)
*p-value that the followup scores are unchanged in pairwise comparison to initial presentation (t-test)

Table 2: Initial and follow-up general health status scores as reflected by the SF36 questionnaire.

comfort, and lesser deficits in other SF-36 categories (Table 2).

Improvement Associated with the Home Program

With respect to self-assessed shoulder function, the average patient improved by four positive answers. Thirteen patients improved by at least six positive responses, sixteen patients by three-to-five responses, and six patients by one or two responses. The total number of 'yes' answers were unchanged in three patients, and another three patients had fewer positive responses at follow-up than at initial evaluation. At latest followup, ten patients answered 'yes' to all twelve SST questions (Figure 1). Ten of the twelve SST shoulder functions were significantly improved by treatment ($p<0.05$, paired t-test); the two most significantly improved functions were sleeping on the affected side and washing the back of the opposite shoulder (Table 1).

With regard to self-assessed health status, the Wilcoxon signed-rank test indicated significant improvement in comfort ($p<0.0001$), physical function ($p<0.001$), social function ($p<0.05$) and physical role function ($p<0.001$) (Table 2).

With respect to the duration of follow-up, the Mann-Whitney test revealed no significant differences ($p<0.05$) in improvement in the health status or shoulder function of patients having follow-up less than twenty-five months in comparison to those having more than twenty-five months follow-up. The single exception was one of the shoulder functions (placing the hand behind the head) which was slightly better with longer followup.

Discussion

Frozen shoulder is a common condition for which there are widely varying recommended treatments. Such treatments include home exercises, intensive physical therapy, manipulation, injected steroids, arthroscopic release, and open surgery

Published reports of treatment effectiveness have focused on the medical metric of range of motion, rather that the status of the shoulder from the perspective of the patient. Recent literature suggests measured range of motion is only roughly correlated with comfort and function.

One objective of our study, therefore, was to prospectively assess the functional and health status deficits perceived by patients meeting specific inclusion criteria for frozen shoulder. The second objective was to use patient self-assessment to document the efficacy of a very inexpensive non-operative treatment based on patient education and home exercises.

This study indicated that, on average, this group of patients meeting strict criteria for frozen shoulder were significantly compromised in their shoulder function and in their self-assessed health status parameters of comfort and physical role function. However, the average frozen shoulder patient did not demonstrate abnormalities in mental status or in general health status. This result is in contrast to the opinion held by some that patients with a frozen shoulder have a 'typical personality.'

As a group the shoulder function and health status of these patients were significantly improved with the basic home program. However, all patients were not improved and many of those who were improved did not regain full normal function. Thus, this study was able to document both the general efficacy of the treatment program as well as to identify those patients who responded incompletely to it. These results provide a basis for objective comparison of the efficacy of this same program in other practices and for comparison of this program to other forms of treatment for frozen shoulder.

In conclusion, this study demonstrates the practicality of using self-assessment to document the shoulder function and health status of patients before and after treatment (the 'ingo' and the 'outcome'). It also demonstrates the efficacy of a simple home program in the management of idiopathic frozen shoulder from the important perspective of the patient. A similar approach can be used for the practical evaluation and management of other orthopaedic conditions.

Recommended Reading

Matsen III FA, Lippitt SB, Sidles JA, and Harryman II DT: Practical evaluation of management of the shoulder. W. B.

Saunders Company, Philadelphia, 19-109, 1994.

Miller MD, Wirth MA, Rockwood CA: Thawing the frozen shoulder : The " patient " patient. Orthopaedics Vol.19 : 849-853, 1996.

Shaffer B, Tibone JE, and Kerlan RK: Frozen shoulder. A long-term follow-up. J Bone and Joint Surg Am *74(5)*: 738-746, 1992.

Ware JE, and Sherbourne CD: The MOS 36-item short form survey (SF 36).I.Conceptual framework and item selection: Med Care, V. 30: 473-481, 1992.

LEGENDS.

FIGURE 1

Graph depicting total "Yes" responses to the SST questionnaire following "initial consultation" and then again at "follow-up" after treatment.

TABLE 1

Initial and follow-up shoulder function scores as reflected by the Simple Shoulder Test.

Table 2

Initial and follow-up general health status scores as reflected

by the SF36 questionnaire.

