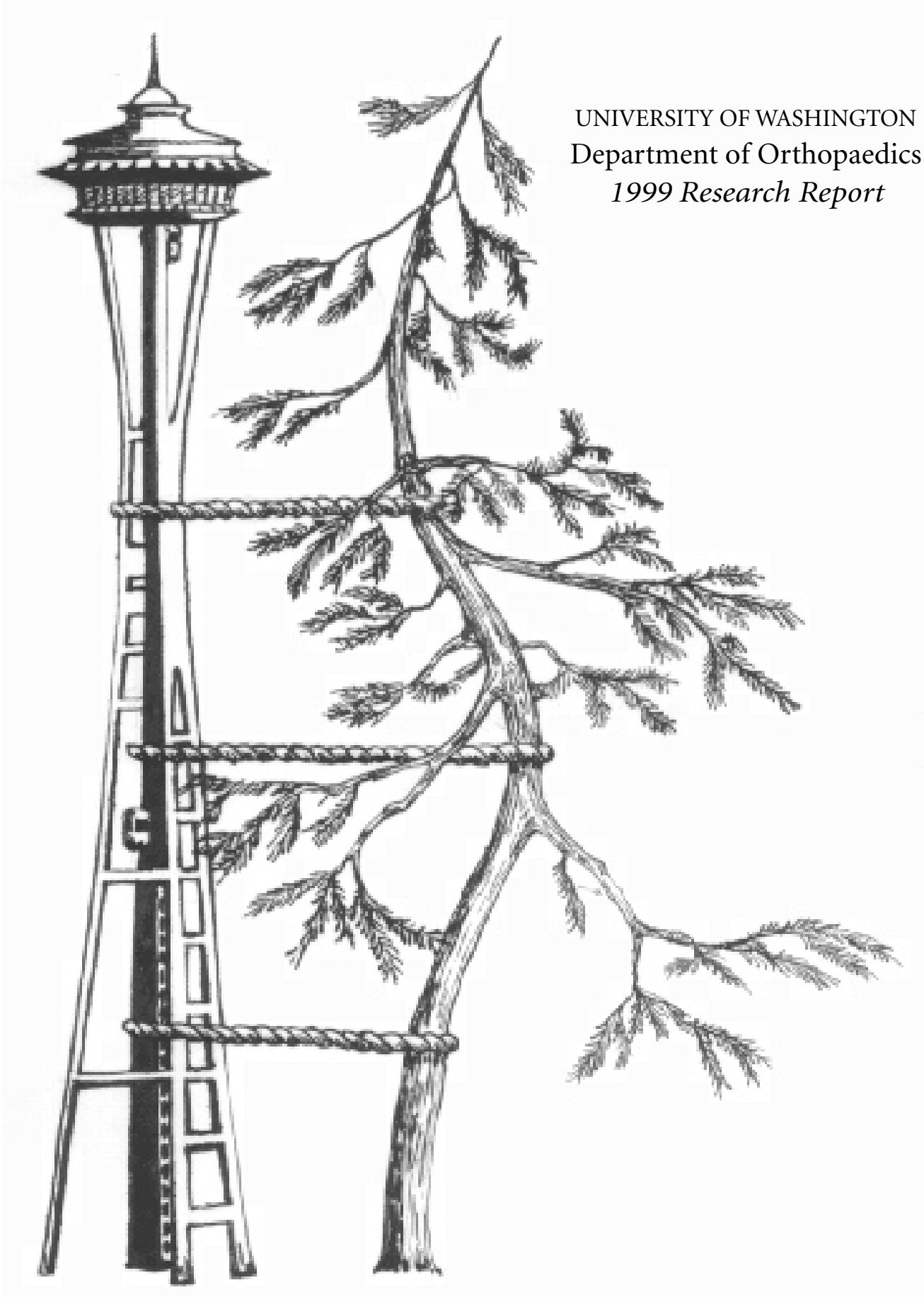
UNIVERSITY OF WASHINGTON

Department of Orthopaedics

1999 Research Report



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Department of Orthopaedics

1999 Research Report

UNIVERSITY OF WASHINGTON SCHOOL OF MEDICINE

Department of Orthopaedics
University of Washington
Seattle, WA 98195

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Cover Illustration: "Builders No. 1" by Jacob Lawrence
1970, Gouache on paper
Courtesy of the Artist and Francine Seders Gallery
Collection of Henry Art Gallery, Seattle
Photograph: University of Washington Media Services

Contents

Foreword

Our cover artist this year is Jacob Lawrence, an important twentieth century artist who now lives in Seattle. Lawrence's style uses flat, strongly outlined shapes in bold geometric patterns to typify the daily life and history of black people in America. Our cover painting is entitled "The Builders" - a most suitable selection for a Department of faculty, residents and staff dedicated to the construction and reconstruction of the human frame. This painting even features some of our traditional orthopaedic tools: hammers, saws and nails. But in building as in Orthopaedics, the end result is determined not by the tools, but who holds them. The builder, the surgeon, is the method!

This year has been poignant for the Department, in that a number of our faculty, family and friends sustained major orthopaedic injuries. Our prayers and best wishes go out to them. These 'up close and personal' experiences make us recognize that, as proud as we are of what Orthopaedics can offer, we have a long way to go before we are as effective builders as we would like to be. Our hope lies in the research we do, in our commitment to contribute to the base of knowledge on which Orthopaedics is based.

Our research efforts are permanently enhanced by the endowments that have become mainstays of our research programs. The Burgess Chair has enabled its holder, David Eyre, to continue make major contributions to our understanding of the development and decay of the human frame. The Hansen Chair, held by Ted Hansen, provides core support for our research program in Orthopaedic Biomechanics. The Jerome Debs Chair, held by Steve Benirschke, supports cutting edge research in the management of complex foot and ankle injuries. These enduring programs are now joined by the E.A. Codman/DePuy Professorship for Shoulder and Elbow Research. In recognition of his consistently excellent research, always done with a sharp focus on the End Result, Douglas T. Harryman II has been appointed by the University as the first holder of this Professorship. The illustrations at the right show Amory Codman above and an illustration of one of Doug's many innovations: the arthroscopic release of a frozen shoulder.

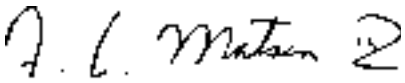
We are well on the way to a professorship in spine surgery in recognition of the innovative research of Drs Mirza and Chapman. Finally, we have launched a campaign to establish a Chair for Women's Sports Medicine and Fitness – this Chair will help us come to grips with the disproportionately high injury rate among active women and lack of gender- specific information on how these injuries can be best prevented and managed.

If you'd like to learn more about the Department of Orthopaedics at the University of Washington, visit us at www.orthop.washington.edu. If you'd like to learn about how you can support our research and educational programs or have other questions for us, please drop us a letter or an Email at matsen@u.washington.edu or simonian@u.washington.edu.

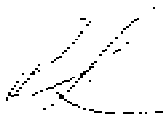
As always we must conclude by expressing our profound appreciation to all the friends, staff, students, residents and faculty who have made this Department the Best in the West. Thanks for your special contribution to our missions of research, teaching and patient care.

Our next issue will be in the new millennium - stay tuned.

Best wishes,



Frederick A. Matsen III, M.D.
Chairman



Peter T. Simonian, M.D.
Chief, Sports Medicine Clinic

E.A. Codman, 1869-1940

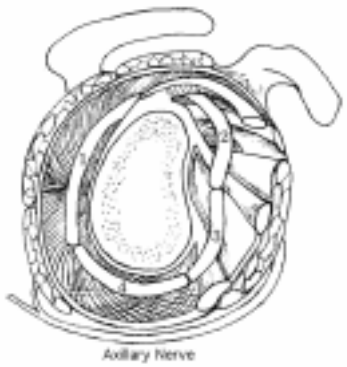


Diagram depicting the typical sequence of capsular release: (1) postero-superior and posterior, (2) antero-superior, rotator interval and subcoracoid recess, (3) antero-inferior; middle and inferior glenohumeral ligaments and (4) postero-inferior; postero-inferior recess and inferior sling.

Chronic Distal Biceps Tendon Ruptures Reconstruction with Autogenous Semitendinosus

Douglas T. Harryman II, M.D., David G. Duckworth, M.D., Michael J. Moskal, M.D., Tim A. DuMontier, M.D., Kevin L. Smith, M.D., and Frederick A. Matsen III, M.D.

Rupture of the distal end of the biceps brachii tendon occurs infrequently and usually presents only in middle-aged males (Figure 1). These tears generally cause substantial loss of supination and elbow flexion strength leading to significant functional impairment.

Most surgeons recommend acute anatomical repair within a maximum of two or three weeks after injury to avoid difficulty. In chronic distal biceps tears, achieving an anatomic repair is unlikely because of prolonged contracture of the musculotendinous unit, tendinous attenuation and scarring between the muscular planes of the forearm. For these reasons, clinicians have recommended either nonoperative management or attachment of the retracted distal biceps tendon stump to the brachialis, a method which does not restore supination strength.

In 1991, we began offering reconstruction of the distal biceps using an autogenous semitendinosus interposition graft to patients with disabling loss of elbow flexion and forearm supination. The purpose of this study was (1) to describe our surgical method for reconstructing a chronic rupture of the distal biceps tendon using a free autogenous semitendinosus graft and (2) to determine the outcome in terms of strength and elbow range, forearm rotation and functional activities of daily living after reconstruction.

Materials and Methods

The first procedure was performed in 1991. Since then, a total of nine patients with ten ruptures have had reconstruction of the distal biceps tendon using a semitendinosus graft (Table 1). All patients were male and their average age was 46 years at the time of repair (range, 29 - 61 years). The mean interval between rupture and tendon reconstruction was 9.0 months (range, 1-19 months). The average follow-up for seven of nine patients with more than two-year follow-up was 39 months (range, 24-74 months). All injuries resulted from a sudden eccentric force against a contracted biceps with a flexed elbow.

All operative procedures were performed by one of the senior authors (DTH II and FAM III). All reconstuctions utilized a double stranded semitendinosus autograft to bridge the gap between the retracted biceps tendon and the radial tuberosity. A two incision technique was utilized in six of ten cases and a one incision technique in four cases.

All patients were available for follow-up clinical examination and Simple Elbow Test self-assessment questionnaire (source SET-FAM III). Clinical examination included flexion, extension, pronation, and supination motions in all patients. Flexion and supination strength measurements using a Cybex isokinetic dynamometer were obtained in seven patients with eight repairs having follow-up of greater than two years.

Operative Technique

Under tourniquet control, an anterior curvilinear Henry-type incision is made over the antecubital fossa and the radial tuberosity is exposed. An elliptical hole is opened in the radial tuberosity. Surgical dissection is directed proximally to expose the distal stump of the retracted biceps tendon which is usually adherent to the coracobrachialis. The entire distal biceps muscle is mobilized while protecting the musculocutaneous nerve until an elastic muscular bounce is recreated.

The single or two incision technique can be used to secure the semitendinosus to the radial tuberosity. The one-incision technique requires greater *distal dissection* in the forearm and the two-incision technique requires a *separate incision* on the extensor surface. When a single incision is chosen, six drill holes are placed in a ring distal to the elliptical tendon insertion site in the radial tuberosity and three sutures are passed (Figure 2A and 2B).

The semitendinosus graft is harvested. The looped mid-section of a folded tendon is implanted into the radial tuberosity. Sutures are passed in a Bunnell fashion through each limb of the tendon using a tapered #5 Mayo needle to avoid cutting fibers. After attaching the tendon, full supination and pronation is performed to insure that the radial tuberosity and reconstructed autograft tendon has free passage through the proximal radio-ulnar bursa.

The free proximal ends of the graft are passed through the central musculo-tendinous fibers of the distal biceps and are pulled toward the radial tuberosity while the elbow is flexed to adjust light tension in the reconstructed musculo-tendinous unit and then sutured in place.

Postoperatively, the elbow is immobilized in flexion but motion begins the day after surgery. Each week after surgery, passive extension with the supinated forearm is increased by 10° until full motion is recovered. Passive supination and pronation is performed with the elbow flexed at 90° until maximal flexion and extension are recovered. Twelve weeks after reconstruction, active assisted flexion-extension and supination-pronation are begun. Resistance to flexion is increased one pound each week to four pounds by four months after the repair. At six months, slow repetitive curls under a comfortable load are performed until fatigue. The patient should permanently avoid sudden heavy loads against elbow flexion.

Results

All ten reconstructions remained intact and were assessed using side to side strength and motion measurements (Figure 3). Excellent range of motion was maintained in 8 of 9 patients and elbow strength was within a mean of 15% of the opposite side in the seven patients having a two year follow-up. Follow-up examination results which include range of motion

Case	Age All	Age Male	Injured/ Dominant side	Work Comp	Delay in Rx (Mths)	Time to Operation (Mths)	Maximum Recovery (Mths)	Sports? Before/ After	Biceps Sx's Persist?	Leg Sx's (graft)	RTW?	Success? Y/N
1	60		R/R	Yes	NA	16	24	N/N	cramps & stiffness	parasthesias	Retired	Yes
2	46		L/L	Yes	2	3.5	12	N/N	mild weakness	No	Yes	Yes
3	29		L/R	No	12	4.5	12	Y/Y	No	No	Yes	Yes
4-R	61		R/R	Yes	12	12	12	N/N	R-hand weakness	occ. cramps	Yes	Yes
5-L	-		L/R	-	24	19	18	N/N	mild weakness	No	NA	Yes
6	43		R/R	Yes	2	7	8	Y/Y	occ. cramps	occ. pain	Yes	Yes
7	34		L/R	Yes	3	6	18	Y/Y	pain and stiffness	No	Yes	Yes
8	47		R / R	No	2	1	6	Y/Y	No	No	Yes	Yes
9	54		R / L	No	6	17	6	N/N	No	No	Yes	Yes
10	36		R / R	Yes	2	4	Recovering	N/N	No	Yes	Yes	Yes
	Avg 47yrs		Avg ± SD	7/9-Y	7 ± 8	9 ± 6	14 ± 6	4/4 Yes	6/10-Yes	3-Yes	9-Yes	10-Yes

Table 1: Preop/Postop Demographics.

Case	Range of Motion Ext° - Flex° (Pron/Sup)	Strength Deficit (%) Flexion (60°/sec) Side	Strength Deficit (%) Flexion (60°/sec) NI/Recon	Endurance Deficit (%) Flex work (180°/sec) (20 reps) Side	Endurance Deficit (%) Flex work (180°/sec) (20 reps) NI/Recon	Strength Deficit (%) Supination (30°/sec) Side	Strength Deficit (%) Supination (30°/sec) NI/Recon	Endurance Deficit (%) Supn work (150°/sec) (15reps) Side	Endurance Deficit (%) Supn work (150°/sec) (15reps) NI/Recon	Simple Elbow Test # Yes
1	0° -140° (80°-80°)	24%		-42%		15%		0%		10
2	20° - 140° (80°-65°)	40%		50%		0%		50%		11
3	0° / 145° (80°-80°)	17%		31%		-44%		22%		12
4-R	5° / 145° (80°-80°)	18%		15%		0%		0%		12
5-L	5° / 145° (80°-80°)	Index side		Index side		Index side		Index side		12
6	0° / 145° (80°-80°)	-11%		-29%		-16%		17%		12
7	0° -140° (80°-80°)	3%		6%		28%		-23%		12
8	10° - 130° (50°-80°)	-1%		-32%		-10%		-18%		12
9	check	*		*		*		*		NA
10	check	*		*		*		*		NA
	4° - 143° (76°-78°)	15% ± 17%		5 ± 35%		-4 ± 23%		7 ± 25%		11.6

* no strength testing until >12 months

Table 2: Functional Assessment.

and strength testing are summarized in table 2.

All patients returned to work following surgery, which in five cases involved heavy manual labor. Five patients, active in sports pre-operatively, were able to return with minimal functional disability. Three complications occurred; one posterior interosseous nerve neuropraxia which completely resolved, one heterotopic bone formation which was successfully managed by excision and irradiation and one case of adhesions between the graft and brachialis requiring surgical release. Affirmative answers averaged 11.6 out of 12 on the Simple Elbow Test (Table 3). The time to reach maximum functional recovery was an average of 14 months (range: 6 to 24 months). All patients regarded their operation as successful.

Discussion

Morrey and colleagues, compared results of immediate anatomical reattachment, delayed reattachment,

Simple Elbow Test

1. Is your elbow comfortable at rest?
2. Does your elbow allow you to sleep comfortably?
3. Can you reach the small of your back to tuck in your shirt?
4. Can you place your hand behind your head with your elbow straight out?
5. Will your elbow allow you to pull on socks or stockings?
6. Can you lift one pound to the level of your shoulder?
7. Can you use your elbow to help rise from a chair?
8. Can you carry twenty pounds at your side?
9. Will your elbow allow you to comb your hair?
10. Will your elbow allow you to throw a ball?
11. Does your elbow allow you to wash the back of your opposite shoulder?
12. Can you work full time at your regular job?

Table 3: The Simple Elbow Test.

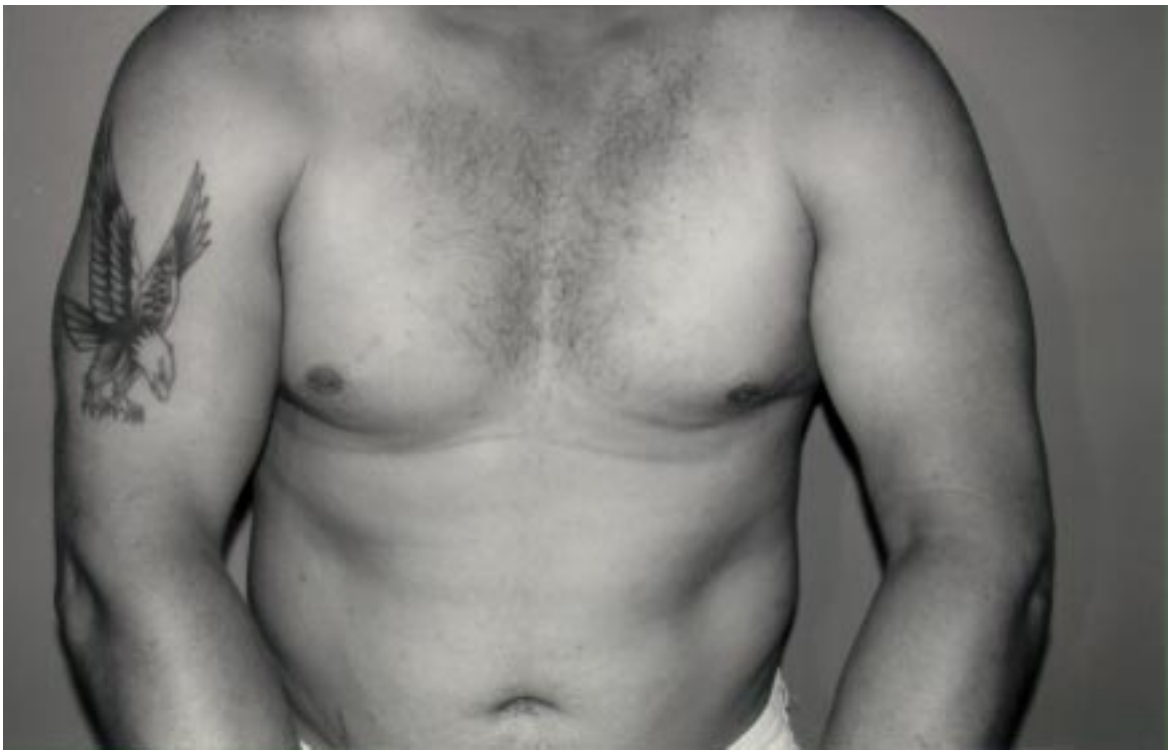


Figure 1: Clinical photograph of a patient with a chronic distal biceps tendon rupture and a retracted biceps (see arm with tattoo).

attachment to the brachialis tendon, and nonoperative treatment of distal biceps ruptures. Immediate reattachment restored normal strength by one year in comparison to nonoperative treatment, which resulted in a 40% loss of supination strength and 30% loss of flexion strength. Attaching the brachialis muscle made no significant improvement in supination strength.

Recently, a case report using the hamstring autograft in a similar way that we have described was reported, however, our repairs antedate this report and no series has been published on using grafts to re-establish the lost length of biceps tendon. Hamstring autograft is commonly used for tendon grafting and has minimal donor site morbidity.

Chronic ruptures of the distal biceps tendon can be managed successfully by using a semitendinosus autograft to bridge the defect between the retracted biceps tendon and radial tuberosity. This technique is relatively simple,

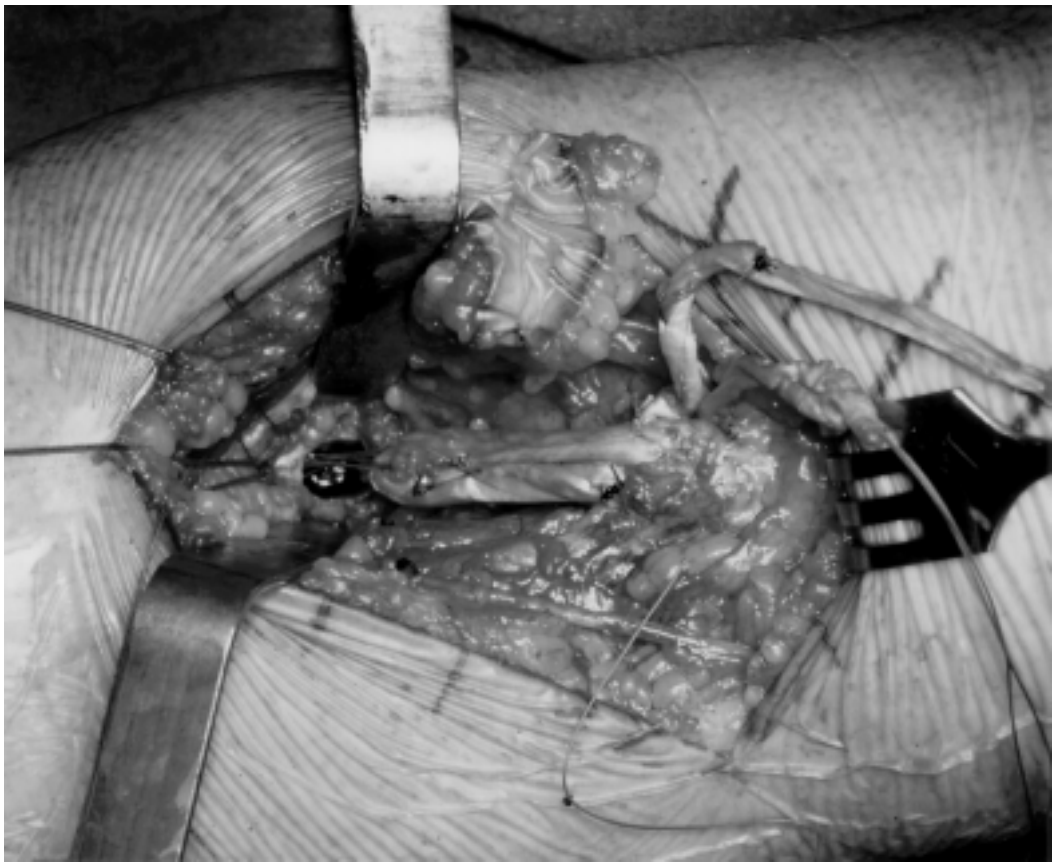


Figure 2A: Insertion of looped semitendinosus autograft into the radial tuberosity. For the one-incision method, the graft is initially secured into the radial tuberosity. Then the tendon is repaired to the distal biceps tendon stump. Tension is adjusted with the elbow flexed 90°.

reliable, and reproducible. Patients recovered elbow and forearm strength and returned to normal activities without significant donor site morbidity. Overall our patients were satisfied with the surgical procedure and believed that it improved their elbow function, relieved discomfort, and restored supination and flexion power. Patients were able to return to work, sporting activities and cosmetically have a more normal appearing arm. We conclude that semitendinosus autograft should be considered for patients who have a chronic tear of the distal biceps tendon (greater than 3 weeks) which has retracted so that it can no longer reach the radial for direct reattachment.

Recommended Reading

Baker, B.E and Bierwagen, D.: Rupture of the distal tendon of the biceps brachii. Operative versus non-operative treatment. J Bone Joint Surg.1985, (67A), 414-417.

Boyd, H.B. and Anderson, L.D.: A method of reinsertion of the distal biceps brachii tendon. J Bone Joint Surg.1961, (43A)7:1041-1043.

Hang, D.W., Bach, Jr., B.R., and Bojchuk, J.: Repair of Chronic Distal Biceps Brachii Tendon Rupture using Free Autogenous Semitendinosus Tendon. Clin. Orthop. 1996; 323:188-191.

Morrey, B.F., Askew, L.J., An, K.N., and Dobyns, J.H.: Rupture of the distal tendon of the biceps brachii. A biomechanical study. J Bone Joint Surg. 1985, (67A), 418-421.

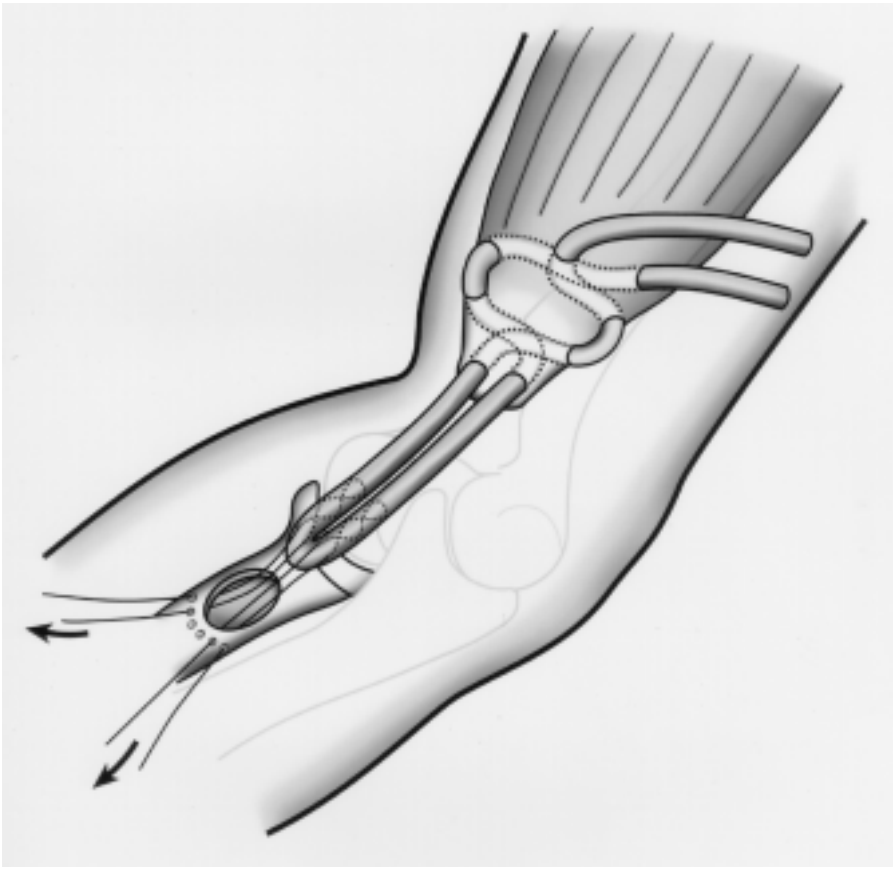


Figure 2B: Insertion of looped semitendinosus autograft into the radial tuberosity. For the one-incision method, the graft is initially secured into the radial tuberosity. Then the tendon is repaired to the distal biceps tendon stump. Tension is adjusted with the elbow flexed 90°.

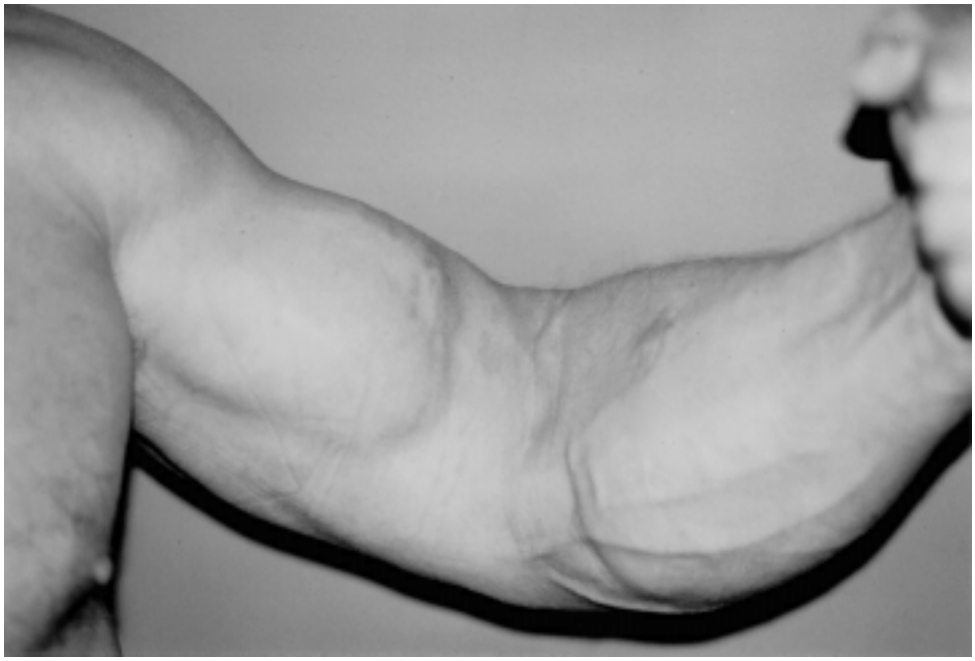


Figure 3: Clinical photograph of a patient at two years who recovered excellent strength of elbow flexion and supination.

Risk of Early Closed Reduction in Cervical Spine Subluxation Injuries

Gerald A. Grant, M.D., Sohail K. Mirza, M.D., Jens R. Chapman, M.D., H. Richard Winn, M.D., David W. Newell, M.D., Dolors T. Jones, R.N., Mark A. Konodi, M.S., and M. Sean Grady, M.D.

The proper treatment of acute traumatic cervical spine subluxation injuries remains controversial. Clinically significant disc herniation occurs in association with cervical trauma, however, the exact incidence of acute disc herniation remains unknown. No strict guidelines exist in the acute management of these injuries, with regard to the timing of closed reduction and prioritization of imaging studies. Reduction of a dislocation of the cervical spine potentially increases the diameter of the spinal canal at the level of injury and decompresses the spinal cord. However, it has also been theorized that patients with cervical spine subluxation injuries may suffer neurological deterioration following closed reduction in the presence of an associated herniated disc at the level of the injury. We present our experience with 121 patients admitted with cervical spine subluxation injuries. We address the incidence of cervical disc injury and the risk of early closed reduction in these patients.

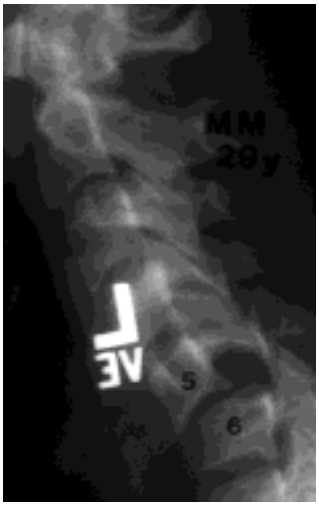


Figure 1: Radiographs can clearly show displacement in a vertebral dislocation.

Materials and Methods

We reviewed 121 patients admitted to Harborview Medical Center in Seattle, Washington with traumatic lower cervical spine injuries (C3-C7). We excluded patients with gunshot wounds, minor fractures, and injuries without subluxation. We retrospectively reviewed the medical records and imaging studies (i.e. CT and MRI) of the remaining 82 patients (63 men and 19 women, average age 42 years).

We treated all patients immediately upon presentation to the emergency room according to ATLS (Advanced Trauma life Support) guidelines following spinal immobilization. We gave all patients methylprednisolone. Senior neurosurgical house officers performed serial clinical examinations using the American Spinal Injury Association (ASIA) motor score and Frankel Scale to assess the degree of neurological impairment. We used Gardner-Wells tongs to apply axial craniocervical traction with fluoroscopic monitoring. Using sequential weight applications, we attempted immediate reduction to improve the spinal alignment and reduce cord compression. We performed open reduction when traction was unsuccessful. We determined the ASIA motor and Frankel scores upon admission to the emergency room, at 6 hours, and 24 hours after reduction.

We obtained cervical magnetic resonance images (MRIs) within 24 hours following closed reduction. We established disc injury from the MRIs as either a herniation or disruption. In a herniation, the disc extruded deforming the thecal sac or nerve roots. In a disruption, the disk space was widened, but without disk extrusion.

For our statistical analysis we crosstabulated several dependent factors with classifications of the disc injury and fracture type to calculate the Pearson correlation coefficient. We compared pre- and post-reduction ASIA Motor scores using a paired-samples t test with p values of $p<0.05$.

Injury Type	Number of Patients	% of Total
Unilateral facet dislocation	26	32%
Bilateral facet dislocation	15	18%
Compressive burst fracture	21	26%
Extension injury	9	11%
Miscellaneous	11	13%

Table 1: Classification of Skeletal Injury.

Results

All of our patients sustained cervical spine subluxation injuries, Table 1. Our immediate, rapid closed reduction was successful in 80 of 82 patients (98%). Our average time to achieve closed reduction was 2.1 ± 0.24 hours (mean ± SEM) from the time of arrival in the emergency room. The average traction weight we applied was 37 ± 4% (mean ± SEM) of body weight (range, 4% to 80%). Despite application of maximal weight, we were unable to adequately realign the spinal column with closed reduction in two patients. Neither of these patients suffered neurological deterioration during our closed reduction attempts.

We were able to perform an MRI within 24 hours of reduction in 76 patients. The incidence of disk injury at the level of the subluxation was 46% (herniation 22% and disruption 24%). The incidence of disk injury was significantly more common in the elderly (greater than 55 years old). The

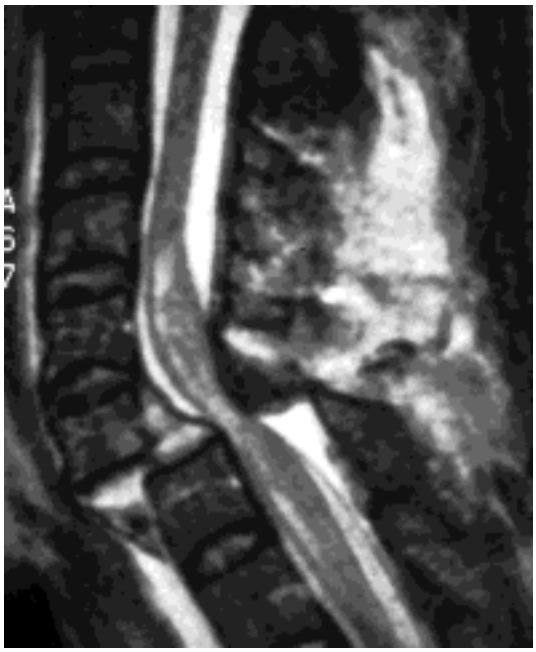


Figure 2: MRI of a dislocated cervical spine visualizes the cord compression inferred from X-rays (Figure 1). This visualization is not necessary to recognize the need for reduction.

Figure 3: Radiographs after closed reduction show that the spinal canal is realigned and spinal cord compression reduced (Same patient as in Figure 1).

presence of a disk injury significantly correlated with the presence of a spinal cord contusion on MRI.

The majority of our patients presented with complete or incomplete spinal cord injuries, Table 2. Neurological recovery, assessed by the ASIA motor scores, significantly improved 24 hours following closed reduction, Table 3. Only one patient deteriorated following immediate closed reduction.

Discussion

Our review of the traumatic cervical spine injuries over the last three years indicates that immediate closed reduction is safe in awake and examinable patients. We successfully reduced 98% of our patients within 2.1 ours of admission to the emergency room. Post-reduction MRI indicated acute disk injury in 46% of the patients in our series. Although a traumatic disk herniation could increase spinal cord compression following closed reduction, our experience does not show this to be a clinically significant concern. Irrespective of the presence of a disk injury, the incidence of neurological deterioration following closed reduction was rare in our series. One patient out of 76 undergoing post-reduction MRI deteriorated 4 ASIA motor points, but did so more than 6 hours following closed reduction. This minor change in motor score was most likely a cervical radicular compromise and not due to spinal cord compression.

The goal of skeletal traction for closed reduction is to alleviate compression of the spinal cord. Several clinicians have strongly advocated imaging studies prior to reduction in any patient with a neurological deficit to assess the injured disk. Obtaining an MRI prior to reduction can add a significant delay and may place the patient at added risk. We do not delay closed reduction in a patient with a cervical subluxation who presents with a complete motor deficit. We also advocate immediate closed reduction for neurologically incomplete and intact patients. None of the 22 intact patients showed any neurological deterioration following immediate closed reduction.

Injury Type	Number of Patients	% of Total
Complete	25	30%
Incomplete	21	26%
Radiculopathy	11	13%
Transient	7	9%
Intact	18	22%

Table 2: Classification of Neurological Injury.

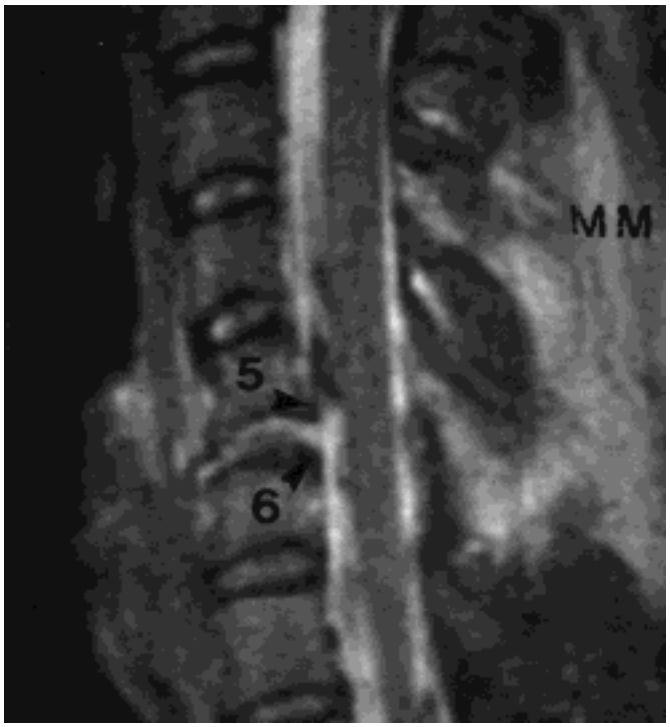


Figure 4: Post-reduction MRI is useful for assessing any residual cord compression.

Neurological Deficit	Pre-Reduction	Post-Reduction
Complete	9.8±2.9	16.9±3.6†
Incomplete	35.8±7.2	47.7±7.8‡

†Significant p=0.001
‡Significant p=0.005

Table 3: Neurological recovery, improvement in ASIA motor scores.

Conclusion

Rapid closed reduction of cervical spine subluxation injuries with traction is safe and effective. In our series, closed reduction was successfully performed within a few hours of the injury. Although a disk injury documented by MRI was often associated with these traumatic cervical spine injuries, the risk of neurological deterioration following closed reduction was rare.

Early Versus Delayed Surgery for Acute Cervical Spinal Cord Injury

Jens R. Chapman, M.D., Sohail K. Mirza, M.D., Walter F. Krengel III, M.D., Paul A. Anderson, M.D., James C. Bailey, M.D., M. Sean Grady, M.D., Mark A. Konodi, M.S., and Hansen A. Yuan, M.D.

Patients with spinal cord injuries comprise a major portion of the trauma victims with high mortality and long term morbidity. As with all trauma victims, the majority of these patients are between the ages of 16 and 32 years, resulting in a disproportionately high loss of productive years of life for both these individuals and for society. One third of these trauma victims have injuries involving the cervical spine. Management of spinal cord injury remains controversial. Recent laboratory studies and clinical trials indicate that early intervention may be associated with improved results. Previous studies, however, have reported increased risk of neurologic deterioration with early surgical intervention. The optimal timing of surgical intervention in cervical spinal cord injuries has not been defined.

The goal of this study was to investigate acute care complications associated with surgery within three days of cervical spinal cord injury versus surgery more than three days following the injury. We specifically wanted to assess the rate of neurologic deterioration with early surgery. We also wanted to determine if the rates of other events such as pulmonary complications were different with early and delayed surgery.

Materials and Methods

We retrospectively reviewed all patients undergoing surgical management for an acute cervical spinal injury with neurologic deficit at two institutions between March 1989 and May 1991. Our study population consisted of 30 patients, 15 patients treated at the State University of New York, Syracuse, New York, and 15 patients treated at Harborview Medical Center, Seattle, Washington.

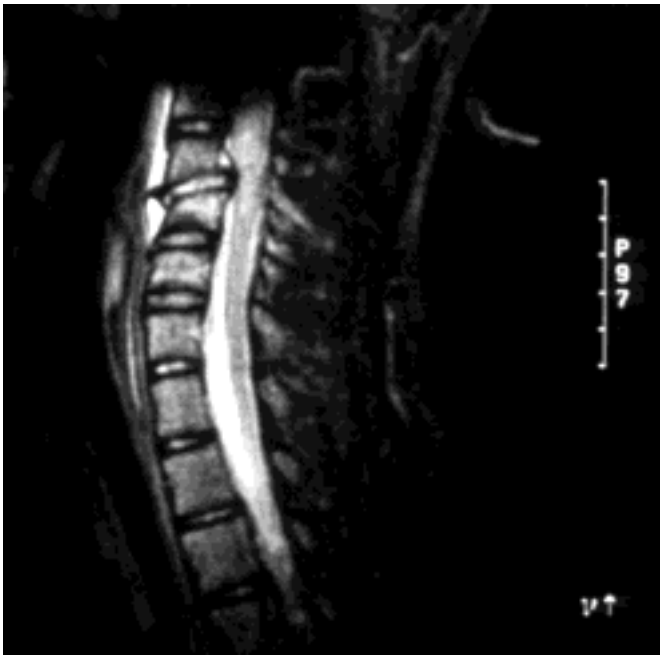


Figure 1: MRI of an 18 year old male with sudden tetraplegia following a football injury.

The goal of surgery was to restore spinal stability, relieve persistent neurologic compression, and allow mobilization of the patient. At the State University of New York, patients with neurologic spinal injuries had surgical intervention usually within 72 hours of injury. At Harborview Medical Center, patients underwent immediate closed reduction; patients were subsequently observed for neurologic status for 10 to 14 days prior to undergoing surgical stabilization. Postoperative treatment was similar at both institutions.

Neurologic status was recorded at initial presentation, preoperatively, and at time of discharge from the hospital or transfer to a rehabilitation unit. In addition to a neurologic exam, neurologic function was recorded as Frankel Grade and American Spinal Injury Association (ASIA) motor score. Glasgow Coma Score was determined for each patient at the time of presentation to the emergency room. Associated non-spinal injuries were also recorded. Injury Severity Score was retrospectively calculated from this data.

Statistical analysis was performed using a two-sample Students t-test assuming unequal variances and chi-square analysis with the Yates continuity correction. Significance was defined by a p-value < 0.05.

Results

The Injury Severity Score averaged 24.8 for the early surgery group and 26.2 for the late surgery group. The Glasgow Coma Score averaged 14.4 for the early surgery group and 14.1 for the late surgery group. Neither difference was statistically significant. The difference in the duration of ICU stay and mechanical ventilation was not significant between the two groups. Duration of acute care stay was longer in the late surgery group: 36.8 days compared to 21.9 days, consistent with the longer pre-operative hospitalization period for the patients in the late surgery group.

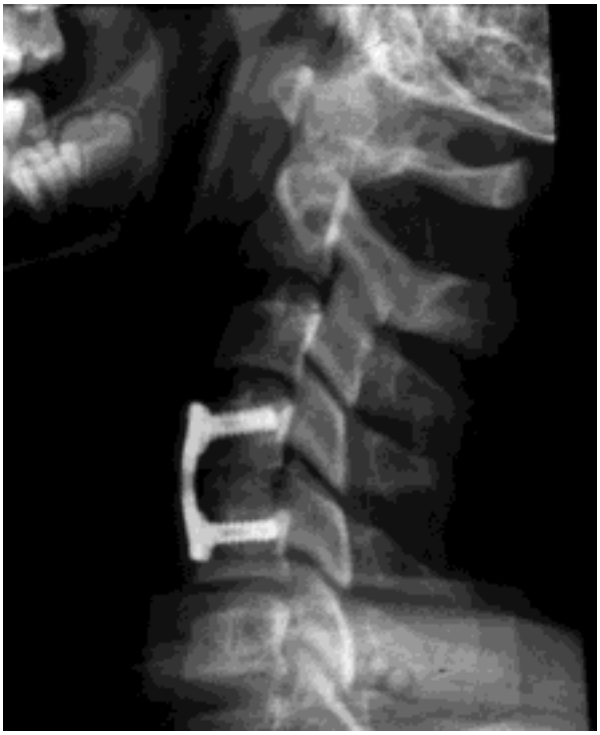


Figure 2: Anterior discectomy and stabilization was performed within 3 hours of injury. The patient had full neurologic recovery.

The improvement in the ASIA Motor score from pre-operative assessment to post-operative assessment was significant in the early surgery group but not in the late surgery. The improvement in the Frankel Grade from the pre-operative level to the post-operative level was again significant in the early surgery group but not in the late surgery group.

The number of major complications and minor complications was not statistically different between the two groups. No patient showed neurologic deterioration during the course of treatment.

Discussion

The results of this study support the position that patients who sustain acute traumatic injuries of the cervical spine with associated neurologic deficit may benefit from surgical decompression and stabilization within 72 hours of injury. Surgery within this early period on patients with acute traumatic injuries of the cervical spine was not associated with increased complications. Patients who underwent surgery within this relatively early time period showed a significant improvement in neurologic status during their acute hospitalization whereas patients who underwent delayed surgery did not show any significant change in neurologic status.

Our study raises the question that factors other than the timing of mechanical decompression may also influence neurologic outcome. Specifically, an unstable spine protected by traction and bed rest may sustain some degree of continued abnormal motion. This skeletal instability at the injured segment may have a deleterious effect on the healing potential of injured neural tissue. Skeletal stabilization in spinal cord injury may similarly protect the neural tissue from further injury and facilitate neurologic recovery. We noticed a difference in neurologic recovery in our two small patient populations even though both of these groups had early mechanical decompression by closed reduction. The group of patients kept in traction and bed rest for two weeks showed less neural recovery.

Timing of intervention has been shown to be important in laboratory models of spinal cord injury. Laboratory studies show evidence of a window of opportunity in the initial few hours following a spinal cord injury where treatment interventions may be fruitful in minimizing the neurologic insult

Conclusions

Surgery within 72 hours of injury in patients sustaining acute cervical spinal injuries with neurologic involvement is not associated with a higher complication rate and early surgery does not result in neurologic deterioration. Early surgery may improve neurologic recovery. This assessment requires more research.

Relationship Between Neurological Deficit and Spinal Cord Deformation in Cervical Spine Injuries

Gregg K. Motonaga, B.S., Randal P. Ching, Ph.D., Mark A. Konodi, M.S., and Sohail K. Mirza, M.D.

Several recent studies of traumatic spinal injury have explored the relationship between the morphology of the spinal canal and the resulting neurological deficit. Researchers have investigated this relationship in two ways. The first approach focused on the variations of normal spinal anatomy that predispose individuals to increased risk of injury or decreased potential for neurological recovery. In these studies the investigators evaluated the risk of neurologic injury measurements of the residual space around the spinal cord. The second approach focused on the neurological consequences associated with spinal canal geometry changes resulting from traumatic injury. In these studies the investigators indirectly measured spinal canal morphology from the contour of displaced bony fragments impinging on the cord.

Regardless of approach, previous studies have represented the amount of pre-existing stenosis or post-injury canal compromise using measurements of the bony canal rather than the spinal cord. The purpose of our study was to document the geometry of both the soft tissue components and bony elements of the cervical spine following injury. This enabled us to test the hypothesis that the severity of neurological deficit in acute cervical spine injuries is related to the degree of residual, post-reduction deformation of the spinal cord.

Measurement	MRI Source	Description
Length of Injury	Sagittal Reconstruction	Total longitudinal length of deformation to the thecal sac
C4 Body Height	Sagittal Reconstruction	Height of C4 vertebra measured at the center of the body
Thecal Sac Area	Axial Scan	Cross-sectional area of the space within the boundaries of the thecal sac
Thecal Sac Sagittal Diameter	Axial Scan	Sagittal diameter of the thecal sac
Thecal Sac Transverse Diameter	Axial Scan	Transverse diameter of the thecal sac
Spinal Cord Area	Axial Scan	Cross-sectional area of the spinal cord
Spinal Cord Sagittal Diameter	Axial Scan	Sagittal diameter of the spinal cord
Spinal Cord Transverse Diameter	Axial Scan	Transverse diameter of the spinal cord

Table 1: Initial Measurements From Cervical MRI Scans.