Figure 1

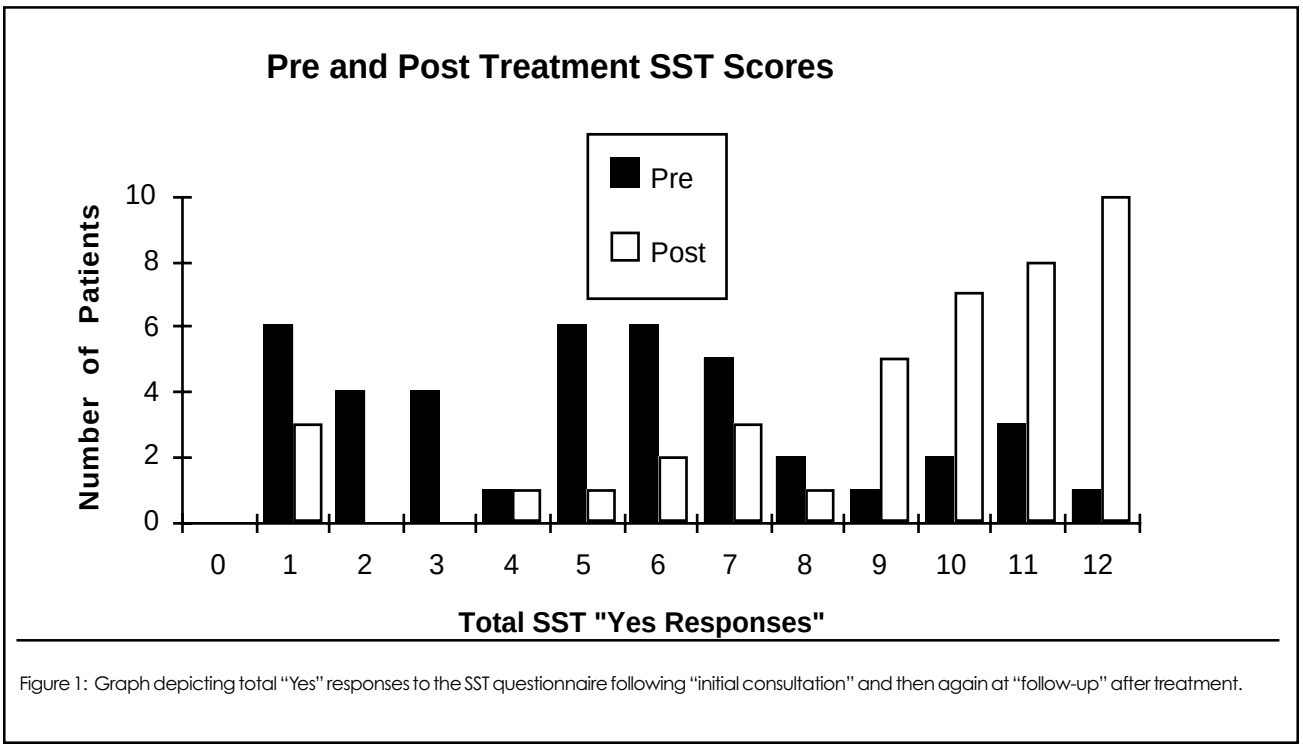


Figure 1: Graph depicting total "Yes" responses to the SST questionnaire following "initial consultation" and then again at "follow-up" after treatment.

Arthroscopic Release is Effective in the Management of Refractory Shoulder Stiffness

Douglas T. Harryman II, M.D.

Shoulder stiffness can severely restrict comfort and function of the upper extremity resulting in prolonged, substantial disability. Over the past five years, we have standardized our approach to the evaluation and management of glenohumeral stiffness. When non-operative management fails to return comfort and function, we consider an arthroscopic release of capsular contractures and adhesions.

The presentation of the clinical problem helps predict the pattern of stiffness. For example, an insidious onset of stiffness is typically associated with global contracture of the joint capsule. On the other hand, motion restrictions which occur after a rotator cuff strain may give rise to posterior capsular tightness, limiting forward elevation, internal rotation and cross-body adduction.

Materials & Methods

In this study, we defined a refractory stiff shoulder as one which was refractory to a consistent non-operative program for more than six months. We established prospective diagnostic criteria for patients with a frozen or post-traumatic stiff shoulder.

Each patient was instructed on a *Jackin's* four-quadrant stretching exercise program. When patients were unable to perform stretching exercises due to pain, an intra-articular steroid injection was offered to increase comfort and facilitate stretching. If the stretching program was maintained for more than six weeks and symptoms increased or range did not improve, then manipulation under anesthesia and injection with corticosteroid was performed and stretching reinstated. Patients with symptoms greater than six months who failed therapy, injection and manipulation were considered for arthroscopic release.

Surgical Method

An interscalene anesthetic was administered. Passive ranges were compared to the opposite side. A gentle manipulative force was applied and if significant asymmetry persisted then an arthroscopic capsular release was performed. Capsular release proceeded in a sequence designed to facilitate visibility and minimize fluid extravasation (Figure 1). The capsule was released one centimeter lateral to the labrum using long-nosed basket forceps or specialized capsular release forceps (Figure 2). Arthroscopic release was followed by a final manipulation and then an intra-articular injection of methylprednisolone. After arthroscopy, the extremity was placed in a continuous passive motion device.

Results

This report concerns thirty patients who failed at least six months (mean: 28 months) of non-operative management for unilateral refractory shoulder stiffness and who were managed by arthroscopic capsular release. Fourteen patients were diabetic. Preoperatively, nineteen patients had unilateral global restriction in movement and eleven patients had partial restriction in motion attributed to a posterior capsular contracture. Follow-up averaged 33 months (range 12 to 56).