Parameter	Description
Length of Deformation	Length of injury divided by the body height of C4
Cord Area Ratio	Spinal cord area at maximum deformation divided by the area at uninjured levels
Cord Sagittal Diameter Ratio	Spinal cord sagittal diameter divided by the sagittal diameter at uninjured levels
Cord Transverse Diameter Ratio	Spinal cord transverse diameter divided by the transverse diameter at uninjured levels
Max Area Ratio	Maximum value of spinal cord area divided by the thecal sac area along the length of the cervical spine
Max Sagittal Diameter Ratio	Maximum value of spinal cord sagittal diameter divided by the thecal sac sagittal diameter along the length of the cervical spine
Max Transverse Diameter Ratio	Maximum value of spinal cord transverse diameter divided by the thecal sac transverse diameter along the length of the cervical spine

Table 2: Summary of Normalized Spinal Cord Deformation Parameters.

Materials and Methods

Our study was a retrospective analysis of 24 patients admitted to Harborview Medical Center, Seattle, Washington for acute cervical spine trauma between January 1995 and February 1997. We reviewed both the magnetic resonance imaging (MRI) scans of the cervical spine and medical records of these patients. All patients had T2-weighted MRIs and neurological evaluations based on the American Spinal Injury Association (ASIA) motor scale. Ten patients had neurologically complete spinal cord injuries and 14 patients had incomplete injuries.

We used a personal computer and flatbed scanner to capture images of the cervical spine from the MRI scans. We scanned one mid-sagittal image from a lateral MRI and seven axial images from the axial MRIs (one axial image at the level of injury and three each above and below this level). Once we captured a complete set of images, we measured several morphological variables from the digitized images using the image analysis program NIH Image. Table 1 describes our initial measurements and Figure 1 shows those measurements in an axial MRI scan. From our initial measurements, we next determined a set of parameters describing spinal cord deformation. We normalized these parameters to account for body-size and gender effects (Table 2).

For statistical analysis we used the StatView software package. We performed linear regression analysis on the relationship between each of our normalized spinal cord deformation parameters and the patient's ASIA motor scores. We also used non-parametric analysis to examine any differences in deformation parameters between the patients with complete and incomplete neurological deficits. We defined significance as a p-value < 0.05.

Parameter	R^2 Value
Length of Deformation	0.46
Cord Area Ratio	0.28
Cord Sagittal Diameter Ratio	0.09
Cord Transverse Diameter Ratio	0.23
Max Area Ratio	0.31
Max Sagittal Diameter Ratio	0.42
Max Transverse Diameter Ratio	0.16

Table 3: Relationship Between Neurological Deficit and Deformation Parameters. Results of Linear Regression.

Results

There was an inverse relationship between each of our seven parameters which measured spinal cord deformation and the neurological deficit. Larger spinal cord deformations were associated with greater neurological deficits, although none of the linear regressions had an R^2-value greater than 0.50 (Table 3). Patients with complete neurological deficits differed from those with incomplete deficits with respect to length of deformation, cord area ratio, cord transverse diameter ratio, maximum area ratio, maximum sagittal diameter ratio, and maximum transverse diameter ratio. The cord sagittal diameter ratio was the only normalized descriptor of deformation that did not differ between the two groups.

Discussion

The regression analyses failed to show a linear relationship between ASIA motor scores and our measures of spinal cord deformation. Our patients had spinal injuries at different cervical levels. The motor scores could possibly have been affected by the differences in injury level. For example, upper cervical (C2-C3) injuries could present with different degrees of motor impairment than lower cervical (C6-C7) injuries. We were unable to account for this potentially confounding influence on neurological deficit in our analysis.

Our non-parametric analysis indicated that six out of seven of our spinal cord deformation measures were different between the patients with complete neurological deficits and those with incomplete deficits. A relationship existed between neurological deficit, measured by the ASIA motor score and the spinal cord deformation, measured by our deformation parameters. In future research we plan to study the predictive power of our deformation measures in determining potential post-reduction neurological deficit.

Conclusion

We found a relationship between the degree of spinal cord deformation (post-reduction) and neurological deficit in acute cervical spine injuries. We were able to identify six parameters from MRI scans that described the deformation of the spinal cord and may be useful in predicting whether patients have complete or incomplete injuries. Further research will allow us to better predict the neurological outcome from spinal cord deformation measurements.

Recommended Reading

Eismont FJ, Clifford S, Goldberg M, Green B. Cervical sagittal spinal canal size in spine injury. Spine 1984; 9:663-666.

Fontijne WPJ, De Klerk LWL, Braakman R, Stijnen T, Tanghe HLJ, Steenbeek R, van Linge B. CT scan prediction of neurological deficit in thoracolumbar burst fractures. J Bone Joint Surg 1992; 74B(5):683-685.

Hashimoto T, Kaneda K, Abumi K. Relationship between traumatic spinal canal stenosis and neurologic deficits in thoracolumbar burst fractures. Spine 1988; 13:1268-1272.

Matsuura P, Waters RL, Adkins RH, Rothman S, Gurbani N, Sie I. Comparison of computerized tomography parameters of the cervical spine in normal control subjects and spinal cord-injured patients. J Bone Joint Surg 1989; 71A:183-188.

Pavlov H, Torg JS, Robie B, Jahre C. Cervical spinal stenosis: Determination with vertebral body ratio method. Radiology 1987; 164:771-775.

Rasmussen PA, Rabin MH, Mann DC, Perl II JR, Lorenz MA Vrbos LA. Reduced transverse spinal area secondary to burst fractures: Is there a relationship to neurologic injury? J Neurotrama 1994; 11:711-720.

Creatine Supplementation

John O'Kane, M.D.

Oral creatine supplementation has become extremely popular among adult and adolescent athletes in an attempt to "get an edge" over the competition. Its popularity comes despite limited information regarding the safety of long term supplementation and often conflicting data regarding its effectiveness. This article reviews creatine's biochemistry, potential benefits, side-effects, safety, and recommended dosage. Results of a survey of common dosage and side-effects among division 1 college athletes will be discussed.

Overview

Creatine is an organic compound normally found in skeletal muscle. It combines with phosphorus to form phosphocreatine (PC). PC serves as a donor of phosphate to make and regenerate ATP which is the energy source for contracting muscle. ATP is normally generated for short intensity activity by glycolosis or anaerobic (without oxygen) metabolism. Longer duration or aerobic activity is fueled by ATP from aerobic metabolism. Before either form of metabolism starts producing ATP, in the first few seconds of exercise, energy is supplied by existing ATP in the muscle. Theoretically, by increasing the concentration of PC in the muscle, the amount of ATP to fuel initial exercise is increased. A second theoretical benefit of increased PC in muscle is the ability to regenerate ATP stores faster between episodes of exercise.

Creatine is normally synthesized in the body by the liver, kidneys, and pancreas at a rate of 1-2 g per day. About 2 g per day is lost by the body through the kidneys. Dietary intake from mostly fish and meat is about 1 g per day but varies significantly. Most individuals store approximately 125 mmole/kg (range 90-160 mmoles/kg) of creatine in skeletal muscles. Those with diets low in meat and fish tend to be in the lower range. The maximum concentration obtainable in skeletal muscle is 160 mmoles/kg. Creatine consumed after muscles are maximally loaded is filtered by the kidneys and lost in the urine.

Creatine is produced synthetically for supplementation. It is not currently banned by the NCAA or IOC. It is viewed by the FDA as a supplement and is therefore not regulated.

Benefits

In certain studies, subjects taking creatine have shown improvement in performance. The improvement is generally in the form of increased time to exhaustion or increased power output performing short burst, high intensity, repetitive activities. Most of the studies demonstrating positive results use a cycle ergometer and the improvement is noted only in the repeated bouts of exercise.

It is hypothesized that creatine may increase the ability to gain strength through weight training, largely by decreasing recovery time between sets. This is not proven.

Studies examining swimming and running performance are mixed at best. It is hypothesized that weigh gain (see side effects) from creatine supplementation may offset any potential gains from small incremental increases in strength.

Studies examining performance in endurance exercise do not show any benefit from creatine.

There are no studies assessing "on the field" performance.

One issue that has caused confusion is that certain individuals, and certain study groups, show a benefit while others do not despite similar test protocols. It is hypothesized that subjects with little creatine in their regular diet (i.e. vegetarians) may benefit more than those with high dietary intake. This could account for some of the mixed results.

Side Effects

There is very little research on side effects. Weight gain is widely recognized which could be a good or bad effect depending on the sport. The weight gain is likely secondary to increases in both intra and extracellular water. Studies have shown that the early weight gain is not from increased size or number of muscle cells.

Muscle cramps and strains are reported by athletes taking creatine. This evidence is anecdotal only and there is no proof that creatine is responsible. It is hypothesized that increases in intracellular water may have adverse physiologic or mechanical effects on the muscle cells resulting in increased strains.

Side effects reported by 52 college baseball and football players over a winter conditioning season are reported in Table 1.

Safety

Studies on the short term safety of creatine have not demonstrated any significant irreversible changes in blood chemistry, liver function, or kidney function. The kidneys have to "work harder" filtering high concentrations of

	Total percentage
muscle cramps/strains	33%
GI–diarrhea	31%
GI–other	27%
undesirable weight gain	13%
dehydration/thirst	13%
other	23%
none	27%

Table 1: Side effects reported by 52 college baseball and football players over a winter conditioning season are reported.

creatine particularly during loading, but there is no evidence thus far that damage is done. There is no clear pattern of adverse health effects with the extensive short term experience.

There are no data to support or call into question the long term safety of creatine. This is arguably the most concerning feature of creatine supplementation.

Creatine is unregulated by the FDA in its production, distribution, or sale. Thus the quality control of the ingredients is not specified.

Dosage

Currently a loading dose of 5 g, 4 times a day for 5 days followed by 2 g per day has been recommended. At this dosage the muscles ability to absorb creatine is saturated. Taking a higher dose increases the cost and potential for side effects.

In the baseball and football survey, it was common for the recommended maintenance dosage to be exceeded. Overall, 75% of the athletes exceeded 5 grams/day. Of those, 35% took more then 9 grams/day and 6% took 17-20 grams/day. The unnecessarily high dosages used by these athletes may explain the high incidence of side-effects reported in the survey.

Conclusion

Creatine may result in small ergogenic gains in some athletes doing specific types of short burst, repetitive activities especially if used in conjunction with a training program. There are many questions that remain regarding long term safety, side-effects and dosage. Because of the widespread use of creatine supplementation, it is important for health professionals to continue to seek more information regarding creatine so that they may prudently and accurately advise their patients.

Recommended Reading

Juhn MS, Tarnopolski M. Oral creatine supplementation and athletic perfomance: a critical review. Clin J Sport Med 1998; 8(4): 286-297.

Juhn MS, Tarnopolski M. Potential side effects of oral creatine supplementation: a critical review. Clin J Sport Med 1998; 8(4): 298-304.

Stricker PR. Other ergogenic agents. Clinics in Sports Medicine, Sports Pharmacology 1998; 17(2): 284-286.

Increased Type II Collagen Turnover in Trained Marathon Runners Versus Age-Matched Controls

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Normal articular cartilage, composed of chondrocytes, collagens, proteoglycans, water, and non-collagenous matrix proteins, has unique biological and material properties that enable it to withstand significant loads without apparent detrimental effect. Although the maximal tolerable repetitive impact load is unknown, it is thought that articular cartilage can withstand a single impact load of up to 25 megapascals (MPa) without demonstrable injury. Normal physical activities, including running and jumping, are not thought to exceed this threshold in normal joints. However, if this capacity is exceeded by repetitive submaximal loading over time or by a single overloading event, damage to the joint may result.

The relationship between articular cartilage and weight-bearing exercise is complex. While motion and moderate activity is probably beneficial, certain athletic pursuits in general and many activities at an elite level may lead to overload of articular cartilage and predispose to osteoarthritis. Several studies have investigated the relationship between long distance running and osteoarthritis in both humans and animals. While some of the epidemiological results are contradictory, analysis of the published data as a whole suggests that elite level running (high miles per week or high lifetime miles) leads to an increased risk of osteoarthritis. As such, the present study was undertaken to assess the effect of pre-marathon training (repetitive loading) and completion of a competitive marathon (concentrated repetitive load) on the breakdown/ turnover of type II collagen, the principal collagen of articular cartilage, and type I collagen, the principal collagen of bone.

Materials and Methods

Healthy, age-matched volunteers without known orthopaedic or rheumatologic disease were recruited from the orthopaedic department of a teaching hospital and divided into two groups based upon their intention to participate (runners, N=7) or not participate (controls, N=6) in a marathon. All subjects were males with the exception of one runner. No participant had any history of articular injury or known familial predisposition to osteoarthritis, although one runner and one control had undergone arthroscopic partial medial meniscectomy in the remote past. All subjects were residents, fellows, or graduate students not taking medication. An exercise and running history was obtained from each. Body mass indices were calculated for all participants and reported as kg/m^2.

Second morning void urine samples were obtained at four weeks pre-race and at one, four, eight, and fifteen days post race. Urinary levels of a cross-linked type II collagen C-telopeptide fragment were assayed with a monoclonal antibody by an enzyme-linked immunosorbent assay (ELISA) and reported as Col 2 CTx / mg creatinine (2CTx). This experimental assay utilizes an antibody that recognizes a proteolytic neoepitope of type II collagen generated in vitro by matrix metalloproteinases and is thought to have the potential to follow cartilage degradation in degenerative joint disorders. Type I collagen breakdown was measured by a commercially-available urinary assay and reported as nM bone collagen equivalents / mM creatinine (NTx). The data were analyzed using repeated measures analysis of variance (ANOVA) techniques.

Results and Discussion

Runners ran an average estimated 21 miles per week (range 10 - 40) in the year preceding the marathon, while controls ran an average estimated two miles per week (range 0 - 12). Runners also had completed a significantly greater number of previous marathons than the controls. All participants were non-obese, height and weight proportionate with body mass indices in the normal range. No difference between the average BMI of the runners and the controls was noted. As a group (all time points combined), the runners had increased 2CTx levels as compared to the controls, and the difference was statistically significant (mean increase = 42%, $p = .035$). No difference in NTx levels was noted (controls = 43.9 + 21.1; runners = 39.2 + 17.9 nM bone collagen equivalents / mM creatinine). The difference between 2CTx and NTx levels as a function of time was not statistically significant ($p = 0.6$). However, the difference in the 2CTx levels between the runners and the controls at the eight day post race time point was large ($p = 0.6$, uncorrected for multiple comparisons).

The present pilot study is the first to demonstrate increased turnover or breakdown of cartilage type II collagen in trained athletes, as assessed by a novel molecular method. Although this difference may be a result of an adaptive or selective mechanism peculiar to athletes who choose to participate in distance running, this finding also could be a consequence of repetitive trauma to the articular cartilage of the lower extremities and spine. If this latter explanation of the current data proves correct, it could have significant implications for long distance runners. Interestingly, the urinary 2CTx (type II collagen breakdown product) values for runners and controls in this study are very similar to those previously reported for normal adults and adults with arthritis, respectively. Given the notoriously poor sensitivity of radiographic and clinical parameters for all but the most advanced stages of osteoarthritis, a non-invasive marker for early degradation of cartilage type II collagen as an indicator of pre-clinical articular cartilage pathology is potentially beneficial. Such a tool only facilitate monitoring of the natural history of active joints as well as the effectiveness of medical management. In athletes, appropriate activity restriction or modification of exercise/ rehabilation protocols might have the

potential to prevent or delay the onset of osteoarthritis in at risk individuals, possibly prolonging their careers and enhancing retirement years.

Recommended Reading

Buckwalter, J.A. and H.J. Mankin, Articular cartilage. Part II. Degeneration and osteoarthrosis, repair, regeneration, and transplantation. J Bone Joint Surg, 1997. 79A: p. 612-632.

Buckwalter, J.A. and N.E. Lane, Athletics and osteoarthritis. Am J Sports Med, 1997. 25(6): p. 873-881.

Atley, L.M., Shao, P., Ochs, V., Shaffer, K., Eyre, D.R. Matrix metalloproteinase-mediated release of immunoreactive telopeptides from cartilage type II collagen. Trans Orthop Res Soc, 1998. 23: p. 850.

Subluxation of the Talocalcaneal Joint in Symptomatic Adult Flatfoot

Dheera Ananthakrisnan, M.D., Randal P. Ching, Ph.D., Allan F. Tencer, Ph.D., Sigvard T. Hansen, Jr., M.D., and Bruce J. Sangeorzan, MD.

Though a significant percentage of the population has a foot that could be described as flat, only a small number of these flatfeet have functional limitations or manifest clinical problems.(23,29,31) What distinguishes painful flat foot from a symptom free flatfoot is unknown. It is known that the shape of the bone is altered in some hindfoot deformities.(2) Soft tissue injury or abnormality may also contribute to an acquired deformity. (4,11,17,21,24) In addition, patients with a symptomatic flatfoot are likely to have a diminished arch on the contralateral side.(8) This suggests that there may be an anatomic shape that predisposes a foot to clinical deformity. However, there is no unifying objective method of understanding different types of flat feet. The use of two dimensional radiographs has been sufficient neither to distinguish the subtle differences between flatfoot and normal foot, nor between normal and abnormal flatfoot.

Because of the suggestion on plane radiographs of some of flatfeet that the subtalar and talonavicular joints are subluxed, the term 'peritalar subluxation' has been coined to describe this category of severe symptomatic flatfoot. Actual subluxation has never been documented, however. If there is actual subluxation, it may provide some insight into the pathology and its treatment.

This project was designed to quantitatively define the relationship between the articular surfaces of the talus and calcaneus in a simulated weight bearing position in patients with severe symptomatic flatfoot.

Methods

Computed Tomography scans of the feet of eight patients with symptomatic flatfoot were used to reconstruct a model of the talo calcaneal articulation. The scans had been performed on a custom loading frame developed to simulate weight bearing in a neutral position with a 75N axial compressive load. The digital Computed Tomography image data were used to make three dimensional computer models of the articular surfaces of the talus and calcaneus of each foot. These were used to calculate the percentage of the articular surface that was in contact, and conversely, the percentage subluxed. Two surfaces were built for each bone. The posterior facet was one surface and the anterior and middle facets were combined to form the second surface. The data were compared to scans from feet of four control patients without hindfoot deformity, using Mann-Whitney non-parametric analysis (Figure 1 and 2).

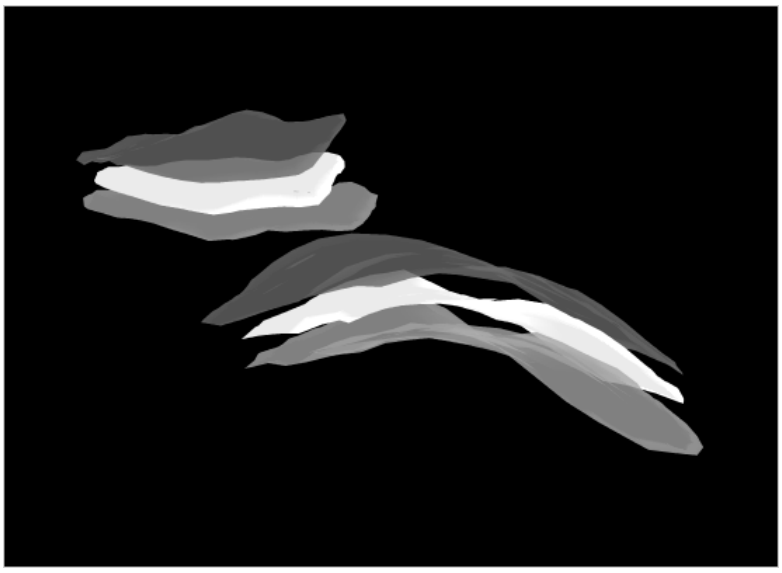


Figure 1: The surface objects were modeled using computer-aided design (CAD) software (FORM Z, Autodessys Inc., Columbus Ohio) which was used to render the surface of each facet. This is a model of a right control foot viewed in a CAD environment from posteriorly to display the curve of the joint surface. The dark gray surface on top is the talar joint surface. The lighter gray surface on the bottom is the calcaneal surface. The middle surface (white) is an artificial surface that represents the area of overlap on CT. Note that the saddle shaped posterior facet and the more planar middle facet surfaces are nearly coincident.

Results

The contact was measured and reported individually from the perspective of both the calcaneus and talus because the joint surfaces were slightly different sizes. The posterior facet was analyzed alone while the middle and anterior facets were analyzed as a single surface. In each case the data are reported as the average ratio of the area of the joint in contact to the entire surface area. The area not in contact is considered subluxed (Figure 3 and 4).

Posterior Facet

The ratio of the part of the posterior facet of the calcaneus in contact with the talus to the entire area of the joint surface was .68 +/- .092 in flatfeet and .92 +/- .022 in the control surfaces (p=0.0066). Alternatively, it could be stated that 32% of the surface of posterior facet of the calcaneus is subluxed in the flatfeet and 8% is subluxed in the controls. Viewed form the perspective of the posterior facet of the talar articular surface, the ratio of contact to entire surface area in flatfeet was .69 +/- .116 versus 0.89 +/- .046 in the controls (p=0.0415). Conversely, it could be said that 31% of the talar posterior facet is subluxed in the study

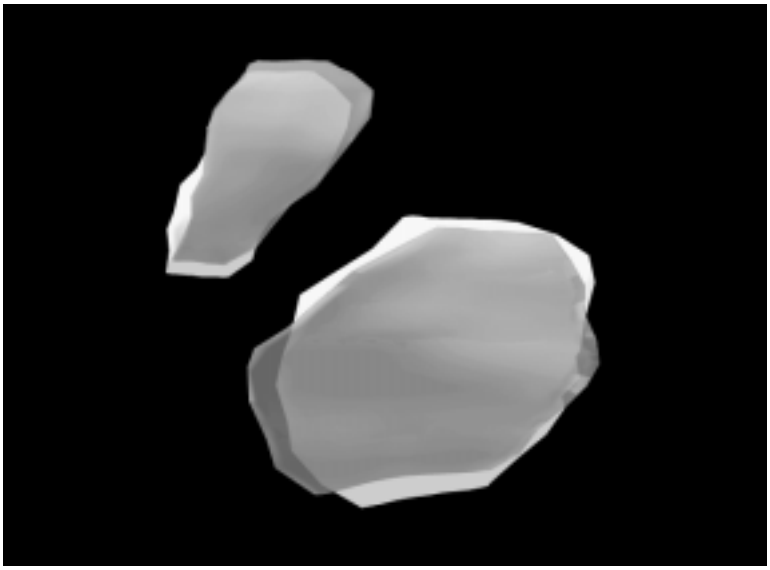


Figure 2: The rendered surface of a right control foot viewed as if looking down at the subtalar joint. The dark gray shade represents the surface of the talus, light gray, the calcaneus. Note that the surfaces are aligned.

population versus 11% in the controls. These differences were significant.

Anterior/middle Facet

The ratio of contact of the anterior/ middle facet of the calcaneus to total joint surface was .51 (+/- .23) in the flatfeet versus .95 (+/- .06) in the control group (p=0.0066). Alternatively this could be stated that 49% of the posterior facet of the calcaneus is subluxed in the flatfeet while only 5% is subluxed in the normal group. The talar articular surface of the flatfeet had a contact ratio of .44 (+/- .21) versus .87 (+/-.08) in the control group (p=0.0066). This could alternatively be stated the 56% of the talar middle facet surface is subluxed in the flatfeet while only 13% is subluxed in the normal group. These differences were significant.

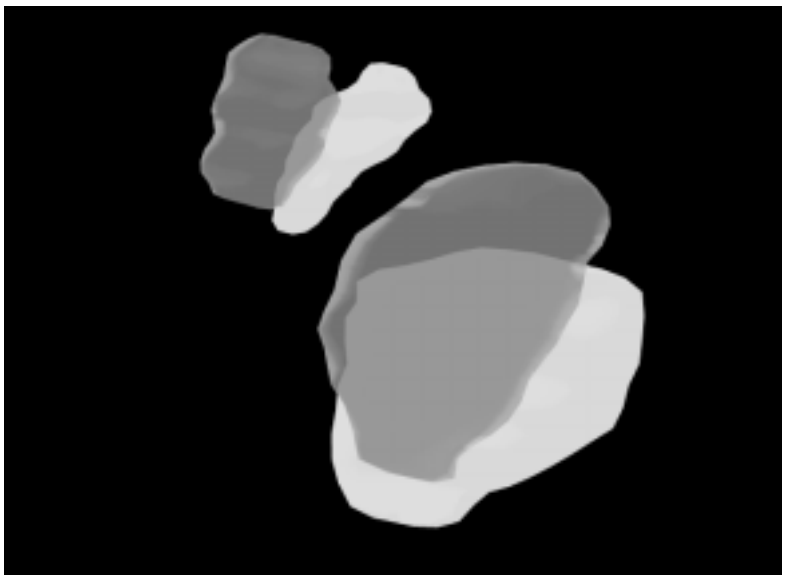


Figure 3: The rendered surface of a right flatfoot viewed as if looking down at the subtalar joint. The light shade represents the surface of the talus, the darker represents the articular surface of the calcaneus. Note that the calcaneal surface images are posterior and lateral to the talar surfaces. The middle/anterior facet surface is nearly dislocated.