Each patient's motion was documented according to the American Shoulder and Elbow Surgeons standard examination. Functional outcome and general health status were patient-assessed using the Simple Shoulder test

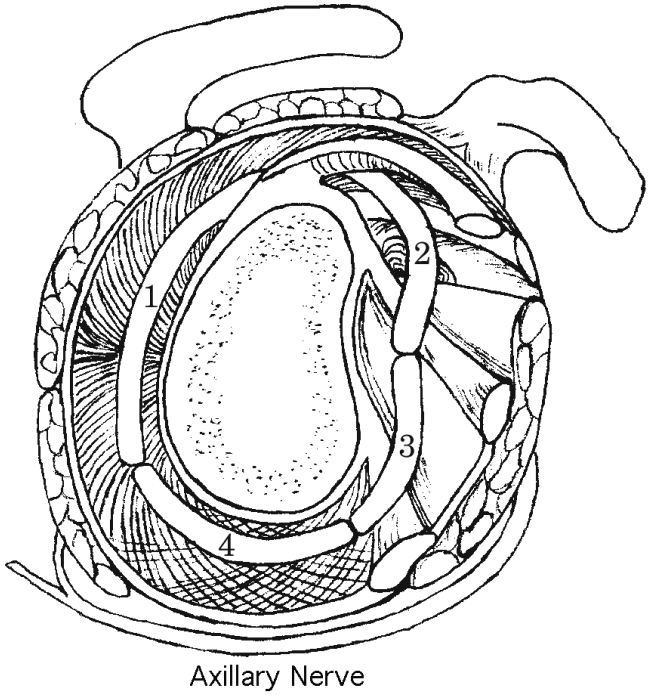


Figure 1: Diagram depicting the typical sequence of capsular release: (1) postero-superior and posterior, (2) antero-superior, rotator interval and subcoracoid recess, (3) antero-inferior; middle and inferior glenohumeral ligaments and (4) postero-inferior; postero-inferior recess and inferior sling.

and the SF-36 before and after surgery.

Active assisted range of motion was measured, recorded, and compared to the opposite extremity at each visit. A *stiffness ratio* was created to characterize the motion of the affected shoulder in comparison to the normal one (SR=Avg.Six $Ranges_{stiff\ side}$ ÷ Avg.Six $Ranges_{normal\ side}$). The stiffness ratio for all patients prior to release averaged 0.41. The day after surgery, motion had dramatically improved to a mean of 0.78. An additional 15% of motion was gained after discharge from the hospital to the latest follow-up visit to yield an average ratio of 0.93 at last follow-up (Figure 3).

Outcome Measures

At last follow-up, all 12 functional self-assessment questions on the Simple Shoulder test were significantly improved (9 of 12 SST questions at $p<0.001$ and three at $p<.006$), and only a small percentage of patients indicated worsening. Before surgery only 6% of patients were able to sleep comfortably on their side and 35% could place one pound on a shelf at shoulder height. After surgery, 73% were able to sleep comfortably on the affected side and 83% were able to place one pound on a shelf at shoulder height.

Six of nine SF-36 general health status scores were improved substantially (Figure 4). Improvements were most significant for physical ($p<0.01$) and social function ($p<0.04$), physical role function ($p<0.04$), bodily pain ($p<0.01$), mental health ($p<0.04$), and general health perception ($p<0.01$). There were no significant changes in the overall scores for emotional role, vitality (energy/fatigue) and general health change.

Eighteen of twenty-five eligible patients were off work before capsular release. After capsular release, eighteen of twenty-five had returned to work. Three patients developed recurrent refractory stiffness. The only complication was a single axillary neuropraxia which resolved spontaneously. No patient developed instability.

Discussion

The course of frozen shoulder syndrome is often considered "self-limited", resolving in two to three years. However, long-term follow-up studies of three to ten years have recognized ongoing limitations of shoulder movements in 90% and persistent pain and disability in over 40% of patients despite aggressive treatment. Even with aggressive non-operative or open operative treatment, the recovery is long in coming and frequently incomplete.

Our data indicate that 73% of our patients with severely symptomatic refractory stiffness of more than two years duration recovered function and comfort within three months and 88% percent by six months after arthroscopic capsular release. Gains in general health status and shoulder function were improved in all but two patients. Within three to six months after surgery, average total motion had recovered to nearly 90% of the opposite unaffected shoulder.

Conclusion

This study outlines the results of managing the refractory stiff shoulder by arthroscopic capsular release. Patients with long term disability have recovered and returned to work soon after surgery and were not restricted in the use of the extremity during rehabilitation. Dramatic gains in motion and function were realized soon after the release where previous treatment had been ineffective. Immediate gains in motion provided a sense of encouragement which improved general health perception and stimulated patients to perform exercises more vigorously. Patients could return to work or sports as soon as comfort allowed. Based on this experience, we recommend arthroscopic capsular release as an effective treatment for refractory shoulder stiffness.

Recommended Reading

Harryman II DT: Shoulders: frozen and stiff. *Instr Course Lect* 1993; 42: 247-57.

Harryman II DT: The Stiff Shoulder. In Rockwood CA, Matsen III FA, (ed.): *The Shoulder*, ed. 2. Philadelphia, W. B. Saunders, 1997, vol. 2, In press.

Harryman II DT, Matsen III FA, Sidles JA: Arthroscopic Management of Refractory Shoulder Stiffness. In press, J. Arthroscopy, 1997.

Matsen III FA, Lippitt SB, Sidles JA, Harryman II DT: *Practical Evaluation of Management of the Shoulder*. Philadelphia: W. B. Saunders Company, 1994: 19-109.

Tables and Figures

Figure 1

Diagram depicting the typical sequence of capsular release: (1) postero-superior and posterior, (2) antero-superior, rotator interval and subcoracoid recess, (3) antero-inferior; middle and inferior glenohumeral ligaments and (4) postero-inferior; postero-inferior recess and inferior sling.

Figure 2

Axillary nerve next to the probe after performing a complete posterior to anterior release of the inferior sling. The nerve must be protected when releasing the postero-inferior portion of the capsule. The inferior border of the subscapularis muscle (S) is seen anteriorly between the joint capsule and the axillary nerve. The capsule has been released approximately one centimeter peripheral to the glenoid labrum (L).

Figure 3

Graph of pre-operative and post-operative stiffness ratios for each patient at their longest follow-up interval. The 45° oblique line indicates "no-change." The perpendicular distance from the diagonal to each point above the line represents the relative improvement after capsular release. The mean motion for the affected shoulder was 93% of the asymptomatic shoulder. No patient's motion worsened after capsular release.

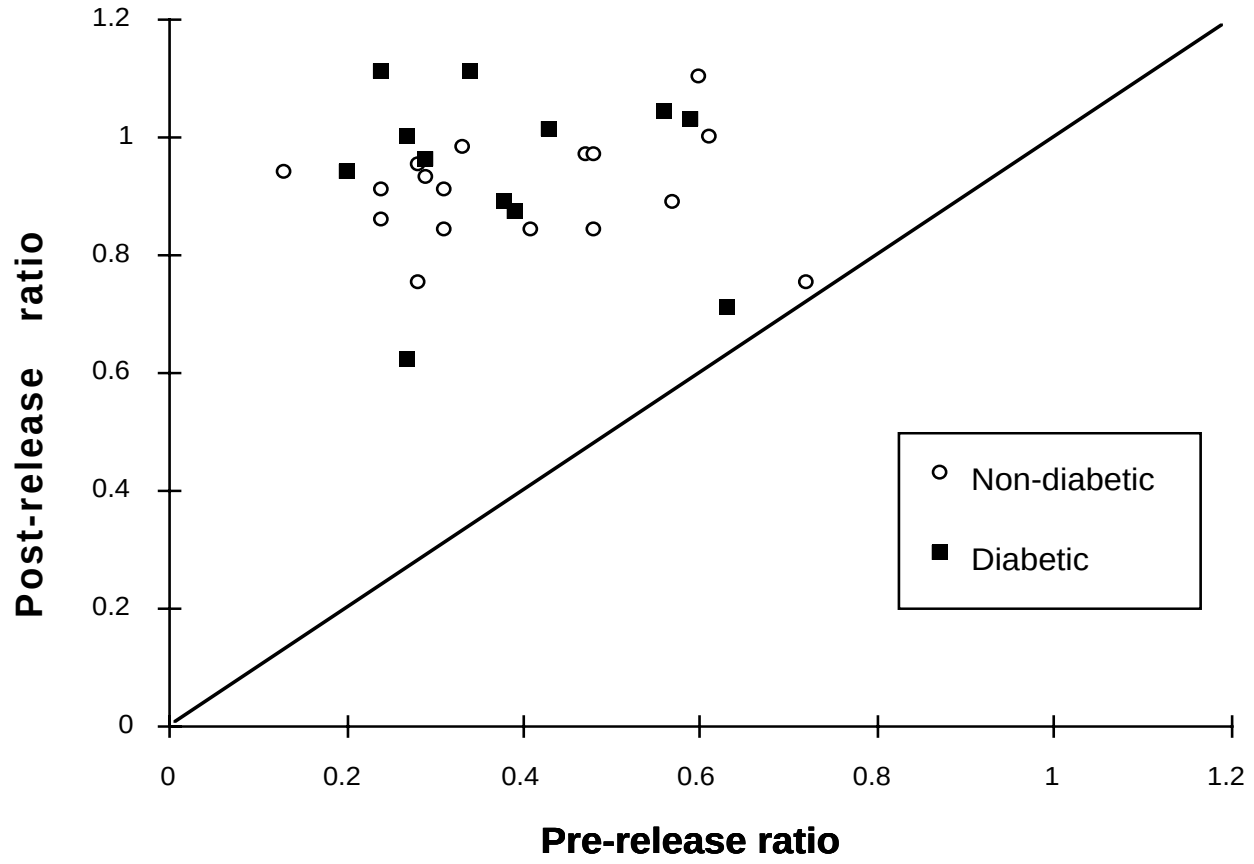


Figure 3: Graph of pre-operative and post-operative stiffness ratios for each patient at their longest follow-up interval. The 45° oblique line indicates "no-change." The perpendicular distance from the diagonal to each point above the line represents the relative improvement after capsular release. The mean motion for the affected shoulder was 93% of the asymptomatic shoulder. No patient's motion worsened after capsular release.