The stimulus for this investigation was the sense that treatment of symptomatic flatfoot in adults is not always based on clear objective data. Many treatments have been proposed, each of which may effect change at a different anatomic location. A possible starting point to evidence based treatment is to better define the pathological condition. In this case, we attempted to define the relationship of the major tarsal bones to one another.

Conclusions

There is greater subluxation of the talo calcaneal joint during simulated weight bearing in patients with symptomatic flatfoot than there is in the talo calcaneal joint in people with a normal arch. The subluxation is greater in the anterior and middle facet that it is in the posterior facet. Though it does not preclude other causes, least one component of the altered shape of a symptomatic flat foot is a the loss of the intergrity of the talocalcaneal articulation.

Recommended Reading

Anderson, J.G., Harrington, R.E., Ching, R.P., Tencer, A.F., Hansen, S.T. Jr., Sangeorzan, B.J.: Alterations in Talar Morphology Associated with Adult flatfoot. Foot and Ankle, 18:705-709, 1997.

Cowan, D. N.; Robinson, J. R.; Jones Polly, D. W., Jr. and Berry, B.H.: Consistency of visual assessments of arch height among clinicians. Foot and Ank. Int., 15:213-217, 1994.

Dyal, CM, Feder, J, Deland, JT Thompson, FM Pes Planus in patients with posterior tibial tendon insufficiency: Asymptomatic Versus Symptomatic Foot. Foot and Ankle, 18:85-88, 1997.

Evans, D. E.: Calcaneo-valgus deformity. J. Bone and Joint Surgery, 57-B:270-278, 1975.

Gadzag, A.R.; Cracchiolo, A. 3rd.: Rupture of the posterior tibial tendon. Evaluation of injury of the spring ligament and clinical assessment of

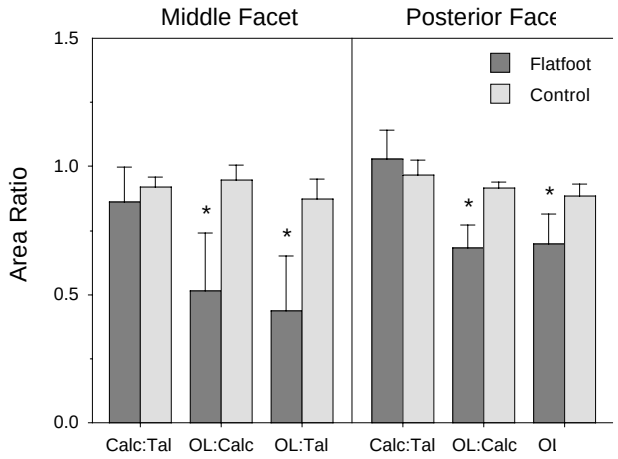


Figure 4: Graphic display of data. All data were expressed as a ratio to normalize for the foot size. A ratio of 1.0 would mean that one articular surface is perfectly coincident with the other. Calc/Tal= ratio of the surface area of the calcaneus to that of the talus; OL/Calc= ratio of the overlap area (area in contact) over the total joint surface the calcaneus OL/Tal = overlap area of the surface over the total joint surface the talus. Subluxed area is the converse of the overlap area. The data for the anterior and middle facet are displayed on the left , the posterior facet on the right. There were no significant differences in size between the surfaces of the flatfeet versus those of the normal feet or between the surface of the talus versus that of the calcaneus. There were significant differences in subluxation in the both middle/anterior and posterior facets. Note also the very small error bars in the control feet versus the large bars in the flat feet.

tendon transfer and ligament repair. J. Bone and Joint Surg., 79A:675-81, 1997.

Jones, B. S.: Flatfoot: A preliminary report of an operation for severe cases.

Pedowitz, W. J. and Kovatis, P.: Flatfoot in the adult. J. Am. Acad. Orthop. Surg., 3(5):293-302, 1995.

Correlation of the Simple Knee Test With the Lysholm Score for Follow-up of ACL Reconstruction

Michael H. Metcalf, M.D., Roger V. Larson, M.D., Peter T. Simonian, M.D., and Frederick A. Matsen III, M.D.

There is need for orthopaedic surgeons to document the functional status of their patients before and after treatment to determine the efficacy of their management. Because the surgeon is an important variable in the result, it is important that surgeons know their own results rather than relying on outcomes reported in the literature – "The surgeon is the method".

Some approaches to outcome documentation consume substantial time and resources; others do not capture the patients' perception of their comfort and function ; still others are not sufficiently sensitive to clinical problems with the anatomic area of interest. The ideal method would be a rapid self-assessment that patients can easily complete within a few minutes without assistance, whether in the office or at home. The tool must discriminate dependably between normal and pathological knee function.

The Simple Knee Test (SKT) was developed as a tool to facilitate the documentation of treatment effectiveness based upon changes in self-assessed patient function. Its simple functional questions facilitate communication between patients and physicians regarding pre and post treatment status. The SKT is sensitive to common knee pathologies and be completed within a few minutes without assistance.

This study uses the SKT to demonstrate functional outcome of a commonly performed procedure: ACL reconstruction. Our goals were 1) to demonstrate the correlation of the SKT score with that of the more traditional Lysholm score and 2) to use the SKT to compare results of ACL reconstructed patients with age-matched controls.

Materials and Methods

148 consecutive patients who had an ACL reconstruction by a single surgeon (RVL) from September, 1989 to September, 1991 were retrospectively reviewed at an average of 6 years after surgery. Each reconstruction utilized a double-looped semitendinosus and gracilis autograft. The average age at surgery was 29 years old (range 13-51). There were 95 males (64%) and 53 females (36%). Each patient was contacted via telephone and completed a Lysholm score and the Simple Knee Test.

The total number of SKT questions that each patient answered affirmatively at follow-up was divided by 15 (the total number of SKT questions) and this ratio was compared to the ratio of each patient's follow-up Lysholm score divided by 100 (the highest Lysholm score possible). A correlation coefficient was computed for these ratios.

Responses to each SKT question were then compared to responses by 360 age and activity level-matched controls. In addition, patient responses were compared to those of an age and activity level-matched group of known ACL-deficient patients prior to reconstruction. An unpaired t-test was used to compute a p value for each SKT question. Significance was defined as p–value < 0.05.

1	Does your knee allow you to sleep?
2	Will your knee straighten fully?
3	Will your knee bend all the way?
4	Is your knee free from swelling?
5	Does your knee move smoothly without catching or locking?
6	Can you sit comfortably with your knee bent for 1 hour?
7	Can you enter and leave a car without difficulty?
8	Can you stand and walk without your knee giving away?
9	Does your knee allow you to walk two blocks without difficulty?
10	Does your knee allow you to do your usual work?
11	Will your knee allow you to go down stairs easily?
12	Will your knee allow you to run?
13	Will your knee allow you to participate fully in your sport?
14	Will your knee allow you to kneel comfortably?
15	Can you hop on one leg?

Table 1: The Simple Knee Test.

Results

109 of the original 148 could be located for follow-up (74%). Four patients were eliminated from the study because they had required a subsequent ACL reconstruction on the same knee. An additional patient was eliminated because he had sustained a severe lateral plateau fracture.

The average patient with an ACL reconstruction could perform 13 of the 15 Simple Knee Test questions at follow-up. This contrasts to the typical patient prior to reconstruction who could perform only 7 of the 15 SKT questions. Normal control individuals typically can perform 15 of the 15 SKT questions. (Table I)

The SKT results were highly correlated with the Lysholm Score (correlation coefficient 0.80 ($p<.0001$)) (Figure 1).. The average Lysholm score of the reconstructed group was 92 (range 63-100). However, despite good Lysholm scores, there were a significant number of patients who were not free from swelling, were not able to run, could not participate fully in their sport and could not kneel comfortably

Discussion

Reported Lysholm scores of patients who are more than two years after an ACL reconstruction range between 84 and 95. Our patients' average Lysholm score of 92 is comparable to other series of ACL reconstruction.

Although the results of the SKT correlated with the Lysholm Score, the

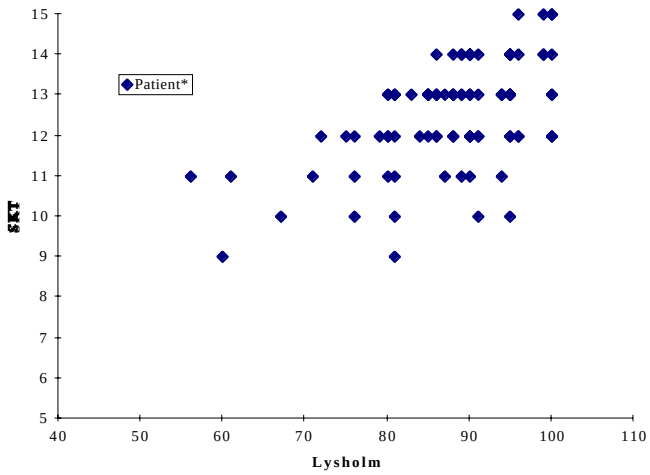


Figure 1: Graph of correlation between SKT results and the Lysholm score. (*Each point may represent more than one patient.)

SKT provided a more specific functional analysis. Each of the 13 SKT question has previously been shown to be statistically independent and therefore focuses on an independent aspect of patient function. For example, in this study only 57% of patients could comfortably kneel on their knee. The inability of 43% of the patients being unable to kneel comfortably may be related to the technique of graft fixation to the tibia. This potential problem could not have been identified from the Lysholm score.

Patient education and communication is facilitated by the SKT. Despite good Lysholm scores, there were a significant percentage of patients that were not free from swelling, were not able to run, could not participate fully in their sport and could not kneel comfortably. Patients can understand functional data present in this way, however few patients would understand what it means to have an average Lysholm score of 92.

In summary, the SKT has been shown to be highly correlated to the more established Lysholm score. The SKT has the additional advantage of isolating specific areas of concern that may be overlooked by a single numerical score. Finally, the SKT facilitates communication with patients regarding the likely results of treatment.

Recommended Reading

Metcalf MH, Larson RV, Simonian PT, Matsen FA, III. The Simple Knee Test: A quick and sensitive self-assessment of knee function. University of Washington Orthopaedic Research Report. 1998.

Arciero RA, Scoville CR, Snyder RJ, Uhorchak JM, Taylor DC, Huggard DJ. Single versus two-incision arthroscopic anterior cruciate ligament reconstruction. Arthroscopy 1996; 12:462-9.

Novak PJ, Bach BR, Jr., Hager CA. Clinical and functional outcome of anterior cruciate ligament reconstruction in the recreational athlete over the age of 35. Am J Knee Surg 1996; 9:111-6.

Simonian PT, Harrison SD, Cooley VJ, Escabedo EM, Deneka DA, Larson RV. Assessment of morbidity of semitendinosus and gracilis tendon harvest for ACL reconstruction. Am J Knee Surg 1997; 10:54-9.

Elbow Medial Collateral Ligament Isometry: Evaluation of the Ulna Insertion Site

Peter T. Simonian, M.D.

The ulnar collateral ligament of the elbow (UCL) consists of an anterior bundle, a posterior bundle and transverse fibers. The anterior bundle has been shown to be the primary restraint to valgus stress at the elbow. The anterior bundle of the UCL is the most discrete of the three portions of the ligament complex. It's margins are readily distinguished from the surrounding joint capsule and it's fibers are often intimately associated with the deep surface of the flexor mass. The posterior bundle consists of a less distinct fan shaped thickening of the posterior capsule. The transverse fibers originate and insert on the ulna covering a bony depression on the medial portion of the trochlear notch and contribute little or nothing to the stability of the elbow.

The UCL originates from the anterior inferior surface of the humeral medial epicondyle. The width of the origin varies but in most cases occupies the middle two thirds to three quarters of the epicondyle in the coronal plane. This UCL origin is a relatively reproducible area to find during ligament reconstruction when compared to the osseous UCL insertion. The anterior bundle inserts on the medial border of the coronoid at the sublime tubercle.

The origin of the anterior bundle of the UCL lies slightly posterior to the rotational center of the elbow. The anterior bundle is further divided into an anterior band and a posterior band. The eccentric origin of these components of the anterior bundle in relation to the rotational center through the trochlea creates a cam effect during flexion and extension. The anterior band tightens during extension and posterior band tightens during flexion. This reciprocal tightening of the two functional components of the anterior bundle allows the ligament to remain taught throughout the full range of flexion despite it's eccentric origin in relation to the rotational center of the elbow.

This complex anatomy and interaction of the bands of the anterior bundle of the UCL may limit the success of achieving a successful isometric reconstruction with a single graft. Current UCL reconstruction techniques describe a single humeral tunnel to emulate the origin and two separate ulnar tunnels to emulate the insertion. The purpose of this study was to attempt to find the optimal position or positions for reconstruction of the ulnar insertion of the UCL.

Materials and Methods

Five fresh, cadaveric elbow specimens were used for this study. Displacements during elbow range of motion were measured with a liquid

	0 deg	20 deg	40 deg	60 deg	80 deg	100 deg	120 deg	140 deg	Mean
Position A	**0 mm**	**0.45 mm**	**1.47 mm**	**2.36 mm**	**2.77 mm**	**2.89 mm**	**2.85 mm**	**2.34 mm**	**1.89 mm**
(stnd dev)		(0.48 mm)	(0.94 mm)	(1.02 mm)	(1.19 mm)	(1.45 mm)	(1.48 mm)	(1.61 mm)	
Position B	**0 mm**	**1.58 mm**	**2.56 mm**	**3.58 mm**	**4.76 mm**	**5.41 mm**	**5.44 mm**	**5.06 mm**	**3.55 mm**
(stnd dev)		(2.17 mm)	(2.77 mm)	(3.39 mm)	(4.26 mm)	(5.00 mm)	(5.34 mm)	(5.17 mm)	
Position C	**0 mm**	**1.05 mm**	**2.21 mm**	**3.55 mm**	**4.73 mm**	**5.46 mm**	**5.57 mm**	**5.40 mm**	**3.49 mm**
(stnd dev)		(1.07 mm)	(1.27 mm)	(1.50 mm)	(2.13 mm)	(2.64 mm)	(3.00 mm)	(2.70 mm)	
Position D	**0 mm**	**1.08 mm**	**2.10 mm**	**2.84 mm**	**3.53 mm**	**3.65 mm**	**3.37 mm**	**3.01 mm**	**2.45 mm**
(stnd dev)		(0.54 mm)	(0.57 mm)	(0.87 mm)	(0.79 mm)	(1.14 mm)	(1.29 mm)	(1.44 mm)	
Position E	**0 mm**	**1.92 mm**	**3.34 mm**	**4.58 mm**	**5.38 mm**	**5.60 mm**	**5.31 mm**	**4.79 mm**	**3.86 mm**
(stnd dev)		(1.41 mm)	(1.77 mm)	(1.76 mm)	(1.81 mm)	(2.24 mm)	(2.43 mm)	(2.49 mm)	
Position F	**0 mm**	**1.08 mm**	**2.74 mm**	**4.65 mm**	**6.16 mm**	**7.35 mm**	**7.23 mm**	**7.39 mm**	**4.58 mm**
(stnd dev)		(0.76 mm)	(0.80 mm)	(1.30 mm)	(1.27 mm)	(2.04 mm)	(2.31 mm)	(2.91 mm)	
Position G	**0 mm**	**1.43 mm**	**2.67 mm**	**3.87 mm**	**4.58 mm**	**4.31 mm**	**3.52 mm**	**2.79 mm**	**2.90 mm**
(stnd dev)		(0.84 mm)	(1.20 mm)	(1.43 mm)	(1.53 mm)	(1.27 mm)	(0.96 mm)	(1.09 mm)	
Position H	**0 mm**	**1.08 mm**	**2.96 mm**	**5.14 mm**	**6.58 mm**	**6.82 mm**	**6.28 mm**	**5.34 mm**	**4.28 mm**
(stnd dev)		(0.26 mm)	(1.05 mm)	(1.66 mm)	(1.76 mm)	(1.87 mm)	(1.68 mm)	(1.85 mm)	
Position I	**0 mm**	**1.50mm**	**3.86 mm**	**6.25 mm**	**9.08 mm**	**9.74 mm**	**9.97 mm**	**9.41 mm**	**6.23 mm**
(stnd dev)		(0.99 mm)	(1.94 mm)	(2.34 mm)	(3.78 mm)	(3.81 mm)	(4.06 mm)	(3.62 mm)	

Table 1: Average displacements and standard deviations measured at the nine various points on the ulna at various degrees of elbow flexion.

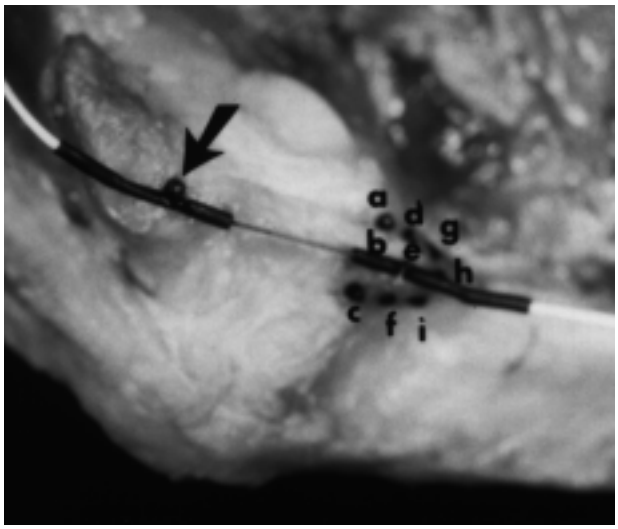


Figure 1: Isometry displacement during elbow range of motion was measured with a liquid mercury strain gauge. The gauge was fixed to the humeral origin of the medial collateral ligament with a straight needle drilled into the origin (arrow). The gauge was sutured to the eyelet of the needle. The other end of the gauge was sutured to the eyelet of second straight needle. Nine drill holes spaced 5 mm apart were then made in the ulna with a drill the same diameter as the straight needle. The central hole (position E) was drilled in the center of the sublime tubercle of the proximal ulna (where the gauge is shown in the picture). The eight other positions (positions A-D and F-I) were drilled around the central position E. Positions A-C were proximal, position D was directly anterior and position F was directly posterior to the central point E. Positions G-I were most distal. Positions A, D, and G were anterior, positions B, E, and H were central in the anteroposterior plane, and positions C, F, and I were posterior.

mercury strain gauge. The gauge was fixed to the humeral origin of the medial collateral ligament with a straight needle drilled into the origin at the epicondyle. The gauge was sutured to the eyelet of the needle. The other end of the gauge was sutured to the eyelet of a second straight needle. Nine drill holes spaced 5 mm apart were then made in the ulna with a drill of the same diameter as the straight needle. The central hole (position E) was drilled in the center of the sublime tubercle of the proximal ulna. The eight other positions (positions A-D and F-I) were drilled around the central position E. Positions A-C were proximal, position D was directly anterior and position F was directly posterior to the central point E. Positions G-I were most distal. Positions A, D, and G were anterior, positions B, E, and H were central in the anteroposterior plane, and positions C, F, and I were posterior. The needle with the mounted strain gauge was then placed into each of the drilled ulna insertion positions (Figure 1). For each of these nine insertion points, strain gauge measurements were recorded at 20 degree intervals as the elbow was moved from 0 to 140 degrees of flexion. A total of 72 measurements was recorded for each specimen. The strain gauge was zeroed at 0 degrees of flexion each time the strain gauge was moved to a new position on the ulna.

Results

The degree of excursion between the fixed origin and multiple insertion sites studied increased up to 100 or 120 degrees before decreasing with further flexion. The degree of excursion was the least for the most proximal and anterior points studied.

The following data averaged the excursion for all degrees of elbow flexion tested for each position on the ulna (table 1, graph 1). The most anterior positions (A,D,G) had the least average excursion through the range of motion. Point A, the most proximal of these anterior locations, had the least mean excursion at 1.89 mm. Position I, the most distal and posterior position, had the greatest averaged excursion at 6.23 mm, more than three times that of position A. Interestingly, position E, the central point, had a mid-range amount of average excursion at 3.86 mm.

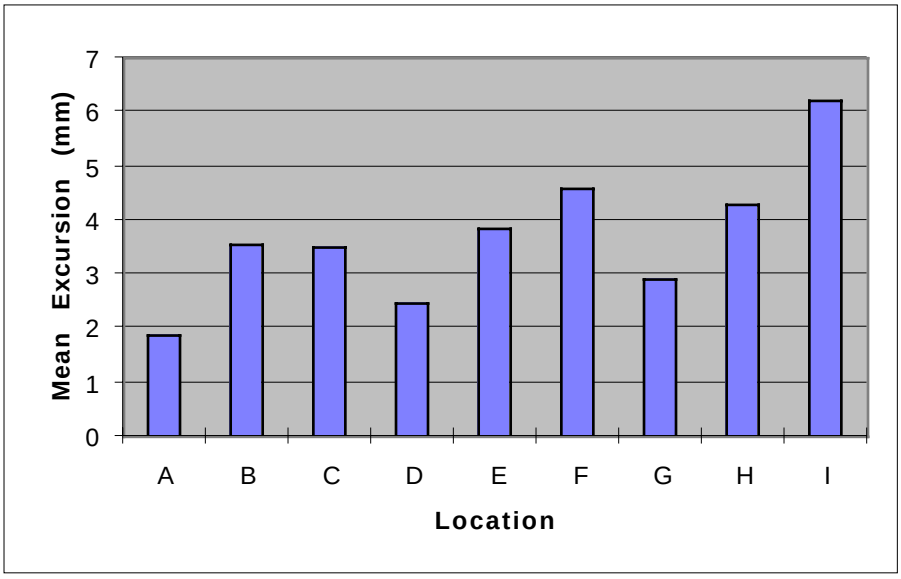
Discussion

The spectrum of UCL injuries can be managed conservatively in non-throwing athletes, allowing even elite level participation in most sports. The overhead athlete represents an exception. The extreme valgus loads generated by the throwing motion place tremendous stress across the medial joint. Subtle injury to the ulnar collateral ligament can lead to disabling instability in the throwing athlete in the setting of repetitive valgus stress. Reconstruction is indicated for those in high demand upper extremity sports such as baseball pitching, javelin throwing and serving sports. Overhead athletes with medial elbow pain or a sense of movement in the elbow with valgus loads during sports participation who also have UCL laxity on physical exam may be candidates for ligament reconstruction.

Sixty eight percent of overhead athletes who underwent reconstruction in one report were able to return to their previous level of participation. Those with previous operations on the elbow had a lower chance of returning to their previous level of participation. A possible factor for the limited success of this surgery may be related to the difficulty in finding a single isometric ulnar insertion point for the complex anterior band of the UCL.

The anterior bundle of the ulnar collateral ligament has been shown to be the primary restraint to valgus stress. The anterior bundle is further divided into an anterior band and a posterior band. The eccentric origin of these components of the anterior bundle in relation to the rotational center through the trochlea creates a cam effect during flexion and extension with the anterior band tightening during extension and posterior band tightening during flexion. This action of reciprocal tightening of the two functional components of the anterior bundle has been thought to keep the ligament taught throughout the full range of flexion despite it's eccentric origin in relation to the rotational center of the elbow. However, the results of the present study would suggest that current reconstruction techniques using a common tunnel for UCL origin and any combination of ulnar insertion sites tested do not achieve the reciprocal stabilizing action of the native ligament.

Graft fixation for UCL



Graph 1: The mean strain gauge excursion at eight different degrees of elbow flexion for each ulna location tested. The most anterior positions (A,D,G) had the least averaged motion through an elbow range of motion. Point A, the most proximal of these anterior locations, had the least mean excursion at 1.89 mm. Point I, the most distal and posterior position, had the greatest averaged excursion at 6.23 mm, more than three times that of point A. Point E, the central point, had a mid-range amount of averaged excursion at 3.86 mm.

reconstruction is achieved through bone tunnels in the ulna and medial epicondyle. The technique originally described by Jobe places convergent drill holes at the anterior and posterior margins of the sublime tubercle of the ulna separated by a 1 cm bone bridge. The hard cortical surface of the tubercle provides an excellent bone bridge for graft fixation. For graft fixation in the medial epicondyle, Jobe originally described fashioning divergent drill holes from a single entry hole on the anterior distal epicondyle. Based on the results of this study, a more optimal position for these two drill holes should be as anterior and proximal relative to the sublime tubercle as possible. Another option that might improve the emulation of the reconstructed UCL when compared to the native UCL might be a two tunnel origin as well as insertion; however, this technique was not addressed in the present study.

No insertion point tested on the ulna demonstrated isometry. The degree of excursion between the fixed origin and multiple insertion sites studied increased up to 100 or 120 degrees before decreasing with further flexion. The degree of excursion was the least for the most proximal and anterior points studied.

The most anterior positions (A,D,G) had the least average excursion through an elbow range of motion. Point A, the most proximal of these anterior locations, had the least mean excursion at 1.89 mm. Point I, the most distal and posterior position, had the greatest averaged excursion at 6.23 mm, more than three times that of point A. Point E, the central point, had a mid-range amount of averaged excursion at 3.86 mm.

The complex anatomy of the anterior band of the UCL may limit the success of achieving a successful isometric reconstruction. The optimal position for reconstruction of the insertion of the UCL with a single origin from the medial epicondyle of the humerus was 5 mm anterior and 5 mm proximal to the sublime tubercle of the uln

Recommended Reading

Morrey, B. F., and An, K. N.: Articular and ligamentous contributions to the stability of the elbow joint. Am J Sports Med, 11: 315-19, 1983.

Morrey, B. F., Tanaka, S., and An, K. N.: Valgus stability of the elbow: A definition of primary and secondary constraints. Clin Orthop, 265: 1991.

O'Driscoll, S. W., Jaloszynski, R., Morrey, B. F., and An, K. N.: Origin of the medial ulnar collateral ligament. J Hand Surg, 17A: 1992.

Schwab, G. H., Bennett, J. B., Woods, G. W., and Tullos, H. S.: The role of the medial collateral ligament. Clin Orthop, 146: 42-52, 1980.

Andrews, J. A., and Whiteside, J. A.: Common elbow problems in the athlete. J Orthop Sports Phys Ther, 17: 289-95, 1993.

Conway, J. E., Jobe, F. W., Glousman, R. E., and Pink, M.: Medial instability of the elbow in throwing athletes. Treatment by repair or reconstruction of the ulnar collateral ligament. J Bone Joint Surg, 74A: 67-83, 1992.

Jobe, F. W., Stark, H., and Lombardo, S. J.: Reconstruction of the ulnar collateral ligament in athletes. J Bone Joint Surg, 68A: 1158-63, 1986.

Wilson, F. D., Andrews, J. R., Blackburn, T. A., and McClusky, G.: Valgus extension overload in the pitching elbow. Am J Sports Med, 11: 83-88, 1983.

A New Technique for Mapping Articular Cartilage Contour and Thickness

Anthony G. Norman, B.S., William M. Doughtery, Ph.D., Howard Chansky, M.D., Peter Simonian, M.D., John M. Clark, M.D., Ph.D., and John A. Sidles, Ph.D.

Accurate measurements of articular cartilage contour and thickness are a valuable adjunct to cartilage research. For example, indentation testing to determine cartilage compliance requires knowledge of cartilage thickness; measurements of cartilage swelling can serve as a parameter of degradation. Techniques used to measure cartilage thickness include histology, ultrasound, needle probe, optical examination and magnetic resonance imaging. Each of these techniques has specific advantages and limitations. Here we describe a new method which has potentially better accuracy and versatility compared to those techniques in current use.

Method

Five pairs of tibial plateaus were removed from 5 adult New Zealand white rabbits after sacrifice following our IACUC guidelines. Three 0-80 machine screws were placed through the plateau into bone using tapped drill holes for rigid fixation. A cast of each plateau was immediately made using hydrophilic silicone dental casting compound (Aquasil, Dentsply, Milford, DE). The material sets within 6 min. with maximal linear dimensional change of 0.03% and yields 20 micron detail reproduction. Each cast was mounted on a precision, two axis motorized table (Parker) and scanned using a laser displacement sensor (Keyence, model LK-081, Lake Oswego, OR) at a frequency of 2000 acquisitions per mm. The sensor measures distances with a nominal resolution of 3 microns. The table motors and data acquisition sequence were run through a 100kHz 16 bit board (National Instruments PCI-MIO-16XE-10) using Labview software and a Macintosh PowerMac 8500. Measurements were taken in a grid covering the entire plateau including both condyles. Each scan required 15 min. to complete, and the final data sets were decimated to 0.1 mm spacing between sampled points, yielding a grid of 300 x 300 measured heights for each tibial surface. Then, all the plateaus were immersed for 48h in a 400 IU/100 ml papain solution at pH 7 and 38°C, completely removing all the articular cartilage down to the tidemark. A second grid of distance measurements was made from casts of the treated plateaus.

Using the screw impressions as fiducial landmarks that remained unaltered in the pre-digestion and post-digestion impressions, the pre- and post-digestion data sets were superimposed. This step required alignment of the two data sets in three translational and three rotational degrees of freedom. The required rotations and translations were determined by numerically minimizing the root-mean-square difference between the two data sets within 1.5 mm diameter discs centered on each screw impression. Repeated scans of the same impression, with the impression mounted in varying alignment on the scan table, showed that the software adjusted the alignment to within an root-mean-square surface error of 40 microns or less. All numerical analysis was conducted in Mathematica 3.0, using Mathematica's built-in two-dimensional interpolating functions, and the resulting subtracted surfaces were exported as digital files to the public domain program NIH Image.

Soft tissue thickness over the plateau was calculated as the difference between the pre- and post-digested data sets. The five pairs of knees were evaluated by making right-left comparisons of joint contour and cartilage thickness along a standardized line across the plateau (fig. 1). Maximal cartilage thickness in the medial and lateral

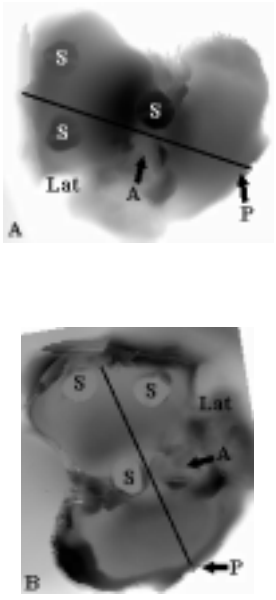


Figure One. Maps of the plateau casts in which density corresponds to surface elevation (A) and cartilage thickness (B). Screws (S) are used to align pre- and post digestion scans. ACL (A) is visible.

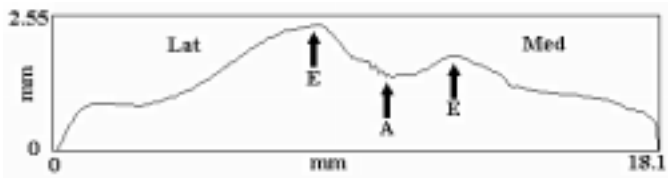


Figure Two. Plot of plateau surface contour along line P in fig. 1A. Eminences (E) are visible as highest points.

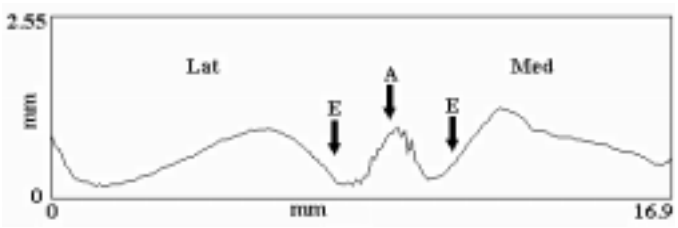


Figure Three. Plot of cartilage thickness along line P in fig. 1B. Thickest cartilage is medial adjacent to eminence.

plateau was also calculated.

Results

This method produced maps of cartilage surface contour and thickness over the entire plateau. The data could be viewed en face as a map in which elevation or thickness was represented by density (fig. 1). The joint contour or cartilage thickness in any specified area could then be plotted (figs. 2, 3). Maximum thickness was 1.50 ± .19 mm on the medial plateau and 1.1±.27 mm on the lateral. Right to left variation was small (1%).

Discussion

The method presented here is unique in its ability to produce detailed maps of articular cartilage surface anatomy and thickness. Such maps are especially helpful when comparing one joint to another, or when looking for focal areas of cartilage alteration. The maximum thickness values here compare closely to those reported elsewhere for the rabbit; no previous high-accuracy maps of global cartilage thickness have been reported. Pending proof of their accuracy, these techniques will have many applications in orthopaedic research relating to cartilage anatomy and response to injury.

The distance measurements reported here have three main error sources: the ± 3 micron accuracy of the sensor; the 0.03% deformation of the casting material; and numerical error resulting from superimposition of the pre- and post-digestion scans. By using casts, we eliminated optical error due to translucency of the cartilage, at the price of introduced error due to variation in casting. We anticipate that, with careful casting technique, 10 micron absolute accuracy may be obtainable over an entire tibial plateau. Direct scanning of the cartilage is possible if the surface of the cartilage is covered with an opaque powder, and this alternative technique would eliminate the need for casting.

Recommended Reading

Jukka, et al, J. Biomech. 28:32

Clark et al, JBJS 72B:866

Clark, et al, J Anat 191:215.

Importance of Surface Integrity to Healing of Articular Cartilage Defects

Julie Switzer, M.D., Anthony G. Norman, B.S., and John M. Clark, M.D., Ph.D.

The standard experimental model for articular cartilage injury is a drill hole made through the articular surface. Such superficial defects of cartilage do not heal spontaneously[1], leading to speculation that properties of the synovial fluid interfere with healing. In this study, we examine the repair response in cartilage defects with and without an intact overlying surface layer. Our hypothesis was that surface integrity influences the healing response.

Methods

Using a drill guide and fluoroscopy, 1.5 mm diameter drill holes were made in the articular cartilage of the central patella of one knee, (randomized right or left), in 24 adult New Zealand white rabbits.

Six animals were in group A, and 9 in groups B and C. In 2 animals of each group, the hole in the cortex was occluded with wax (**bw** in figure 1b) to block periosteal invasion. Animals were sacrificed at 3, 4 or 6 weeks post surgery and the patellae were fixed in 2% glutaraldehyde, decalcified in EDTA, embedded in epoxy resin and sectioned for light and electron microscopy. Animal care was approved by our IACUC.

Results

New bone formation and osteoid were observed at the unobstructed external opening of all drill holes, where an extensive, periosteum-based blood supply entered. When the hole was occluded by bone wax, new bone formation was impeded, but cartilage repair was not. However, by 6 weeks, all defects in cartilage which did not transgress the surface (figure 2a) were filled in by a combination of swelling of surrounding cartilage and formation of new, chondroid tissue containing both round cells in lacunae and abundant metachromatic ground fibrous substance. This tissue was histologically distinct from the more fibrous cartilage associated with new bone formation, and never formed if the hole did not penetrate into articular cartilage. If a hole passed through the articular surface, the surface did not heal in the period examined.(figure 2b)

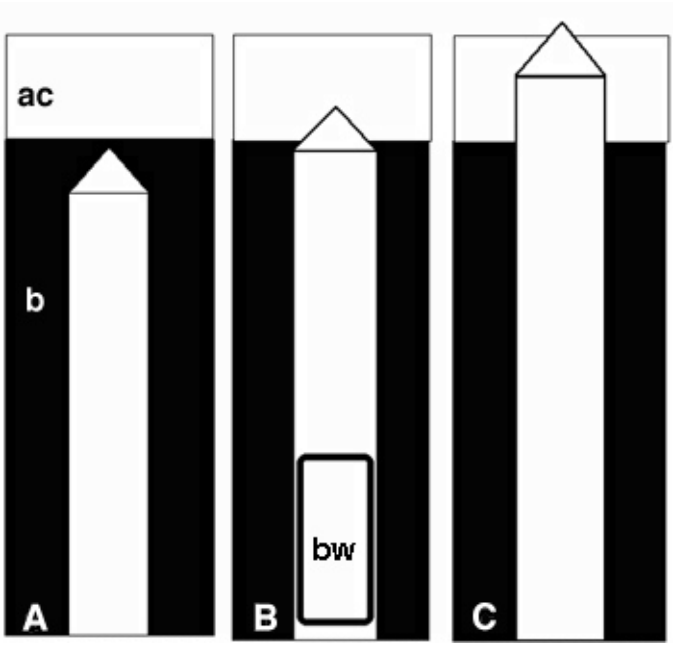


Figure One: The holes were made through the anterior cortex of the patella, passed through the body and ended in one of three locations illustrated in figure 1: A) In the subchondral bone (b); B) In the articular cartilage (ac); C) In the synovial space, having passed completely though the cartilage.

Discussion

This experiment demonstrates that drill hole defects in articular cartilage promptly fill with hyaline cartilage when the overlying surface layer is intact. These reverse drill holes complement the typical defects created by drilling through the surface which produce small volumes of fibrous tissue compared to the abundant hyaline tissue seen in our closed lesions in the same time frame. Surface integrity appears to influence the healing response. Longer term follow-up and determination of collagen types are necessary to demonstrate the competency of the repair tissue.

Acknowledgment

Drills were supplied by Synthes (USA)

Recommended Reading

Caplan et al CORR, 342:255, 1997

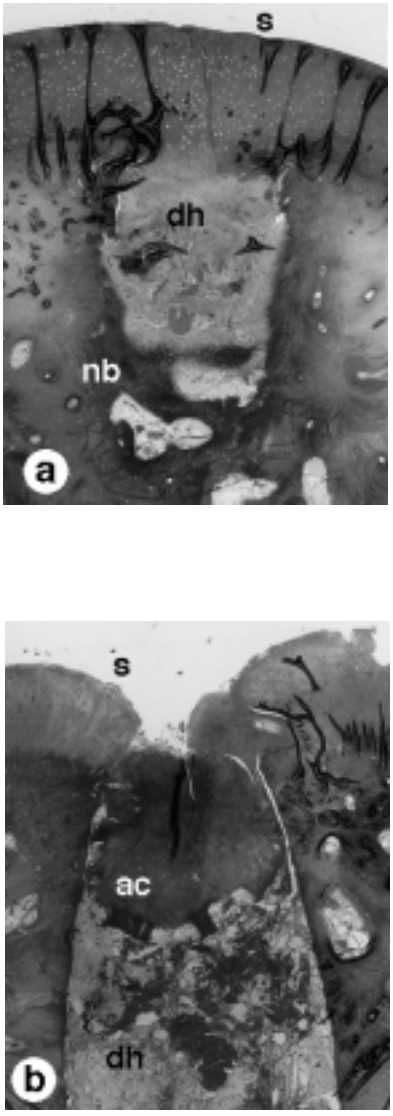


Figure Two: Lesions at 6 weeks. a) Drill hole (dh) into cartilage. Defect has filled with hyaline cartilage; only sign of injury is absence of calcified layer. New bone (nb) is forming in hole. b) Drill hole through surface (s). Surface remains disrupted. Undermined articular cartilage (ac) has herniated into hole.

Collagen Type II Cross-Linked Telopeptides: A Promising Marker of Cartilage Degradation in Arthritis

Lynne M. Atley, Ph.D., Ping Shao, B.S., Kathy Shaffer, B.S.*, Vince Ochs, B.S.*, J.D. Clemens*, and David R. Eyre, Ph.D.

A specific cartilage degradation marker has potential value in chondroprotective drug development and clinical management of arthritis patients.

Introduction

There is a need for minimally invasive biochemical assays that can assess the rate of cartilage degradation in patients with degenerative joint diseases. The collagen framework of cartilage turns over extremely slowly in the normal adult and its gross degradation in articular cartilage is believed to be a critical, irreversible event in osteoarthritis. A degradation assay for cartilage collagen is particularly desirable. We describe an advance in developing an immunoassay designed to measure pyridinoline-cross-linked telopeptides from type II collagen in human urine.

Materials and Methods

Monoclonal antibodies (mAbs) were raised in mice to a peptide, EKGPDP, the specific sequence in the C-telopeptide domain of human type II collagen, that contains a cross-linking lysine. An antibody, mAb 2B4, showed high binding affinity to the synthetic peptide, to protease digests of cartilage collagen and to pyridinoline-containing cross-linked C-telopeptide fragments isolated from human urine that embodied this core sequence. A microtiter-plate ELISA was developed that could quantify the natural antigen (col2CTx) in cartilage explant culture media (1), urine (2), serum and synovial fluid. Urines were compared from growing children, normal adults and arthritic patients, expressing results as ng of cross-linked EKGPDP/mg

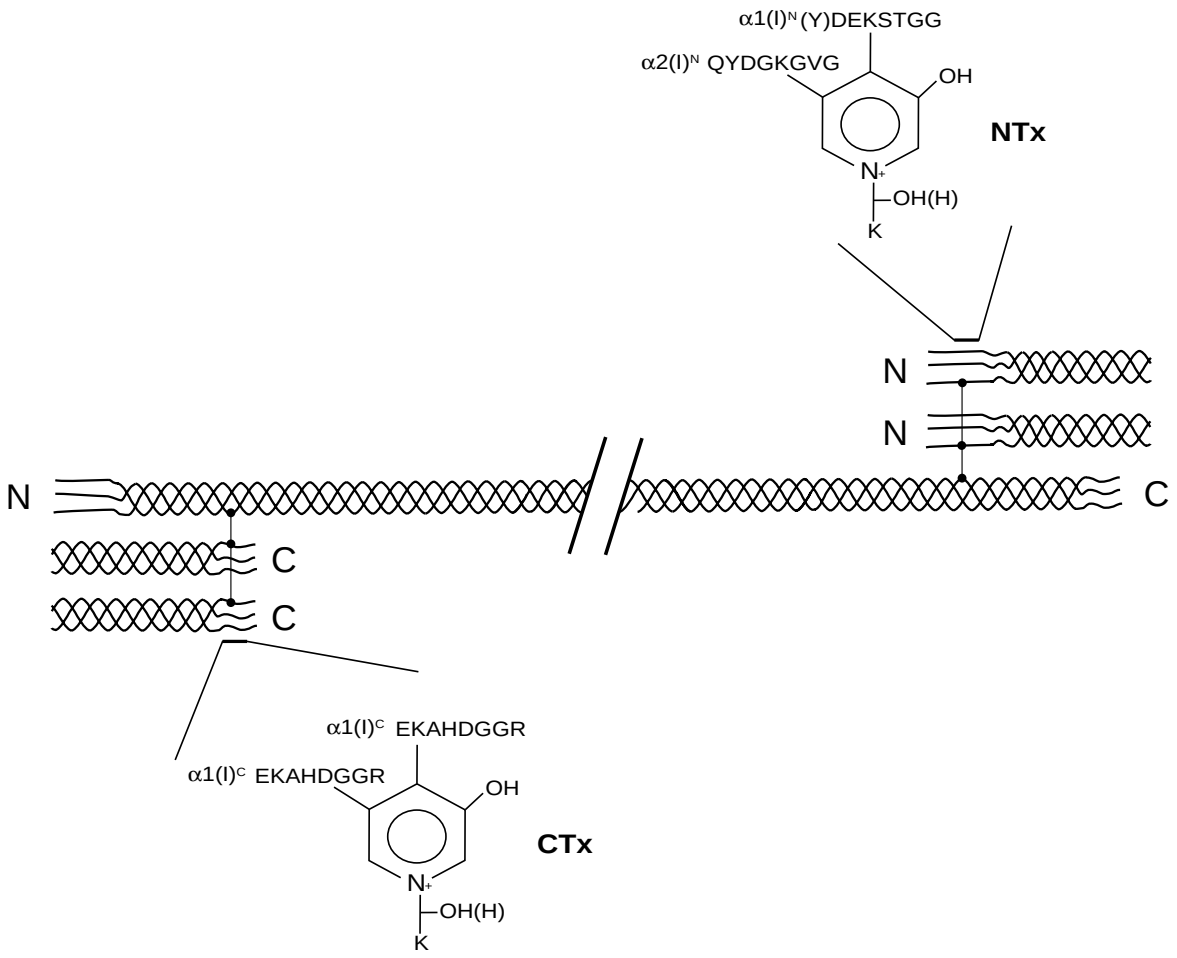


Figure 1: This figure depicts the two molecular sites of cross-linking in type II collagen and shows the C-telopeptide core sequence recognized by mAb 2B4 as a cross-linked degradation product.

creatinine. Recombinant preparations of metalloproteinases (MMPs) and other proteinases were tested for their ability to generate the colCTx antigen from human type II collagen. MMPs were generously supplied by Dr. G. Murphy, Strangeways Research Lab., Cambridge, UK and Dr. R. Martin, Roche BioScience, Palo Alto, CA.

Results and Discussion

Fig. 1, depicting the two molecular sites of cross-linking in type II collagen, shows the C-telopeptide core sequence recognized by mAb 2B4 as a cross-linked degradation product. This pyridinoline-based fragment was the major form of 2B4-immunoreactive antigen isolated from human urine. The profile of such immunoreactive peptides of low molecular weight (<2 kDa) was similar in urine of children and adults. The excretion rate was about 100-fold higher in children than in normal adults consistent with the active degradation of growth plate collagen in children. Initial comparisons with arthritis patients indicate a wide range of individual values and a significantly higher excretion than in control subjects. Collaborative studies are ongoing to correlate levels with clinical measurements of disease activity. The 2B4 epitope proved to be an MMP-generated proteolytic neoepitope of type II collagen degradation. All the MMPs tested (MMP1, 3, 7, 8, 13 and 14) were active but matrilysin was the most potent. Using synthetic peptides as substrates, it was shown that cleavage of the P/L bond was essential for 2B4 epitope recognition (illustrated in Fig. 2).

References

Atley et al. Arth Rheum 40:584, 1997

Eyre et al. J Bone Miner Res 11:S413, 1996.

*Ostex International , Inc., Seattle, WA

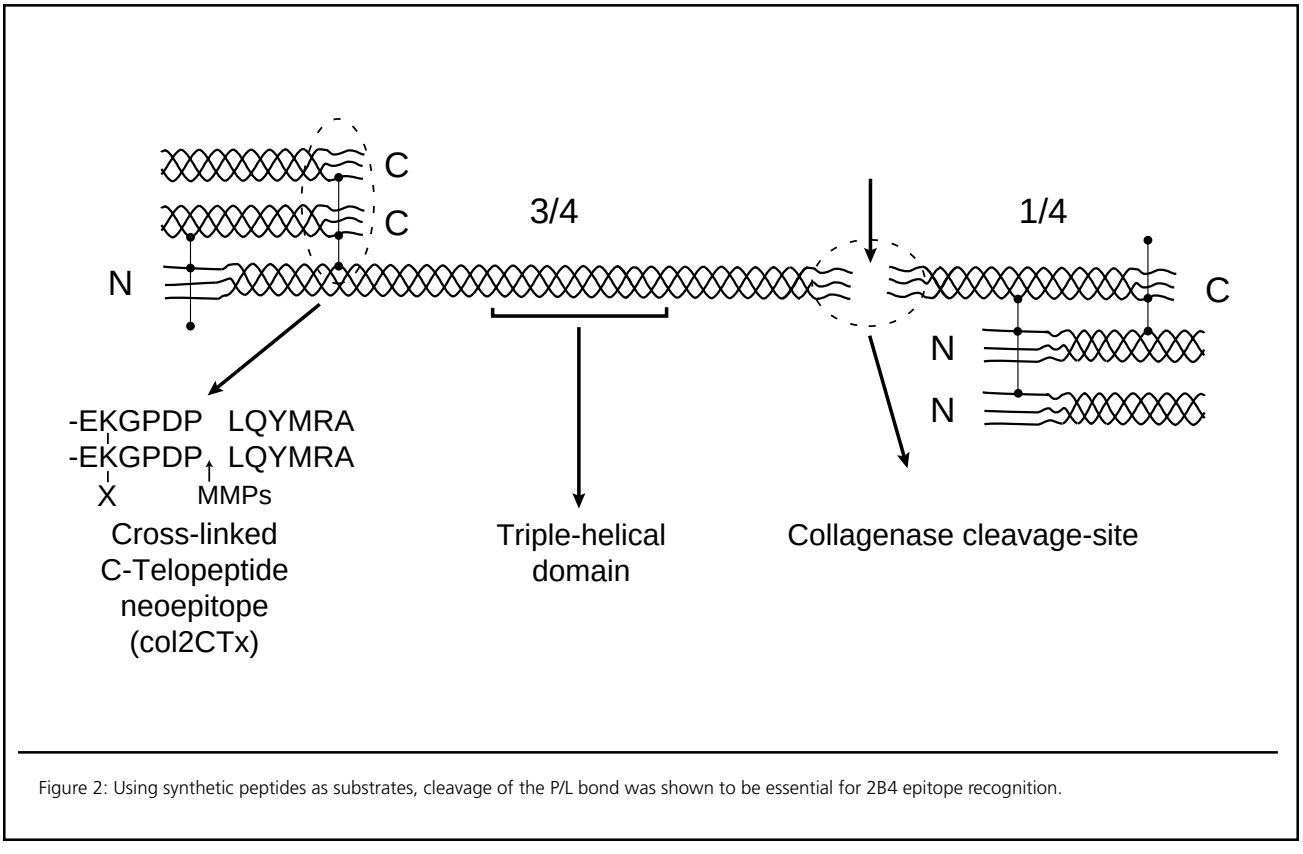


Figure 2: Using synthetic peptides as substrates, cleavage of the P/L bond was shown to be essential for 2B4 epitope recognition.

Expression of Cartilage Extracellular Matrix and Potential Regulatory Genes in a New Human Chondrosarcoma Cell Line

HOWARD CHANSKY, M.D., JAMES R. ROBBIN, WENDY H. RASKIND, STEVEN CHA, ERNEST U. CONRAD, M.D, JOHN M. CLARK, M.D., JAMES D. BRUCKNER, M.D., AND LINDA J. SANDELL, M.D.