Patients with Late-Stage Rheumatoid Arthritis and Osteoarthritis of the Shoulder Differ Significantly in Self-Assessed Shoulder Function and Status

Kevin L. Smith, M.D., Frederick A. Matsen III, M.D., Susan E. DeBartolo, and Gretchen Von Oesen

Late-stage arthritis of the glenohumeral joint is regarded as a clinical entity with specific treatment options, including shoulder arthroplasty. However, the nature of the underlying arthritic process may have a substantial effect on the clinical manifestations and the management of the condition. For example, rheumatoid arthritis and osteoarthritis of the glenohumeral joint may both lead to late-stage shoulder arthritis, but the clinical complaints and challenges in overall management may be quite different. These disease-specific differences may be easily overlooked in the evaluation and management of patients with shoulder arthritis. Clinical decision making regarding the treatment of an individual with shoulder arthritis requires an evaluation of both joint-specific function and overall health status. The authors suggest that standardized self-assessment tools provide a practical method for characterizing these two important dimensions of the patient's clinical presentation.

This report concerns the prospective study of patients meeting predetermined criteria for late-stage rheumatoid and osteoarthritis of the shoulder. These patients completed self-assessments of health status and shoulder function at the time of their presentation for evaluation and management. The resulting data permit comparison and contrast of patients with these two distinct forms of shoulder arthritis.

Methods

This prospective study concerned a consecutive group of patients presenting to our practice for evaluation and management of their late-stage glenohumeral arthritis.

All patients:

1. Satisfied the following predetermined criteria for rheumatoid arthritis or primary osteoarthritis of the shoulder:

2. Presented complaining of limited shoulder motion and function.

3. Had no previous surgery on the affected shoulder.

4. Completed the Health Status Questionnaire - Short Form 36 (SF 36) and Simple Shoulder Test (SST) self-assessment questionnaires at the time of presentation to our service.

For the 112 patients in the osteoarthritis group the average age was 64 +/- 12 years; 83 were male and 29 were female. None of these patients had crystal arthropathy or other identifiable underlying causes for their arthritis, and were therefore classified as primary osteoarthritis. For the 28 patients in the rheumatoid arthritis group the average age was 61 +/- 12 years; 6 were male and 22 were female.

The SF-36 is a self-assessment questionnaire which has been used to demonstrate the overall health status of control populations and populations with defined medical and psychological conditions. The SF-36 has no specific relevance to shoulder problems, but rather focuses on the patient's evaluation of their own health, function, vitality, comfort and contentment. Using a standard algorithm, the responses to the questions are used to calculate eight SF-36 parameters; the maximum score for each parameter is 100. Radosevich et al have collected reference data from large populations using this instrument. The SF-36 was chosen because it is the most widely used health status self-assessment tool in all of medicine and allows comparison of the impact of arthritis on health status with that of other conditions such as migraine and congestive heart failure.

The Simple Shoulder Test (SST) is a standardized shoulder-specific self-assessment tool. Its twelve "yes or no" questions were derived from common presenting complaints of patients with shoulder conditions. Normal subjects aged 60-70 years old have been shown to be able to perform essentially all of the SST functions, and the test-retest reliability of the SST is satisfactory for patients with compromised shoulder function. The Simple Shoulder Test was selected for this study because it is the most practical standardized tool with demonstrated sensitivity to the clinical condition of the shoulder.

Data were collected and analyzed using commercially available databases and statistical software (Filemaker Pro, Claris and StatView, Abacus). Data were entered by an individual who was blinded to the patient's diagnosis (SED). Results for the two diagnostic groups were compared using the nonparametric Mann Whitney U test. A Bonferroni correction factor of 1/20 was applied to the p-value required for significance to guard against the possibility of a single Type I error across all twenty SST and SF-36 comparisons, yielding a suggested p-value for significance of $< .0025$. Because it may be over-conservative to apply Bonferroni corrections to conclusions whose purpose is primarily descriptive, the authors have listed all p-values $< .05$.

Results

SST Analysis

The shoulders of these 140 individuals were substantially compromised; however the degree of compromise was variable. The majority of the Simple Shoulder Test functions could be performed by less than half of this study population, whereas normal subjects aged 60-70 years old could perform virtually all of these functions. The self-assessed shoulder function of patients presenting with rheumatoid arthritis of the shoulder was in general not significantly different from those presenting with osteoarthritis. The two groups of patients were significantly different at the $p < .0025$ level only for the underhand toss and placing a coin on a shelf.

SF-36 Analysis

Among the eight SF-36 parameters, the combined study population scored most poorly on the physical role function scale. The mean for the entire group was 27 ± 37, less than half of the age- and sex-matched control value of 70 ± 40 for this scale from the literature. This scale reflects whether the patients perceive that their physical health had interfered with their work or regular activity during the previous 4 weeks. This reduced physical role function score was not significantly different between the rheumatoid arthritis and osteoarthritis patient groups ($p > .0025$). The mental health status score was not significantly lowered in these patients and not significantly different between the two diagnostic groups. By contrast, the remaining six health status scores (including physical function) of individuals presenting with rheumatoid arthritis of the shoulder were significantly worse than for those presenting with osteoarthritis ($p < .0025$).

Discussion

The clinical assessment of patients with arthritic conditions requires both overall and joint-specific evaluations. This study demonstrates that patient self-assessment questionnaires are useful in documenting the differences in shoulder function and health status among patients with late-stage glenohumeral arthritis. The tools used in this study are practical for routine use in orthopaedic practices: they did not require professional or staff time other than that needed to pass out the questionnaires in the office, to collect the questionnaires, and to enter the data into a scoring algorithm. Since such data is derived from standardized self-assessment questionnaires it can be compared over time, among practices, and in follow-up to treatment.

This investigation focused on a cohort of patients who shared the characteristic of having sufficiently severe shoulder joint destruction to present to a specialist for evaluation and management of this specific component of their arthritic condition. Within this highly selected population, standardized self-assessment indicated substantial, yet variable compromise of shoulder function and overall health status. Patients with rheumatoid arthritis showed major and significantly worse health status deficits than those with osteoarthritis. These differences are important considerations in understanding the individuality of patients and in selecting optimal approach to management. For example, patients with severely limited vitality or social function scores may warrant different treatment than individuals with high scores for these parameters. We suspect that the observed differences in general health status between the RA and OA populations relate primarily to the polyarticular and systemic nature of RA.

Individual self-assessment is important because patients are the ultimate judges of their own health and the effectiveness of their health care. This study provides a practical and standardized method of identifying deficits in shoulder function and overall health status in patients with late-stage rheumatoid arthritis or osteoarthritis of the shoulder. It demonstrates the utility of the SF-36 in distinguishing the health status of patients with these two diagnoses. Self-assessment is not only useful in terms of characterizing the differences among groups of patients, but also in the practical and standardized documentation of the specific status of individual patients.

We suggest that tools such as the SST and SF-36 are practical, inexpensive and standardized tools for:

- providing important insights into individual patient's perception of their shoulder function and health status
- documenting shoulder function and health status in a manner that facilitates comparisons among practices
- establishing the pretreatment baseline or 'ingo' against which the 'outcome' can be compared to determine efficacy and effectiveness.

Recommended Reading

Fitzpatrick R, Ziebland S, Jenkinson C, Mowat A, Mowat A: The social dimension of health status measures in rheumatoid arthritis. International Disabilities Studies 13(2):34-37, April-June 1991.

Lyons RA, Lo SV, Littlepage BNC: Comparative health status of patients with 11 common illnesses in Wales. Journal of Epidemiology and Community Health 48(4):388-390, August 1994

Matsen FA III, Lippitt SB, Sidles JA, Harryman DT II: In, Practical Evaluation and Management of the Shoulder. W.B. Saunders, Philadelphia, 1994.

Radosevich DM, Wetzler H, Wilson SM: Health status questionnaire (HSQ) 2.0: Scoring comparisons and reference data. Health Outcomes Institute, Bloomington, MN, 1994.

Ware JE, Snow KK, Kosinski M, Gandek B: In, SF 36 Health Survey, Manual and Interpretation Guide. The Health Institute, New England Medical Center, Boston, Massachusetts, 1993.