Chondrosarcomas are malignant tumors of cartilage that may arise *de novo* or within a preexisting benign cartilage tumor, from periosteal or perichondral tissues, or within other soft tissues. They are the second most common primary malignant neoplasm of bone in adults, with a mean age at diagnosis of forty years. High grade chondrosarcomas have a relatively poor prognosis and all grades of tumors have significant rates of local recurrence. Attempts to devise histological or biochemical criteria for the classification of chondrosarcomas have met with limited success. The lack of a reliable grading system hinders the development of improved treatment protocols and the ability to provide patients with adequate prognoses.

The cellular origin of chondrosarcomas and the mechanism of tumorigenesis are unknown. The development and progression of chondrosarcoma is likely a multi-step process in which multiple genetic alterations accumulate in a cell. p53 is a tumor suppressor gene located on chromosome 17 that is inactivated in tumors of many types; loss of p53 activity is thought to be a primary event in the development of many malignancies including sarcomas.

Study of the development of chondrosarcomas has been hampered by the lack of suitable stable models that can be evaluated on a molecular level. In order to create such a model we maintained cells derived from human tumors in long-term culture and established several chondrosarcoma cell lines. This report summaries some of studies conducted in our Department seeking to characterize the extracellular matrix phenotype of one of these cell lines, Ch-1, as well as the expression of molecules potentially involved in the regulation of cell differentiation and proliferation.

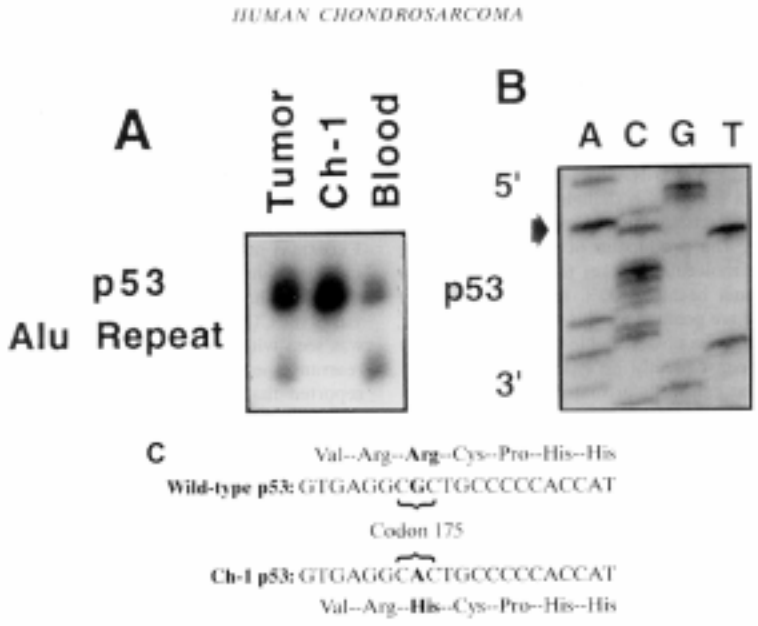


Figure 1: Analysis of p53 in Ch-1. A: Loss of heterozygosity. Autoradiograph of DNA amplified by polymerase chain reaction at the p53 pentanucleotide alu sequence repeat in the first intron. B: Autoradiograph of the sequencing gel showing mutation in cDna amplified from the mRNA of Ch-1 p53. Mutation is indicated by the arrow. C: DNA and protein sequence of normal and mutant p53.

RESULTS

The chondrosarcoma cell line, Ch-1, has a unique phenotype that shares important characteristics with the phenotype of normal chondrocytes such as abundant production of the large proteoglycan aggrecan and the small proteoglycan biglycan and the expression of types IX and XI collagens. Cytogenetic analysis of cell cultures from different passages found a remarkably consistent karyotype which is consistent with the presence of a single cell type.

Messenger RNAs encoding two recently discovered cartilage-derived molecules, Cart-1 and CD-RAP, are also synthesized by Ch-1. Cart-1 is a homeobox gene that may be involved in gene regulation during cartilage differentiation; it is expressed in pre-chondrogenic mesenchyme and in chondroblasts. CD-RAP is a small secreted protein expressed in cartilage at all stages of maturation and in the Swarm rat chondrosarcoma. CD-RAP is also synthesized by melanoma cell lines and is thought to be involved in cell-matrix interactions and regulation of DNA synthesis.

In contrast to what occurs in chondroblasts and mature chondrocytes, Ch-1 cells express no detectable type II procollagen mRNA and consequently no type II collagen is secreted into the extracellular matrix. The synthesis of type II procollagen is difficult to maintain in long-term cell culture of chondrocytes and transformed chondrocytes. In normal chondrocytes there is evidence that expression of type II collagen is strongly regulated as opposed to expression of aggrecan which appears to be constitutive This pattern of collagen regulation is consistent with the phenotype of Ch-1, but as with any line of transformed cells such changes may be the result of genomic instability and multiple random mutations. The

proteoglycan decorin was not detected in Ch-1. Decorin is generally considered to interact with the fibrillar collagens, types I and II. As little or no type I or type II collagens are made, there is no production of a fibrillar extracellular matrix; consequently it is possible that the lack of decorin synthesis is related to the lack of fibrillar collagen synthesis. The lack of type I collagen mRNA synthesis also indicates that these cells are not "dedifferentiated" chondrocytes which switch their fibrillar collagen synthesis from type II to type I.

It has been reported that uncultured high grade chondrosarcomas synthesize lower levels of type II collagen than do tumors of lower grade. Kawashima et al showed an inverse correlation between expression of type II collagen and the ability of well differentiated chondrosarcomas to grow faster and more extensively in athymic mice. Taken together, these observations indicate that high grade chondrosarcoma tumors are characterized by reduced expression of type II collagen. This again is found to be the case in Ch-1.

p53 acts as a tumor suppressor gene because of its inhibitory control of the cell cycle and its role in programmed cell death or apoptosis. Loss of p53 was identified in 3 of 6 informative grade 2 chondrosarcomas we studied, and in none of 7 grade 1 tumors. Reduction to homozygosity, associated with mutation of the remaining allele, is a hallmark of tumor suppressor genes, and is found for p53 in up to 60% of human cancers. Ch-1 conforms to this pattern with a missense mutation of the single identifiable p53 allele at a mutational "hotspot" - codon 175. Although there is yet no evidence that p53 mutations are of prognostic value in chondrosarcomas, there are reports of increased expression of mutant p53 in a subset of high grade chondrosarcomas. The p53 mutation in our source chondrosarcoma tissue may have contributed to the biological aggressiveness of the tumor as well as rendered the tumor amenable to maintenance of the chondrosarcoma phenotype in long term cell culture.

In summary, a molecular phenotype of an aggressive chondrosarcoma cell line derived from a high grade human chondrosarcoma is beginning to emerge. The cell line reported here synthesizes abundant aggrecan and no detectable levels of types I and II collagen mRNAs. The Ch-1 cell line and the Swarm rat chondrosarcoma exhibit similar expression of fibrillar collagen types IX and XI, aggrecan, biglycan and CD-RAP. Preliminary studies show that Ch-1 will be a useful cell line in which to study expression of type XI collagen and CD-RAP. Further evaluation of the p53 tumor suppressor gene, CD-RAP and other regulatory genes may yield insight into both chondrosarcoma pathogenesis and potential adjuvant therapies.

Recommended Reading

Chansky H, Robbins JR, Cha S, et al: Expression of cartilage extracellular matrix and potential regulatory genes in a new human chondrosarcoma cell line [In Process Citation]. J Orthop Res, 16:521-30, 1998.

Dietz UH, Sandell LJ: Cloning of a retinoic acid-sensitive mRNA expressed in cartilage and during chondrogenesis. J Biol Chem, 271:3311-6, 1996.

Dobashi Y, Sugimura H, Sato A, et al: Possible association of p53 overexpression and mutation with high-grade chondrosarcoma. Diagn Mol Pathol, 2:257-63, 1993.

Evans HL, Ayala AG, Romsdahl MM: Prognostic factors in chondrosarcoma of bone: a clinicopathologic analysis with emphasis on histologic grading. Cancer, 40:818-31, 1977.

Gitelis S, Bertoni F, Picci P, et al: Chondrosarcoma of bone. The experience at the Istituto Ortopedico Rizzoli. J Bone Joint Surg [Am], 63:1248-57, 1981.

Kawashima A, Ueda Y, Tsuchiya H, et al: Immunohistochemical localization of collagenous proteins in cartilaginous tumors: characteristic distribution of type IX collagen. J Cancer Res Clin Oncol, 120:35-40, 1993.

Does End-to-Side Nerve Repair Work? A Study of Axonal Sprouting Stimulated from Intact Nerves Across an End-to-Side Coaptation

Wren V. McCallister, B.S., B.A., Peter Tang, M.D., and Thomas E. Trumble, M.D.

Despite increased interest in the regeneration of peripheral nerves due to continued improvement in microsurgical techniques, the ability to manipulate nerve regeneration remains limited. The 1992 report by Viterbo et al. that proposed successful end-to-side axonal sprouting represented a significant advance in the repair of peripheral nerve injuries because an intact nerve could "donate" axons to the distal end of an injured nerve when the injury created a large gap or a very proximal lesion that would severely limit successful nerve regeneration. The initial conclusions appeared to demonstrate an intrinsic ability of axons to sprout across the end-to-side coaptation. More recently, Lundborg et al. reported successful collateral sprouting across an end-to-side coaptation using predegenerated nerves.

An end-to-side attachment of the distal end of a proximally injured nerve to a nearby intact nerve could provide regenerating axons to preserve the motor and sensory targets, enabling otherwise unobtainable functional recovery. The end-to-side axonal sprouting theory is dependent upon axonal sprouting occurring at the site of nerve coaptation.

In addition to end-to-side nerve repair, investigative efforts in the area of peripheral nerve regeneration have focused on neurotrophic factors, peptides shown to be influential in the differentiation, function and survival of neurons. Nerve growth factor (NGF), derived from end-organ targets, and ciliary neurotrophic factor (CNTF), produced by neuron-associated Schwann cells, are two neurotrophic factors which have received significant attention in recent years. The exact mechanisms by which these factors interact are not well understood, however, there is considerable evidence that each has a prominent role in the regeneration of peripheral nerves. Evidence exists for a synergistic effect between CNTF and both basic fibroblast growth factor (bFGF) and brain derived neurotrophic factor (BDNF). In the central nervous system, recent studies have suggested the possibility of a positive interaction between CNTF and NGF. To our knowledge, there are no published reports investigating potential interactions in the peripheral nervous system.

Our goal was to identify evidence of nerve regeneration after end-to-side nerve coaptation in the rat model using electrical stimulation, axonal counting and muscle weights. This study differs from previous studies in two important respects. First, we attempted to enhance the regeneration while previous studies only addressed the presence or absence of regeneration. The ability to stimulate regeneration would improve the clinical effectiveness of end-to-side repair. Second, we sought to identify whether the source of the regenerated axons was from true sprouting of the intact tibial nerve or from the injured proximal peroneal stump.

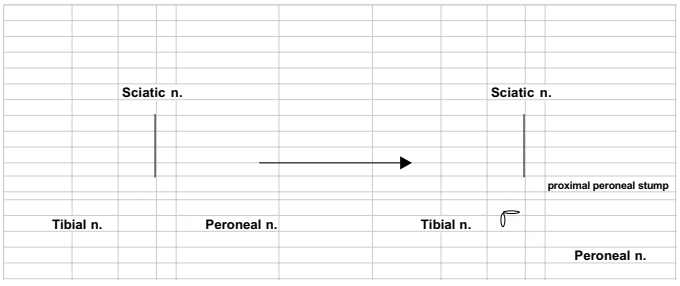


Figure 1: Diagram of end-to-side coaptation technique in the rat sciatic nerve model. The peroneal nerve was coapted to the intact tibial nerve after epineurotomy 1.5 cm distal to its division from the sciatic nerve and secured by two 10-0 nylon sutures. Note the proximal peroneal stump, elongated for illustrative purposes.

Methods

In male Harlan Sprague Dawley rats, an end-to-side repair was made in the right leg (with the left unoperated leg serving as a control) as outlined in Figure 1.

The experimental groups: in Group B, after coaptation, the growth factors (NGF 25 nanograms and CNTF 10 nanograms in a 100 microliter aliquot) were injected into the epineural sheath 1.0 centimeter proximal to the coaptation. Group A received only the coaptation while in Group C the peroneal nerve was transected distally, coiled upon itself and buried in muscle proximally to prevent reinnervation.

Twenty weeks after surgery, the peroneal nerves and tibialis anterior muscles were harvested from the operative and contralateral sides and processed for qualitative and quantitative analysis including axonal counting, light microscopy and wet muscle weights. Before harvesting, nerve stimulation with 0.5 milliamps occurred 1.0 centimeter proximal to coaptation and 1.0 centimeter distal to the coaptation on both the tibial nerve and the peroneal nerve. The foot response (flexion or extension) was recorded.

Statistical Analysis

Standard two-sided tests with significance level a and power 1-b were used for power analyses using the validation data of previous studies. The population sizes (6-7 animals per study group) were computed for 80% power with 95% confidence. To provide an extra margin of safety we elected to use eight animals per group. The data was analyzed using ANOVA with a two-

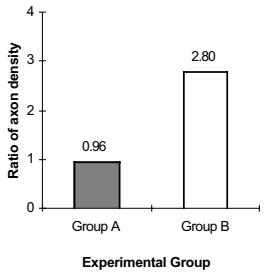


Figure 2: Axonal counting data from peroneal nerve sections twenty weeks after nerve transfer. For Groups A and B, the standard error was 0.11 and 0.15, respectively ($p<0.002$).

tailed student's t test to determine significant differences between the groups.

Results

Axonal Counting

Figure 2 reports the results of axonal counting performed on sections taken from the segment of the peroneal nerve that was transferred end-to-side to the tibial nerve. The results are reported as the ratio of the density (axons per micrometer squared) of the fibers of the experimental side to the control side. These results are statistically significant at $p < 0.002$. Qualitatively, the regenerated fibers were well myelinated, of smaller diameter and higher density when compared to the unoperated control fibers (Figure 3). The histological appearance of sections taken proximal to the site of coaptation but distal to the proximal peroneal stump revealed a significant number of axons traveling on the surface of the outer epineurium (Figure 4). Such axons were not observed in control sections.

Electrical Stimulation

Nerve stimulation in the normal unoperated animal results in a predictable foot response. With stimulation of the sciatic nerve above, and the tibial nerve below, the division of the peroneal nerve the normal animal displays dominant foot flexion with contraction of the gastrocnemius muscle. Stimulation of the peroneal nerve results in foot extension with contraction of the tibialis anterior muscle. After nerve transfer, the normal response was observed in both experimental groups with some exception in the growth factor group. There was an anomalous mixture of foot flexion and extension with stimulation above the coaptation site in four out of eight animals. Two out of eight animals displayed foot flexion with stimulation of the peroneal nerve.

Muscle Weights

Reported as the ratio of the operated to the contralateral unoperated side, the wet muscle weights recorded at the time of harvesting were: Group A, 0.539 ± 0.024; Group B, 0.596 ± 0.022; and Group C, 0.220 ± 0.003 ($p<0.002$).

Discussion

In this animal model we have demonstrated axonal sprouting in the context of end-to-side coaptation stimulated by the injection of NGF and CNTF in combination. Electrical stimulation, axonal counting and tibialis anterior muscle weights indicate the presence of axonal sprouting and successful reinnervation of target muscle. Our results support the work of previous studies in the central nervous system proposing a potential interaction between NGF and CNTF that facilitates nerve regeneration. Most importantly, this study provides evidence that the intact tibial nerve functions as a conduit for the regenerating axons that travel in the outer epineurium of the nerve. If these axons are derived from the proximal peroneal stump, site "Y" Figure 1, this challenges the proposed mechanism of end-to-side axonal sprouting at the site of coaptation. Further, such an alternative explanation to successful end-to-side axonal sprouting questions the potential application of end-to-side nerve repair in the clinical setting.

Recommended Reading

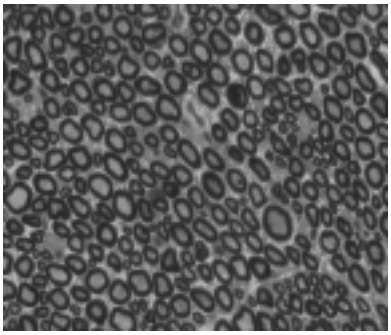
He, C.; and Chen Z.: Enhancement of motor nerve regeneration by nerve growth factor. Microsurgery, 13(3): 151-154, 1992.

Lundborg, G.; Zhao, Q.; Kanje, M.; Danielsen, N.; and Kerns, J.M.: Can sensory and motor collateral sprouting be induced from intact peripheral nerve by end-to-side anastomosis? J. of Hand Surgery (Br) , 19B: 277-82, 1994.

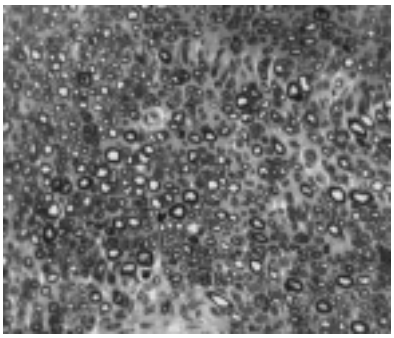
Newman, J.P.; Verity, A.N.; Hawatmeh, S.; Fee, W.E.; and Terris, D.J.: Ciliary neurtotrophic factor enhances peripheral nerve regeneration. Arch. Otolaryngol. Head Neck Surg., 122: 399-403, Apr. 1996.

Pollock, M.: Nerve regeneration. Curr. Opin. Neurol., 8: 354-358, 1995.

Viterbo, F.; Trindade, J.C.; Hoshino, K.; and Neto, A.M.: Latero-terminal neurorrhaphy without removal of the epineural sheath: Experimental study in rats. Sao Paulo Medical Journal, 110(6): 267-275, 1992.



(A)



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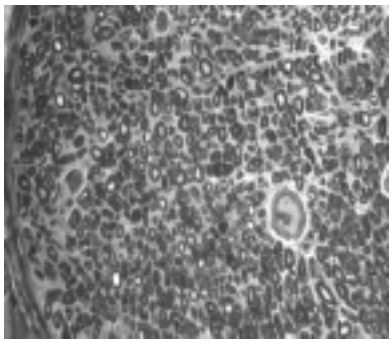

(C)

Figure 3: Histological appearance of sectioned peroneal nerves twenty weeks after nerve transfer (toluidine blue, 40X). (A) normal nerve (B) control coaptation only, Group A (C) growth factor injection, Group B. Note the increased density of smaller, well-myelinated nerves, when compared to normal nerve, consistent with axonal sprouting and regeneration.

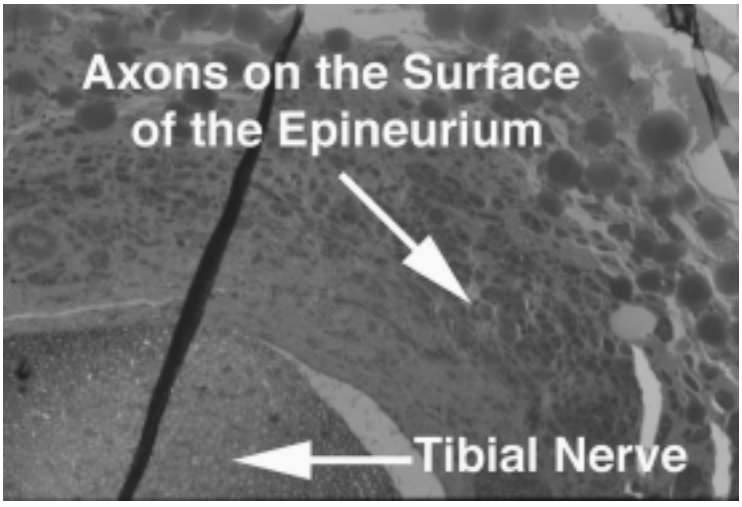

Figure 4. Histologic section taken proximal to the site of coaptation but distal to the proximal peroneal stump (toluidine blue, 40X). Note the significant number of axons traveling on the surface of the outer epineurium distinct from the tibial nerve proper.

Influence of Comorbid Medical Conditions on Pre-Treatment SF-36 Scores

Sohail K. Mirza, M.D., Barry Campbell, B.S., Randal P. Ching, Ph.D., Jens R. Chapman, M.D., Mark A. Konodi, M.S., and Frederick A. Matsen III, M.D.

Medical care is undergoing a revolution in the name of "Quality of Care". Quality is often assumed to be a measurable and valid means of comparison in allocating increasingly limited health care resources. This focus on quality is so intense that quality of care is being considered as an accreditation criterion to ensure compliance to standards of care in a coercive fashion. In this setting of competing physicians, treatments, organizations on the one side and finite resources on the other, it is imperative that we recognize the characteristics of the tools we use to define and measure quality.

A concurrent development is to focus the measurement of health care quality on the patients' perspective. In this outcomes driven approach, the benefits of health care are assessed using standardized patient-oriented outcome assessment instruments. The impact of medical intervention is assessed in terms of the extent to which it meets the patients' expectations and functional needs.

This study was designed to measure the effect of comorbid conditions on the functional status and well being of patients presenting for orthopaedic consultation at a regional academic medical center. The goals of the study were to identify the functional deficits experienced by these patients using a standardized functional assessment instrument, the Short Form (SF)-36, and assess the relative health-status limitation experienced by these patients due to coexisting diseases.

Materials and Methods

This study is a prospective assessment of all new outpatients presenting for evaluation to our institution over a three-year interval from January 1, 1995 to December 31, 1997. We asked all new patients evaluated at the Bone and Joint Center, University of Washington, to complete a questionnaire containing identification data, medical history information, and an SF-36 form prior to their evaluation. The treating physician reviewed these forms for completeness during the initial interview and examination. We subsequently scanned the SF-36 forms into an electronic database and placed the paper copy in the patient's file. Our study population consisted of 8941 patients.

We used the Total Charlson Comorbidity Score to quantify comorbidity in our patients. We selected comorbid diagnoses identified as being important in determining the future health status of patients according to criteria reported by. We used the technique described by Deyo to review patients' electronic medical record for these comorbid diagnoses.

We constructed a Paradox 5.0 database containing the SF-36 information. This database contained an event record, demographic data, diagnosis data, and procedure data. We used a customized scoring routine to standardize SF-36 scoring. This routine used the procedures established in the SF-36 Scoring Manual to produce normalized scores for the eight SF-36 functional domains. Our routine expressed the final domain score for each patient as a percentage of age and sex matched control values.

We stratified the patients into three groups according to their comorbidity score (Table 1). We evaluated the effect of comorbidity on each SF-36 domain score using the software package SPSS 7.5. We calculated correlation coefficients between the Charlson Score and each of the SF-36 functional domain scores. We defined significance as a p-value <0.05. We performed a one way analysis of variance (alpha = 0.05) between the comorbidity groups and each functional domains measured by the SF-36 health assessment instrument. We also conducted post hoc comparisons using the Bonferroni/ Dunn test.

	Group 1	Group 2	Group 3
Charlson Score	"0"	"1-3"	">3"
No. of patients (%)	6897 (77.1%)	1857 (20.8%)	187 (2.1%)
Age	44.4 ± 16.1	53.6 ± 16.4	57.3 ± 16.6
Physical function	0.708 ± 0.343	0.635 ± 0.398	0.544 ± 0.382
Role-physical	0.407 ± 0.508	0.424 ± 0.569	0.346 ± 0.589
Bodily pain	0.518 ± 0.333	0.536 ± 0.362	0.537 ± 0.374
General health	0.907 ± 0.304	0.819 ± 0.338	0.652 ± 0.354
Vitality	0.830 ± 0.375	0.765 ± 0.395	0.623 ± 0.340
Social function	0.732 ± 0.342	0.707 ± 0.351	0.642 ± 0.356
Role-emotional	0.813 ± 0.468	0.798 ± 0.500	0.815 ± 0.505
Mental	0.931 ± 0.262	0.917 ± 0.262	0.879 ± 0.240

Table 1: Patient stratification by total Charlson comorbidity score.

Results

The mean age of the study population was 47 years (SD 16). Results of the one-way ANOVA showed differences in age among the three groups. The patients with higher Charlson scores were older. Correlation was significant at the 0.01 level for physical function, general health,

Domain	Correlation Coefficient*	Significance
Physical function**	-0.095	< 0.0001**
Role-physical	-0.003	0.761
Bodily pain	0.020	0.066
General health**	-0.134	< 0.0001**
Vitality**	-0.097	< 0.0001**
Social function**	-0.037	< 0.0001**
Role-emotional	0.016	0.138
Mental**	-0.035	< 0.0001**

*Spearman's rho
**Significant at the 0.01 level (two-tailed)

Table 2: Correlations between Charlson score and SF-36 domains.

Domain	ANOVA P Value	Group 1 versus 2*	Group 1 versus 3*	Group 2 versus 3*
Physical function	<.0001**	<.0001**	<.0001**	.0010**
Role-physical	0.1290	.2290	.1250	.0589
Bodily pain	0.1120	.0450	.4559	.9645
General health	<.0001**	<.0001**	<.0001**	<.0001**
Vitality	<.0001**	<.0001**	<.0001**	<.0001**
Social function	<.0001**	.0047**	.0006**	.0170
Role-emotional	0.5014	0.244	.9457	.6486
Mental	0.0066**	.0456	.0093**	.0653

*Bonferroni/Dunn, significance level 0.05
**Significant difference

Table 3: Levels of significance between comorbidity groups.

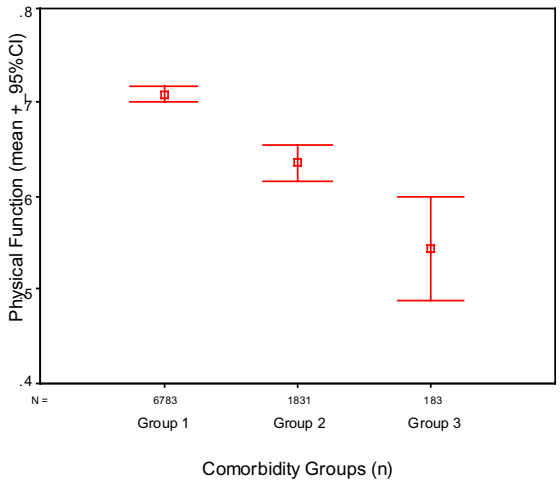

Figure 1: Physical function scores for the three Charlson Score groups expressed as a percentage of age and sex matched control values.

vitality, social function and mental health domains of SF-36. Each of these domains showed a decreased score associated with higher Charlson comorbidity scores. Role-physical, bodily pain, and role-emotional domains did not show statistically significant correlation with comorbidity (Table 2).

Results of the one-way ANOVA supported the hypothesis that the level of comorbidity has a differential effect on the measures of physical function, general health, vitality, social function, and mental health scores of the SF-36 health assessment instrument. Each of these domains showed a progressive decrease with an increasing presence of coexisting medical conditions. As an example, Figure 1 shows this effect for the physical function domain. The patient groups with greater comorbidity had lower physical function scores. The level of comorbidity did not have a differential effect on the measure of role-physical, bodily pain, and role-emotional scores of the SF-36 health assessment instrument (Table 3).

Discussion

The outcomes movement has generated optimistic prospects for improving medical care of our patients. Systematically measuring quality of care will help patients, physicians, and third-party payers make better health-care decisions. Development of standardized and validated instruments of health-status assessment has allowed large scale deployment of outcome assessment techniques. Instruments soliciting subjective data from patients can provide useful information that may be more important in determining the patients' perception of well-being than traditional measures of clinical or physiological indexes. Development of shorter questionnaires has made large scale application more practical. These shorter forms have been demonstrated to be equally responsive in surgical patients when compared with longer instruments.

Interpretation of treatment interventions requires identification of specific patient populations evaluated. Excluding patients with significant comorbidity limits the interpretation of results. Randomization of subjects controls for both known and unknown confounding factors. Controlling for

potential confounding factors in non-randomized trials, however, requires consideration of coexisting diseases and severity of illness. Our work demonstrates that coexisting medical conditions need to be considered in the comparisons of functional assessment in large populations.

Conclusion

Comorbid diseases significantly influence the functional assessment as measured by SF-36 in patients presenting with musculoskeletal complaints. This effect is independent of age, sex, and the primary musculoskeletal diagnosis.

Functional Outcome of In Situ Screw Fixation Versus Flexion Intertrochanteric Osteotomy for Slipped Capital Femoral Epiphysis

MOHAMMAD DIAB, M.D., S. DALUVOY, B.S., J. KASSER, M.D., AND B. SNYDER, M.D.

In slipped capital femoral epiphysis (SCFE) the proximal femoral metaphysis displaces posteriorward to produce an apex anterior deformity. *In situ* screw fixation (ISSF) accepts this deformity. Flexion intertrochanteric osteotomy (FIO) has the potential to restore anatomy, and is theoretically safe in terms of the proximal femoral blood supply. In a retrospective, nonrandomized study of unilateral, chronic, severe, stable SCFE, we compared the outcome of ISSF versus FIO at a minimum of 2 yr. follow-up.

MATERIALS AND METHODS

39 patients met the inclusion criteria, of whom 20 agreed to participate. Ten patients (5 female, 5 male; age 10.6-16.5 yr., average 13.0 yr.; follow-up 3.3-13.0 yr., average 6.8 yr.) underwent ISSF and 10 patients (4 female, 6 male; age 11.6-25.5 yr., average 15.5 yr.; follow-up 2-13.8 yr., average 8.0 yr.) underwent FIO (see figures). Three components entered into the measurement of functional outcome: patient perception, physical examination (range or motion, strength, body mass index [BMI], gait, performance) and radiographic assessment (slip angle, deformity, joint space, and sphericity by AP, frog and true lateral röntgenograms). A Hip Outcome Instrument was derived from established validated instruments: Harris Hip Score (HHS), Musculoskeletal Function Assessment (MFA), Short Form – 36 (SF-36) and Nursing Health Evaluation (NHE).

RESULTS

FIO patients demonstrated a significantly greater BMI ($p<0.05$) and slip angle ($p<0.05$) than ISSF patients. There were no significant differences in MFA, SF-36 or NHE. The HHS was higher for the ISSF group compared with the FIO group (one tailed t-test $p = 0.04$). The FIO group demonstrated significantly improved hip internal rotation compared with the ISSF group ($p<0.05$). There was no significant difference in hip flexion, abduction, adduction, external rotation, walking speed, stair climbing speed or foot progression angle. There was no evidence of osteonecrosis in either group. Chondrolysis followed FIO in 1 patient (who sustained and intraoperative fracture of the femoral neck), but did not occur after ISSF.

DISCUSSION

The rationale for treatment of SCFE with proximal femoral osteotomy is based upon the inferred relationship of deformity to early dysfunction and late coxarthritis. Proof of the latter requires longer follow-up. We found that only hip internal rotation was significantly increased by FIO. Moreover, our results suggest that this may be associated with a diminution in HHS. Within the limited power of this study, we can state that improved outcome after FIO was not realized despite the theoretical advantages. While internal rotation was improved with physical exam, the FIO patients tended to have more pain and a significantly worse HHS. From these "pilot" data, we plan a multicenter study to further test the hypothesis that there is no significant advantage to treatment with FIO compared with ISSF.

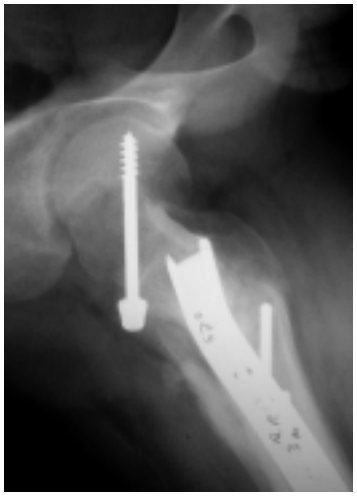

Figure 1: Lateral Radiograph. Flexion Intertrochanteric Osteotomy.

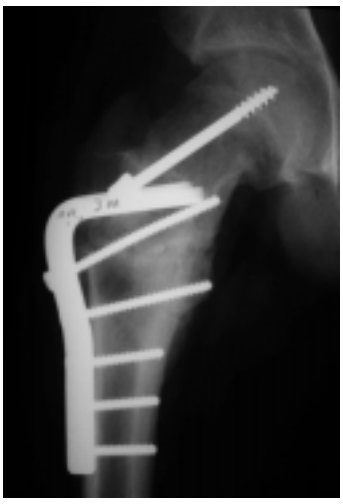

Figure 2: AP Radiograph. Flexion Intertrochanteric Osteotomy.

Somatosensory Evoked Potential Monitoring During Closed Humeral Nailing

William J. Mills, M.D., Jens R. Chapman, M.D., Lawrence R. Robinson, M.D., and Jefferson C. Slimp, Ph.D.

Most closed, isolated humeral shaft fractures can be successfully treated non-operatively, and the indications for surgery are reasonably well established. Surgical stabilization generally involves either plating or intramedullary nailing. In contrast to open reduction and internal fixation with compression plating, locked intramedullary nailing offers the advantages of increased biomechanical strength in load to failure and three point bending stiffness, while closed nailing leaves the fracture hematoma relatively undisturbed, theoretically enhancing fracture healing. However, closed insertion of a locked, reamed intramedullary nail may put neurovascular structures, especially the radial nerve, at risk. Recently, intra-operative somatosensory evoked potential (SSEP) monitoring has proven to be a reliable method of identifying abnormal neural responses, both in instrumentation of the spinal column and acetabular fracture surgery. The purpose of this study was to assess the role of intra-operative SSEP monitoring during closed, locked intramedullary nailing of humeral shaft fractures.

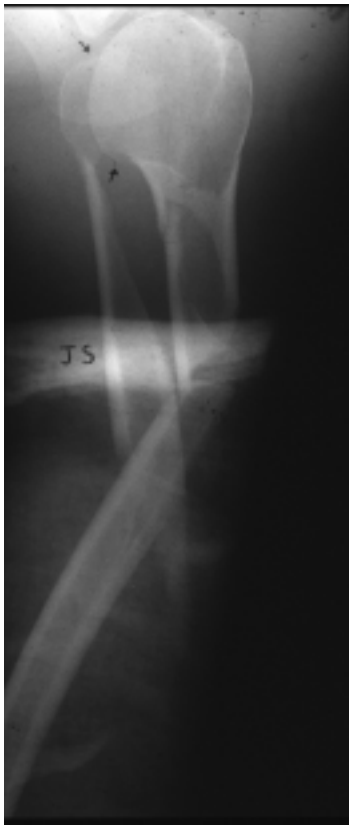

Figure 1: A pre-operative x-ray of a segmentally unstable fracture of the humeral shaft.

Material and Methods

Between April 1991 and February 1994, 81 patients met indications for internal fixation of humeral shaft fractures at Harborview Medical Center. Of these, 45 were treated with interlocked humeral nailing. Thirteen patients treated in this fashion were felt to be at risk for iatrogenic nerve injury secondary to placement of a locked intramedullary nail. This increased risk was perceived because of a) unobtainable preoperative neurological examination due closed head injury (6 patients), or b) anticipation of difficult reduction maneuver due to fracture complexity or displacement likely endangering the radial nerve during manipulation (7 patients). Indications for surgical stabilization included an inability to maintain satisfactory reduction with closed treatment (6 patients), polytrauma (5 patients), floating elbow (1 patient), and malaligned delayed union (1 patient).

SSEPs were used for intra-operative monitoring. Baseline SSEP signal was elicited in all patients prior to beginning the surgical procedure. The radial and median nerves were monitored with recording from cortical and subcortical sites. After sterile preparation of the entire upper limb, pairs of sterile 1/2" needle electrodes were placed for stimulation using 2-3 cm inter-electrode separation. The superficial radial nerve was stimulated at the wrist just proximal to the radial styloid, the median nerve between the flexor carpi radialis and palmaris longus tendons, and the posterior interosseous nerve 2 cm distal to the radial head. Responses were recorded at Erb's point, the C7 spinous process and the mastoid process (sub-cortical sites) and the contralateral scalp (cortical site). Several hundred responses were averaged to obtain a response and recordings were made from each nerve at least once every 20 minutes, but more frequently during fracture manipulation and guide wire or nail insertion and interlocking. Criteria for intra-operative abnormality were amplitude decrease of more than 30% for subcortical sites or more than 50% at the scalp.

The surgical technique consisted of closed manipulation and fracture reduction followed by placement of a guide rod across the fracture site into the distal humerus under fluoroscopic visualization. For the eleven nails inserted in an antegrade fashion proximal interlocking with a single screw was always utilized, while the need for distal interlocking was determined by the fracture pattern and distal canal filling. Distal interlocking was performed with a free hand technique in an anterior-posterior fashion. Both retrograde nails were locked proximally and distally.

Results

Baseline signals were obtainable in 12 of 13 patients for both radial and median nerves. Signal from the median but not radial nerve was obtained in one patient with a severe closed head injury and a displaced fracture of the humeral shaft. A preoperative examination of upper limb function was unobtainable due to his closed head injury. The planned closed nailing was abandoned, a lateral approach to the humerus performed and the fracture site exposed. The radial nerve was found in the fracture site, released and protected, and open nailing continued without further incident.

Intra-operative SSEP changes occurred in 2 of the remaining 12 patients. In one, the superficial radial

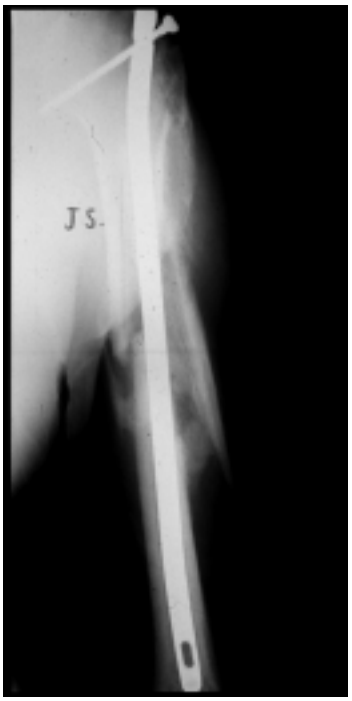

Figure 2: A post-operative x-ray of the fracture.

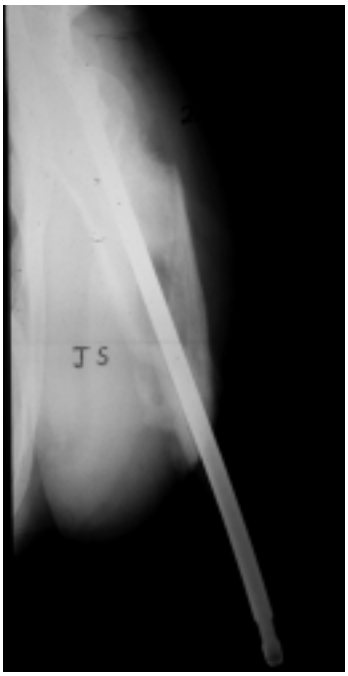

Figure 3: Another post-operative x-ray of the same fracture of the humeral shaft.

nerve response amplitude diminished below established thresholds during fracture manipulation prior to attempted guide rod insertion. Five minutes after altering the manipulation technique and discontinuing longitudinal traction, the amplitude returned to baseline. Two centimeters shortening of the segmentally comminuted humeral shaft were accepted, nailing proceeded uneventfully, and the postoperative neurological examination was normal. Union occurred in a timely fashion. The second patient with intra-operative SSEP changes had a significant drop in the median nerve amplitude during attempted anterior to posterior distal interlocking screw placement. Interlocking was discontinued, and after 5 minutes 75% recovery of the median nerve signal was noted. Distal interlocking was then performed uneventfully from posterior to anterior. No postoperative neurological deficits were identified. SSEP monitoring therefore impacted our surgical technique in 3 of 13 patients (23 %) . No patient monitored during humeral nailing had new neurological deficits postoperatively.

Discussion

For those fractures in which surgical treatment is indicated, closed intramedullary nailing of the humeral shaft may offer distinct biomechanical and soft tissue advantages over open reduction and plate fixation. One possible disadvantage of closed nailing is that the radial nerve is not routinely identified and protected. Many authors have reported postoperative neurapraxia with locked humeral nailing and appropriately recommend caution during fracture reduction and distal interlocking. In patients with a preoperative radial nerve palsy, or other upper extremity neurological deficit, closed nailing risks iatrogenic injury if the nerve is in the fracture site. Clearly, closed nailing in that setting could produce devastating radial nerve injury. The role of SSEP monitoring in closed, interlocked humeral nailing demonstrated here is for that specific group of patients in whom a closed head injury or other factors make upper extremity neurologic status unknown, or in those patients with an intact radial nerve in whom a difficult closed reduction is anticipated.

Somatosensory evoked potentials allow for a sterile, virtually real-time assessment of neural status. At our institutions as well as others, the use of SSEP monitoring has become routine for surgery involving instrumentation of the spine. This study demonstrates the technical feasibility and efficacy of intra-operative upper extremity SSEP monitoring in a select group of patients undergoing closed, interlocked humeral nailing. In three of thirteen patients (23 %) signal changes prompted a change in surgical plan.

Our experience suggest that intra-operative SSEP monitoring during closed humeral nailing in select patients is beneficial. When baseline signals are unobtainable, a limited exposure of the fracture site and identification and protection of the radial nerve may minimize the risk of iatrogenic injury. Similarly significant signal deterioration with manipulation, traction or interlocking attempts suggest the need to release traction, alter reduction maneuvers and possibly modify interlocking technique.

Recommended Reading

Blasier RB and Graham TJ: Locking intramedullary nailing of fractures of the humeral shaft. Am J Orthop 1996; 25(5): Suppl. 31-37

Foster RJ, Dixon GL, Bach AW, Appleyard R: Internal fixation of humeral shaft lesions. Indications and results. Orthop Trans 1983; 7:69

Henley MB, Monroe M, Tencer AF: Biomechanical comparison of methods of fixation of a midshaft osteotomy of the humerus. J Orthop Trauma 1991; 5(1): 14-20

Mast JW, Spiegel PG, Harvey JP, Harrison C: Fractures of the humeral shaft. A retrospective study of 240 adult fractures. Clin Orthop 1975; 112: 254-262

Robinson LR, Slimp JC, Anderson PA, Stolov WC. The efficacy of femoral nerveintra-operative somatosensory evoked potentials during surgical treatment of thoracolumbarfractures. Spine 1993; 18(13): 1793-97

Russell TA, Simard J, Taylor JC, Lavelle DG, Nichols L, Walker B: Interlocking intramedullary nailing of humeral shaft fractures. Orthop Trans 1992; 16(2): 334

Percutaneous Stabilization of U-Shaped Sacral Fractures Using Iliosacral Screws

Sean E. Nork, M.D., Clifford B. Jones, M.D., Susan P. Harding, M.D., Sohail K. Mirza, M.D., and M.L. Chip Routt, Jr., M.D.

Sacral fractures are common injuries in trauma victims and are associated with a high rate of neurologic deficits. Despite numerous reports of zone III sacral fractures, transverse sacral fractures, and spondylolisthesis of the sacral segments, U-shaped sacral fractures have received little mention. The actual pathoanatomy of these fractures is poorly understood but is characterized by bilateral transforaminal sacral fractures with a transverse component in the upper sacrum. Depending on the pattern of the fracture, the caudal segment may be flexed (more common) or extended relative to the cephalad component. This results in the typical kyphotic deformity of the sacrum seen in these fractures (Figures 1 and 2). The goal of this study is to evaluate a percutaneous method of stabilization of these unusual fractures and their early clinical results.

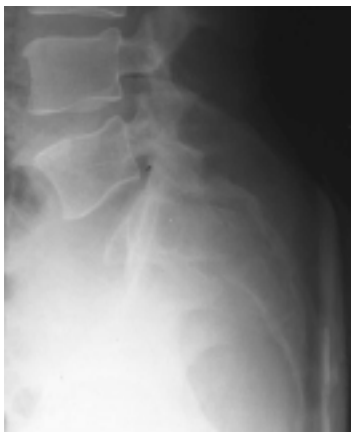

Figure 1: Sacral deformity.

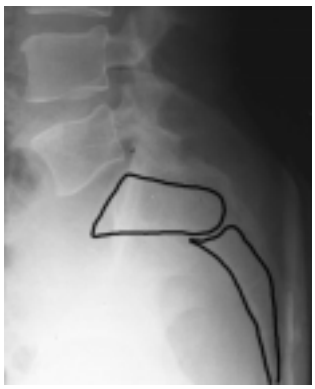

Figure 2: Sacral deformity (outlined).

Materials and Methods

Over a 38 months period, 442 patients with pelvic ring disruptions were treated at Harborview Medical Center, a level one trauma center. Only thirteen (2.9%) of these patients had displaced U-shaped sacral fractures treated with percutaneous iliosacral screw stabilization. There were 11 male and 2 female patients, ranging in age from 21 to 60 years (mean 39 years). Mechanism of injury included accidental falls from heights in four patients, suicide attempts by jumping in three, motor vehicle accidents in two, industrial accidents in two, motorcycle accident in one, and pedestrian versus motor vehicle in one. The average Injury Severity Score (ISS) was 18.1 (range, 9-34). The sacral injuries were further classified according to Roy-Camille based on plain pelvic orthogonal radiographs and routine two-dimensional computerized tomography scans. There were one type 1, twelve type 2, and zero type 3 fracture patterns. All of the fractures were through the upper two sacral segments. Lateral sacral plain radiographs were obtained and in all patients and best identified these fractures.

Clinical signs of hemodynamic instability at admission were present in seven patients. Associated injuries included other spinal fractures in five patients, traumatic brain injuries in four patients, and calcaneal fractures in three patients. A detailed neurologic examination was documented in all patients upon arrival and included motor strength testing, sensory examination, evaluation of rectal tone, and the presence of lower extremity reflexes. Neurologic abnormalities of the lumbar or sacral roots were initially noted in eight patients. Another patient developed progressive paresthesias and motor weakness in the S1 nerve root distribution while in the hospital. Two patients were intubated and pharmacologically paralyzed upon arrival and complete preoperative neurologic examinations were not possible.

Technique

These thirteen patients were treated operatively according to a management protocol for their U-shaped sacral fractures. Preoperative CT scans were evaluated to determine the safe zone for screw insertion. Neurodiagnostic monitoring was not used during screw

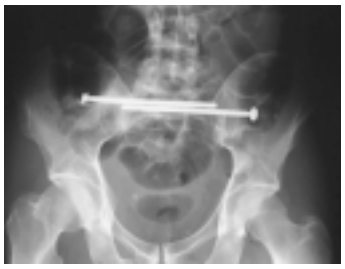

Figure 3: AP after fixation.

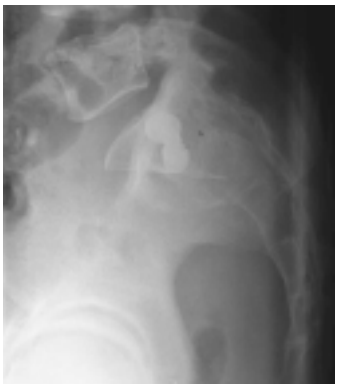

Figure 4: Lateral after fixation.

insertions. Fracture stabilization was accomplished using fluoroscopically guided iliosacral screws inserted percutaneously. Orthogonal pelvic inlet and outlet images, as well as lateral sacral views were obtained intraoperativley and correlated with the preoperative CT scan to assess sacral morphology. The guide pins and cannulated drills were oriented to allow insertion of the screws across both components of the transforaminal sacral fractures (Figures 3 and 4).

Results

Twenty-five fully threaded cancellous 7.0 mm cannulated screws were used. Eleven patients had bilateral screw fixations, one patient had unilateral double screw fixation, and one patient had unilateral single screw fixation. Operative time for screw insertion averaged 48 minutes, with 2.1 minutes of fluoroscopy. Subsequent sacral neurological decompressions were not performed in any patients. All of the patients were immobilized after surgery with an HTLSO orthosis for 12 weeks. Patients were mobilized safely to a cardiac chair immediately after surgery and could be transported in a wheelchair postoperatively.

Accurate and safe screw insertions without foraminal or canal violations were confirmed in all patients with postoperative pelvic plain radiographs and computerized tomograms. A paradoxical inlet view of the upper sacral segments on the injury AP pelvis was seen in 12 of 13 patients (92.3%) and the diagnosis was confirmed with the lateral sacral view in 100% of patients. Computed tomography was useful in confirming the diagnosis in all cases.

There were no deaths. Preoperatively, sacral kyphosis averaged 29 degrees (range, 6 – 75 degrees), while postoperative sacral kyphosis averaged 28 degrees (range, 6 – 63 degrees). All of the fractures healed clinically and radiographically. There were no wound infections. One partial screw disengagement occurred without fixation failure in the only patient treated with a single unilateral screw. This screw was removed twelve weeks after injury.

Of the nine patients with preoperative neurologic abnormalities, only two patients had residual neurologic deficits. Of these two patients, both had multiple lumbar burst fractures which required decompression and instrumented fusions.

Discussion

The diagnosis of U-shaped sacral fractures is difficult. A paradoxical inlet of the upper sacrum on the AP radiograph should alert both the radiologist and the orthopaedic surgeon to this injury and suggests the need for lateral sacral imaging. In this series, the lateral sacral radiograph and the CT scan demonstrated the injury in all patients.