Department of Orthopaedics Faculty

Frederick A. Matsen III, M.D.
Professor and Chair

Stephen K. Benirschke, M.D.
Associate Professor

Stanley J. Bigos, M.D.
Professor

James T. Bruckner, M.D.
Assistant Professor

Howard A. Chansky, M.D.
Assistant Professor

Jens R. Chapman, M.D.
Associate Professor

John M. Clark Jr., M.D., Ph.D.
Associate Professor

Ernest U. Conrad III, M.D.
Professor

David R. Eyre, Ph.D.
Professor

Theodore K. Greenlee Jr., M.D.
Associate Professor

Douglas P. Hanel, M.D.
Associate Professor

Sigvard T. Hansen, Jr., M.D.
Professor

Douglas T. Harryman II, M.D.
Associate Professor

M. Bradford Henley, M.D.
Associate Professor

Roger V. Larson, M.D.
Associate Professor

Sohail K. Mirza, M.D.
Assistant Professor

Vincent S. Mosca, M.D.
Associate Professor

Milton L. Routt Jr., M.D.
Associate Professor

Linda J. Sandell, Ph.D.
Professor

Bruce J. Sangeorzan, M.D.
Professor

John A. Sidles, Ph.D.
Associate Professor

Douglas G. Smith, M.D.
Associate Professor

Kevin L. Smith, M.D.
Assistant Professor

Kit M. Song, M.D.
Assistant Professor

Lynn T. Staheli, M.D.
Professor Emeritus

Michael D. Strong, Ph.D.
Research Professor

Marc F. Swiontkowski, M.D.
Professor

Carol C. Teitz, M.D.
Associate Professor

Allan F. Tencer, Ph.D.
Professor

Thomas E. Trumble, M.D.
Associate Professor

Jiann-Jiu Wu, Ph.D.
Research Associate Professor

Adjunct Faculty

Basia R. Belza, R.N., Ph.D.
Associate Professor, Physiological Nursing

Anne-Marie Bollen, Ph.D.
Assistant Professor, Orthodontics

Charles H. Chesnut, M.D.
Professor, Nuclear Medicine

Gregory C. Gardner, M.D.
Associate Professor, Rheumatology

Thurman Gillespy, M.D.
Associate Professor, Radiology

Daniel O. Graney, Ph.D.
Associate Professor, Biological Structure

John C. Hunter, M.D.
Assistant Professor, Radiology

Frederick A. Mann, M.D.
Professor, Radiology

Susan M. Ott-Ralph, M.D.
Associate Professor, Division of Metabolism

Wendy Raskind, M.D., Ph.D.
Associate Professor, General Internal Medicine

Michael L. Richardson, M.D.
Professor, Radiology

Robert Schoene, M.D.
Professor, Medicine

Peter A. Simkin, M.D.
Professor, Medicine

Tony J. Wilson, M.D.
Professor, Radiology

Joint Faculty

John E. Olerud, M.D.
Professor, Division of Dermatology

Stephen G. Rice, M.D., Ph.D.
Lecturer, Pediatrics

Nicholas B. Vedder, M.D.
Associate Professor, Plastic Surgery

Affiliate Faculty

Michele C. Battié, Ph.D.
Professor and Chair, Department of Physical Therapy, University of Alberta, Edmonton

David A. Boone, C.P.
Director and Co-Principal Investigator, Prosthetics Research Study

Sarah E. Jackins, R.P.T.
Rehabilitation Medicine

UNIVERSITY OF WASHINGTON SCHOOL OF MEDICINE

Department of Orthopaedics
University of Washington
Box 356500
Seattle, Washington 98195-6500

Phone: (206) 543-3690
Fax: (206) 685-3139

Affiliated Institutions

Children's Hospital and Medical Center
4800 Sand Point Way NE
Seattle, WA 98105
(206) 526-2109

Harborview Medical Center
325 Ninth Avenue
Seattle, WA 98104
(206) 731-3466

University of Washington Medical Center
Bone and Joint Center
4245 Roosevelt Way NE
Seattle, WA 98105
(206) 548-4288

Veterans Affairs Medical Center
1660 South Columbian Way
Seattle, WA 98108
(206) 764-2215

Contributors to Departmental Research and Education

MAY 1996 THROUGH APRIL 1997

We express our appreciation to all who have contributed to the work of the Department of Orthopaedics over the past year. Your assistance makes possible special research activities, educational programs, and other projects that we could not facilitate without this extra support from our alumni, faculty, and friends in the community. We owe a special thanks to the University of Washington Resident Alumni who have made significant contributions to help further the education of our current residents.

Alumni & Residents

Class of '50
Einar Henriksen

Class of '52
Park W. Gloyd

Class of '54
Trygve Forland

Class of '55
Robert W. Florence

Class of '56
J. Michael Egglin
John E. Goeckler
Robert L. Romano

Class of '57
John H. Aberle
John R. Beebe

Class of '58
Samuel L. Clifford
James R. Friend
Harry H. Kretzler, Jr.
Kenneth L. Martin

Class of '59
James W. Tupper

Class of '60
William V. Smith
Irving Tobin

Class of '61
Robert C. Colburn

Class of '62
Marr Mullen
Thomas F. O'Toole

Class of '63
Alfred I. Blue
Robert A. Kraft
Robert R. Mensendiek

Class of '64
Harold J. Forney
Theodore K. Greenlee
David E. Karges
Thomas E. Soderberg

Class of '66
F. Richard Convery
Joseph S. Mezistrano
William A. Reilly, Jr.

Class of '67
Ivar W. Birkeland, Jr.
Joseph C. Clifford
Robert F. Smith

Class of '68
Steward M. Scham
Lynn T. Staheli
William T. Thieme

Class of '69
Edward E. Almquist
Sigvard T. Hansen, Jr.
Edward L. Lester
Hugh E. Toomey

Class of '70
John C. Brown
John M. Coletti, Jr.
Malcolm B. Madenwald
Michael Phillips
Robert D. Schrock, Jr.

Class of '71
Franklin G. Alvine
Bruce E. Bradley, Jr.
Nils Fauchald, Jr.
Louis A. Roser
Jerome H. Zechmann

Class of '72
Andrew B. Dott III
Thomas L. Gritzka
Donald D. Hubbard
David J. LaGasse
David R. Nank
John A. Neufeld

Class of '73
Frederick J. Davis
Larry D. Hull
Theodore A. Wagner
Robert P. Watkins

Alumni & Residents

Class of '74
Samuel R. Baker
Robert C. Begg
Richard A. Dimond
Ronald B.H. Sandler

Class of '75
William M. Backlund
Thomas M. Green
Gunter Knittel
Frederick A. Matsen III
Larry R. Pedegana
Donald Plowman
Robert A. Winquist

Class of '76
John F. Burns
Douglas T. Davidson
Douglas T. Kehl
Peter Melcher
Richard A. Zorn

Class of '77
Carl A. Andrews
Steven T. Bramwell
Larry D. Iversen
Mark C. Olson
Geoffrey W. Sheridan

Class of '78
John W. Brantigan
Gary J. Clancey
William Oppenheim
Arnold G. Peterson
Robert J. Strukel
Richard S. Westbrook

Class of '79
Allan W. Bach
Gregory M. Engel
Jonathan L. Knight
Richard L. Semon

Class of '80
John M. Hendrickson
Stuart R. Hutchinson
Douglas Norquist
Michael A. Sousa
Carol C. Teitz

Class of '81
John M. Clark
Dennis J. Kvidera
Martin S. Tullus
Robert G. Veith

Class of '82
William D. Burman
Richard M. Kirby
Steven S. Ratcliffe
John L. Thayer

Class of '83
Robert M. Berry
Edward L. Farrar III
Keith A. Mayo
Elizabeth A. Ouellette
Henry K. Yee
Joseph D. Zuckerman

Class of '84
Jeffrey W. Akeson
Thomas J. Fischer
Jeffrey C. Parker
Kevin P. Schoenfelder
Marc F. Swiontkowski

Class of '85
Paul J. Abbott
William P. Barrett
Richard J. Barry
Daniel L. Flugstad
Jeffrey N. Hansen

Class of '86
Gary D. Bergman
Lawrence Holland
Carlton A. Keck, Jr.
Michael E. Morris

Class of '87
Craig T. Arntz
Herbert R. Clark
Michael K. Gannon
Steven L. Reed

Class of '88
Jonathan L. Franklin
Michael A. Thorpe
Richard V. Williamson

Class of '89
James P. Crutcher, III
Nancy J. Ensley
Martin G. Mankey
Lawrence V. Page
Steve C. Thomas

Class of '90
J. Roberto Carreon
Ken Fujii
David M. Kieras
Walter F. Krengel, Jr.
Jay A. Winzenried

Class of '91
David H. Bishop
Timothy Lovell
Kit M. Song
Mark C. Remington

Class of '92
Elisha T. Powell
Michael J. Sailer
Jeffrey L. Stickney
Donald B. Striplin
John D. West

Class of '93
Philip J. Kregor
Susan Cero
Lyle S. Sorensen
J. Eric Vanderhooft

Class of '94
Eric J. Bowton
Sohail K. Mirza
William T. Obremskey
James W. Vahey
P. Brodie Wood

Alumni & Residents

Class of ’95
Timothy C. Beals
B. Todd Clarke
Scott E. Hormel
Ronald M. Kristensen
William J. Mills

Class of ’96
Vernon J. Cooley
David A. Deneka
Peter W. Mitchell
Peter T. Simonian
William F. Wagner

Class of ’97
Laddie A. Agtarap
Mohammad Diab
David G. Levinsohn
Daniel J. Stechschulte
Randall W. Viola

Class of ’98
David J. Belfie
Jay L. Crary
Oriente DiTano
Donald P. Ericksen
Colin E. Poole

Class of ’99
K. Craig Boatright
Thomas D. Chi
Jeff L. Garr
John D. Michelotti
Julie A. Switzer

Class of ’00
Joel Hoekema
Dan Jones
Cara Beth Lee
Patrick McNair
Brett Quigley

Friends of Orthopaedics

Boston Scientific Corporation
James D. Bruckner
Howard Chansky
Margaret Clark
Ernest Conrad
Douglas P. Hanel
Douglas Harryman
M. Bradford Henley
Roger V. Larson
Neil J. Maki
Joseph Mezistrano
Microsoft
Shirley Minnoch
Vince S. Mosca
Mark Murphy
Omeros
Ortho Consultants
Quattro Consulting
Anthony Romeo
Bruce J. Sangeorzan
John & Constance Sidles
Kevin Smith
Synthes (USA)
3M Corporation
Irving Tobin
Thomas E. Trumble

National Research Grants
Department of Orthopaedics

National Institutes of Health (NIH)

The Collagens of Cartilage and the Intervertebral Disc
David R. Eyre, Ph.D.

Pathology of Inborn Skeletal Diseases
David R. Eyre, Ph.D.

Skeletal Dysplasias
David R. Eyre, Ph.D.

Regulation of Gene Expression in Cartilage
Linda J. Sandell, Ph.D.

Imaging of Molecules by Oscillator-Coupled Resonance
John A. Sidles, Ph.D.

Development of an Extremity Trauma Outcome Scale
Marc F. Swiontkowski, M.D.

Salvage vs. Amputation Following Limb Threatening Injury
Marc F. Swiontkowski, M.D.

Spinal Canal Geometry Changes in Vertebral Fracture
Allan F. Tencer, Ph.D.

Veterans Affairs Medical Center Review Grants

Bimechanics of Flatfoot
Bruce J. Sangeorzan, M.D. and Allan Tencer, Ph.D.

Synthesis and Function of Cartilage Matrix Molecules
Linda J. Sandell, Ph.D.

National Research Grants
Department of Orthopaedics

Centers for Disease Control

Spinal Canal Geometry Changes in Vertebral Fracture
Allan F. Tencer, Ph.D.

Orthopaedic Research and Education Foundation (OREF)

Biomechanics of Femoral Neck Fixation
Jens R. Chapman, M.D.

Multipractice Study of the Effectiveness of Treatment for Rotator Cuff Tears
Douglas T. Harryman II, M.D.

Bristol-Myers Squibb/Zimmer Institutional Grant
Frederick A. Matsen III, M.D.

Randomized Multicenter Trial of Active Versus Passive Motion for the Rehabilitation of Flexor Tendon Injuries
Thomas E. Trumble, M.D.