Surgical stabilization allows safe and early mobilization of the patient from recumbency. Percutaneous fixation should diminish potential blood loss and operative times compared to open techniques. In addition, a percutaneous approach allows for rapid stabilization in the supine position and does not interfere with future sacral decompression. Iatrogenic neurologic injuries and screw errors were avoided in this series despite the use of extra long iliosacral screws (up to 150 mm). This series was limited to kyphotic deformities which allow in situ fixation. Progressive kyphosis was not observed despite this limited internal fixation.

Neurologic abnormalities are commonly associated with these fractures and occur in approximately 85% of cases. In this series, complete neurologic recovery was observed in seven of nine patients without sacral decompression. Because of concern over progression neurologic deficits which was observed in one patient in this series prior to surgery, we feel that stabilization of these injuries is necessary to protect the local neuroanatomy and to allow neurologic recovery. This technique is especially useful in polytraumatized patients which may require multiple procedures and may need to be moved from total recumbency.

Conclusions

Delayed diagnosis is avoided by a high clinical suspicion, early lateral sacral radiographs, and pelvic CT scans. Surgical stabilization allows early mobilization of the patient from recumbency. Percutaneous fixation should diminish potential blood loss and operative times compared to open techniques, and still allows sacral decompression of the local neural elements. Early percutaneous iliosacral screw fixation is an effective for these injuries.

Recommended Reading

Ebraheim NA, Biyani A, Salpietro B. Zone III fractures of the sacrum. A case report. Spine 1996;21:2390-2396.

Gibbons KJ, Soloniuk DS, Razack N. Neurological injury and patterns of sacral fractures. J Neurosurg 1990;72:889-893.

Roy Camille R, Saillant G, Gagna G, Mazel C. Transverse fracture of the upper sacrum. Suicidal jumper's fracture. Spine 1985;10:838-845.

Sabiston CP, Wing PC. Sacral fractures: classification and neurologic implications. J Trauma 1986;26:1113-1115.

Schmidek HH, Smith DA, Kristiansen TK. Sacral fractures. Neurosurgery 1984;15:735-746.

Strange Vognsen HH, Lebech A. An unusual type of fracture in the upper sacrum. J Orthop Trauma 1991;5:200-203.

Screw Fixation of Osteochondral Injuries in Comminuted Acetabular Fractures

Daniel Segina M.D., Sean E. Nork, M.D., and M.L. Chip Routt, Jr., M.D.

Treatment of periarticular fractures is difficult. Accurate articular reduction and stable fixation allows early joint motion and should improve articular cartilage healing. This is especially true for acetabular fractures, where clinical series have demonstrated the direct relationship between patient outcome and the quality of articular reduction. Certain acetabular fractures, especially posterior wall patterns present a challenging problem due to the presence of marginal impaction and/or osteoarticular loose bodies. Various techniques have been described for restoring the acetabular articular surface when loose or marginally impacted osteochondral fragments are encountered. We evaluated small fragment intraosseous screws to secure impacted or loose osteochondral acetabular fragments in acetabular fractures.

Methods

Between January 1996 and December 1998, 85 patients with acetabular fractures involving the posterior wall, were operatively treated at Harborview Medical Center in Seattle, Washington. Eighteen of the 85 patients (21%) had osteochondral impacted or loose fragments amenable to intraosseous screw fixation. There were 15 men and 3 women with an average age of 41.7 years (range 20 to 68). The cause of injury was a motor vehicle accident in all 18 patients. Seventeen of the eighteen patients had posterior dislocations associated with their fractures.

All patients were admitted through the emergency room following a standard protocol, which included an anteroposterior pelvic plain radiograph. After initial resuscitation, the posteriorly dislocated femoral heads were urgently relocated using intravenous sedation and controlled (gentle) manual manipulation. Repeat radiographs confirmed reductions. Additional radiological evaluations consisted of iliac and obturator oblique radiographs (Figure 1). A routine two dimensional pelvic computed tomography (CT) scan was obtained (Figure 2). All 18 fractures were classified according to Letournel. There were 6 elementary posterior wall fractures, 2 associated fractures of the posterior column and posterior wall, and 10 associated transverse and posterior wall fractures. Marginal impaction, as described by Brumback, and /or osteoarticular loose bodies were present in all patients. The patients were placed in distal femoral skeletal traction and admitted to the hospital. Deep venous thrombosis prophylaxis consisted of bilateral thigh high sequential compression devices (KCI Inc.) on the lower extremities and subcutaneous heparin.

A Kocher Langenbeck surgical approach was used for each patient. The posterior wall fragment was retracted superolaterally to reveal the underlying fracture sites. The hip joint was distracted and the osteochondral fragments were removed and the marginal impaction zones were assessed. For those patients with associated fracture patterns, the transverse or posterior column component was reduced, clamped, and secured with cortical lag screws. The osteoarticular fragments were then reduced using the intact acetabulum and femoral head as templates. Depending on their size, the osteochondral fragments were then stabilized using either a 2.7mm, 2.0mm, or 1.5mm extraarticular intraosseous screw directed away from the joint. The screws were inserted through the subchondral cancellous bone of the fragment into the intact acetabulum. Impacted fragments were treated with elevation to the femoral head. The resultant cancellous bone defect was filled with autograft bone obtained from the ipsilateral greater trochanter. If the fragment demonstrated instability after bone grafting of the defect, it was secured with a intraosseous screw. The femoral head was distracted and the articular reduction inspected. The posterior wall was then reduced and secured using a contoured 3.5mm pelvic reconstruction plate. Orthogonal fluoroscopic images demonstrated

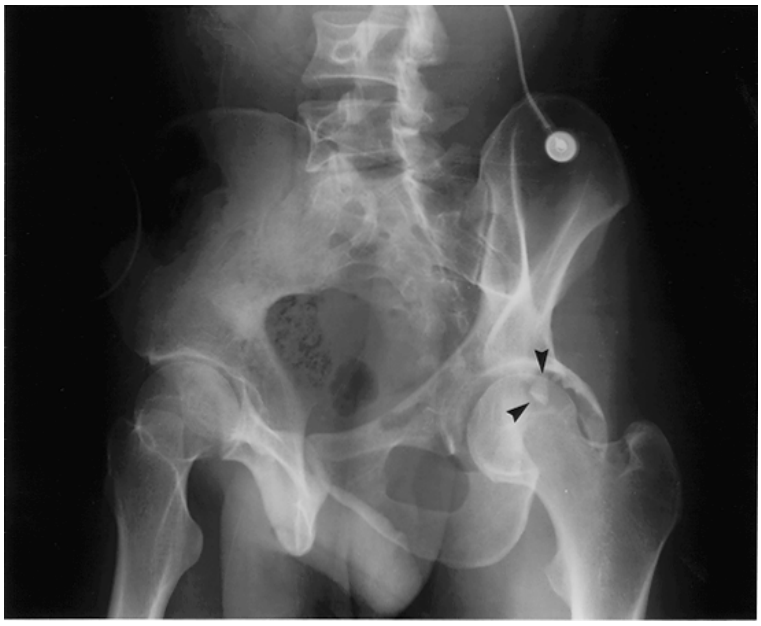

Figure 1: Oblique view showing fracture fragment.

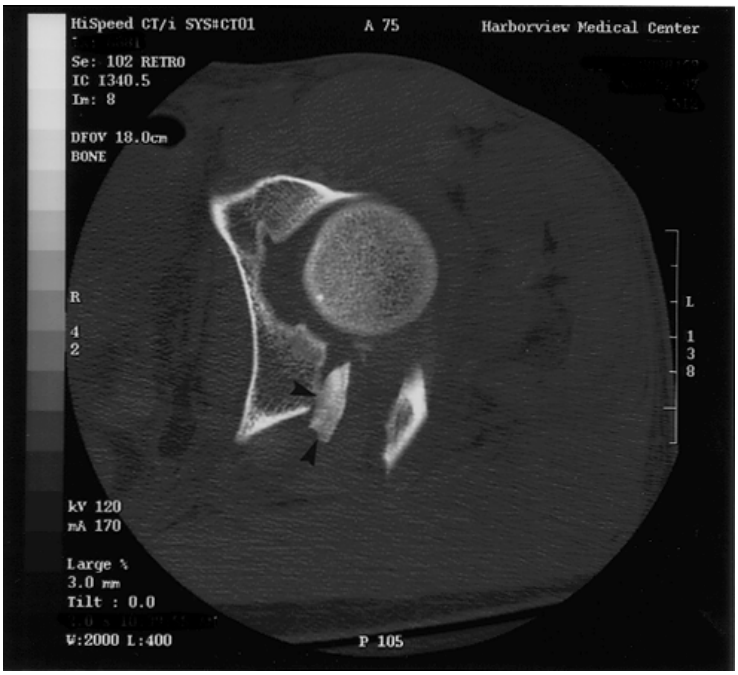

Figure 2: CT scan showing fracture fragments.

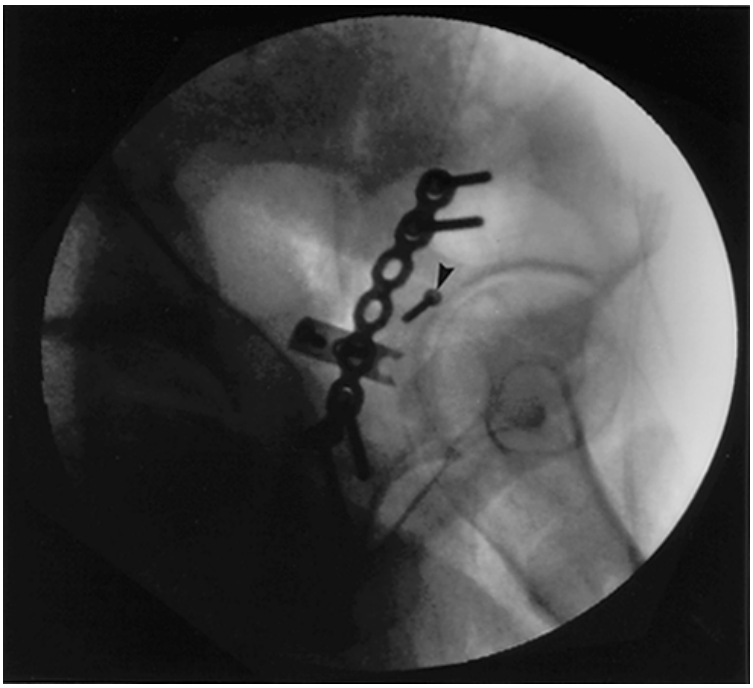

Figure 3: Post fixation x-ray.

implant safety and fracture reduction quality. The wound was closed in layers over suction drains. Post-operative oblique radiographs and a CT scan of the pelvis and acetabulum were obtained (Figure 3, 4, and 5). Continuous passive hip motion devices were used post-operatively until discharge with hip flexion limited to 60 degrees. Weight of leg weight bearing with crutch assist protected the repair for six weeks after surgery. Progressive partial weight bearing was permitted thereafter, followed by full weight bearing three months after operation. Serial oblique pelvic plain radiographs were taken at six , twelve and fifty two weeks post-operatively to asses fracture healing, implant changes, ectopic bone formation, and joint abnormalities.

Results

Fifteen of the seventeen patients with posteriorly dislocated hips had successful closed manipulative reductions. Two patients were noted to have nonconcentric reductions due to intrarticular large osteochondral loose bodies. Both were taken urgently to the operating room for open debridement of the hip joint and repair of their fracturse.

Postoperative acetabular CT scans characterized articular incongruity as gapping, step off, or both. Gaps greater than 2 millimeters were noted in 6 patients, while articular step-off was seen in 4 patients. The intraosseous screw position was also noted. No patient demonstrated an intraarticular position of the intraosseous screw or other implants.

Two of the 18 patients, both with loose osteochondral fragments, required intraosseous screw removal during the procedure. Both patients had malreduced osteochondral fragments. This was realized once the posterior wall reduction was attempted and noted to be inaccurate. After screw and fragment removal, an accurate reduction of the posterior wall was achieved.

One patient developed a deep wound infection 3 months after injury that required operative debridement of the wound and implant removal. His initial postoperative course was complicated by a gangrenous gallbladder with subsequent abdominal wound infection requiring open packing. At reoperation, the intraosseus screw was unchanged in its subchondral extrarticular location. He had progressive hip pain associated with joint space loss, and underwent uncomplicated total hip arthroplasty.

Discussion

Judet and Letournel first described supporting marginally impacted osteochondral fragments with

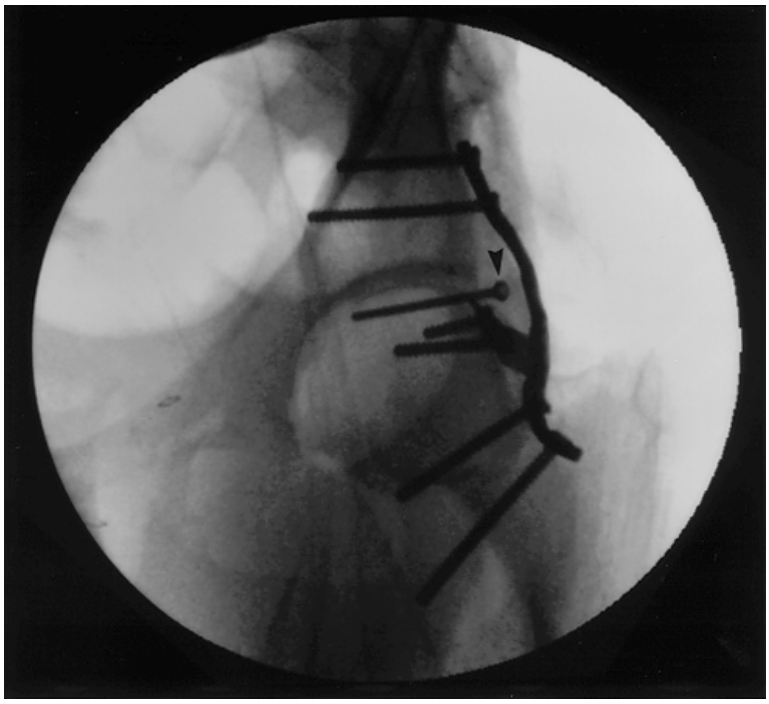

Figure 4: Post fixation x-ray.

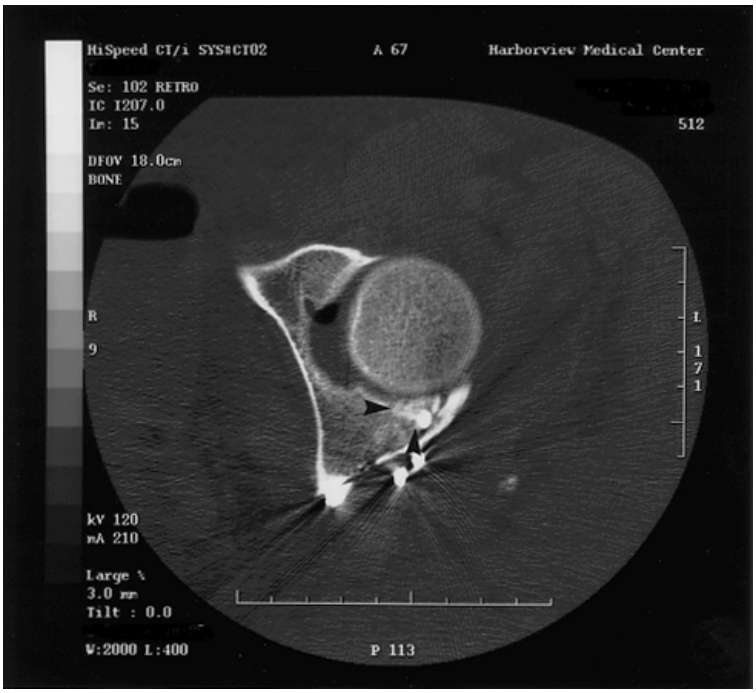

Figure 5: Post fixation CT scan.

autograft cancellous bone. They advocated that the reduction be achieved using the femoral head as a template. While this technique may initially provide for an accurate reduction, assurance of this accuracy can be lost once the posterior wall fragment is reduced. This is a direct consequence of the inability to visualize the joint after reduction and fixation of the wall fragment. Brumback et. al. addressed this potential pitfall, recommending intraosseous Kirschner wire fixation of large or detached osteochondral fragments. McCardel reported on the potential serious complication of Kirschner wire migration to the heart using this technique. They advocated Herbert screw fixation of large osteochondral acetabular fragments. Biomechanical evaluations acetabular fractures have demonstrated the adverse effects of articular incongruity . Olson et al. showed the detrimental effects of articular malreduction in transverse and posterior wall fractures. Both Keith et. al. and Olson et. al. examined the effect of relatively small posterior wall fracture fragments. They demonstrated potential instability and contact pressure changes with a little as 20% involvement of the posterior wall. These studies validate the belief that improved quality of articular reduction translates into improved potential for better patient outcome. This biomechanical data is complemented by clinical studies that demonstrate improved patient outcome with improved quality of articular reduction. Supplemental rigid fixation of osteochondral fragments, in addition to the removal of known intraarticular debris, also offers the best prophylaxis against third body wear.

Small screw fixation of osteochondral fracture fragments in certain acetabular fractures provides an operative adjuvant when reducing and stabilizing these important fragments. The subchondral small intraosseous screw usually allows for stable fixation of loose or marginally impacted osteochondral fragments. The technique avoids discarding potentially important articular components and eliminates the potential problems of wire embolism. In light of the clinical and biomechanical data supporting the importance of accurate articular reduction, the use of a intraosseous screw provides rigid fixation and assurance of reduction prior to the definitive repair of the posterior wall. This hopefully translates into improved long term patient outcome by increasing hip joint congruity.

Recommended Reading

Letournel, E., Acetabulum fractures: classification and management. Clin Orthop, 1980(151): p. 81-106.

Matta, J.M., Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am, 1996. 78(11): p. 1632-45.

Brumback, R.J., et al., Acetabular depression fracture accompanying posterior fracture dislocation of the hip. J Orthop Trauma, 1990. 4(1): p. 42-8.

Goulet, J.A., et al., Comminuted fractures of the posterior wall of the acetabulum. A biomechanical evaluation of fixation methods. J Bone Joint Surg Am, 1994. 76(10): p. 1457-63.

McCardel, B.R., L.E. Dahners, and J.B. Renner, Kirschner wire migration from the pelvis to the heart and a new method of fixation of articular fracture fragments, acetabular reconstruction. J Orthop Trauma, 1989. 3(3): p. 257-9.

Olson, S.A., et al., Biomechanical consequences of fracture and repair of the posterior wall of the acetabulum. J Bone Joint Surg Am, 1995. 77(8): p. 1184-92.

Practical Approaches to Injury Prevention Using Biomechanics and Epidemiology

Allan F. Tencer, Ph.D.

Biomechanics can provide insight into the mechanisms of traumatic injury. Epidemiology addresses injury risk factors. The combination of these two disciplines can make significant contributions to injury prevention. The three projects described below demonstrate how collaboration between the Orthopaedic Biomechanics Lab and the Harborview Injury Prevention Center can address these types of problems.

Prevention of cervical spine whiplash in rear-end automobile accidents

Cervical spine hyperextension-flexion (whiplash) injuries in rear-end automobile collisions represent between 65% and 85% of all medical insurance claims. In this project, a cushion is being developed to be placed between the occupant and the seat back and head restraint, that (1) stiffens the seatback-head restraint connection, (2) provides a closer fit to the driver's spine, neck, and head, and most importantly, (3) absorbs energy during impact which would otherwise be transferred to the driver's head and neck. These modifications are proposed to reduce the complex relative motions between the driver's head and torso during a rear-end impact which results in the whiplash (actually, shearing, extension, and flexion) motions of the cervical vertebrae. The anti-whiplash cushion design was based using both epidemiological and biomechanical studies. The seated positions of 722 drivers relative to their head restraints were studied, which showed than about 25% had head restraints close (within 3" of their heads) while 60% had head restraints which were either too low or too far back, and 10% had no head restraints in their vehicles. A complete analysis of 238 low speed rear-end accidents showed that risk factors for developing whiplash symptoms included, prior degeneration of the cervical spine, a rotated position of the head prior to impact ,and a struck vehicle speed change of at least 7 mph. A biomechanical study of human volunteer response to rear-end impact demonstrated that the car seat is effective at transferring considerable energy of impact to the occupant. There is a time lag between impact of the torso with the seat back, which is thrust forward, and the head, which is still falling backwards into the head restraint. Based on these observations, prototype anti-whiplash cushions are currently being tested. (Funded by the Harborview Injury Prevention Center, the Centers for Disease Control and Prevention, and the Physical Medicine Research Foundation).

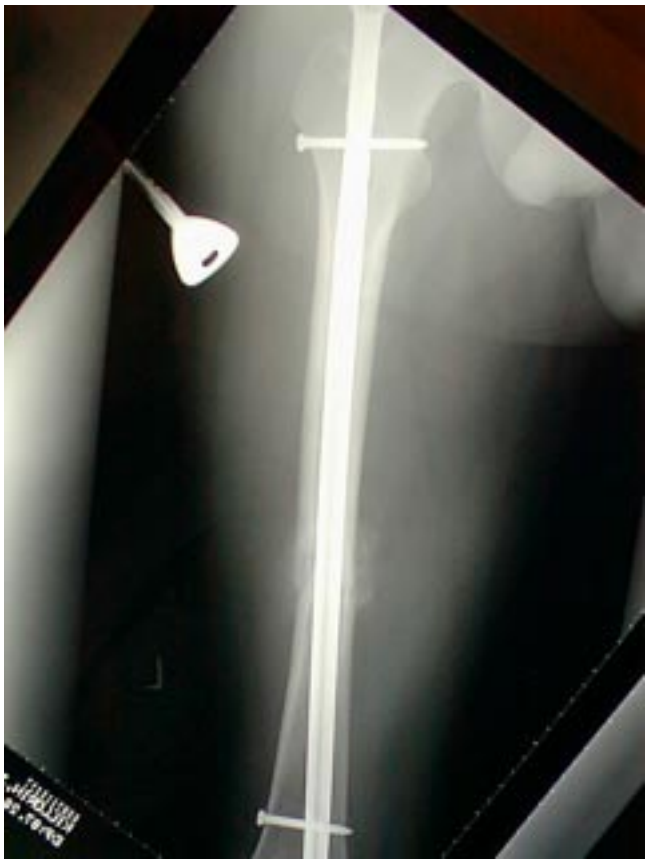

Figure 1: AP x-ray of femur fracture with interlocking nail.

Prevention of femur fractures in frontal automobile collisions

Direct impact of the knee with the dashboard can result in supracondylar or midshaft femur fractures or patellar injuries. Federal Motor Vehicle Safety Standard (FMVSS 208) defines a permissible maximum axial force of contact between the knee and the dashboard of 1700 lbs. This is well below the observed mean fracture load of the femur (about 2500 lbs in an axial distal to proximal direction), however, isolated fractures of the femur, even in shoulder belt, seat belt, and air bag restrained occupants continue to occur. To study the epidemiology of actual accidents, the National Highway

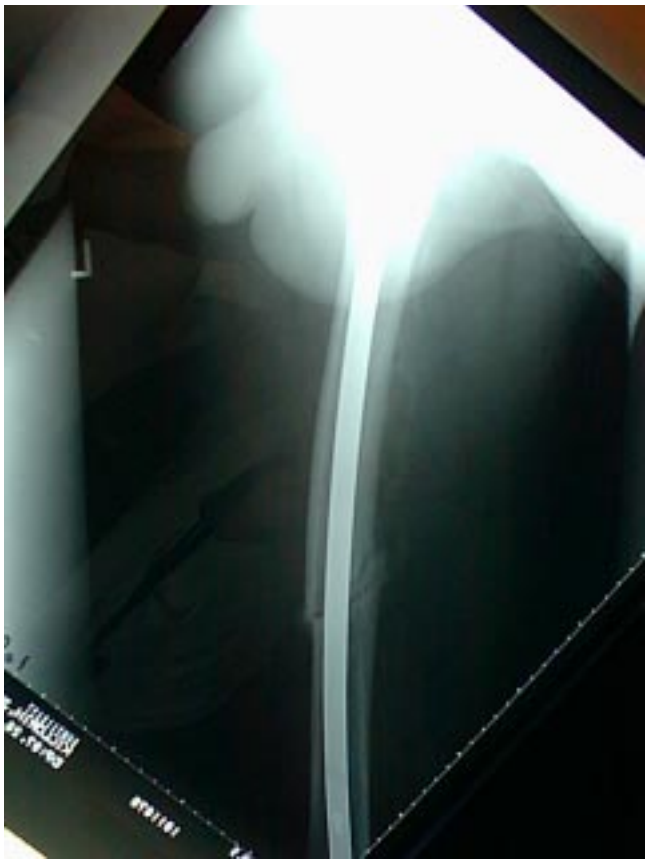

Figure 2: Lateral x-ray of femur with interlocking nail.

Transportation Safety Administration (NHTSA) has developed 8 regional centers where complete engineering analyses to determine forces of impact and occupant contact with the interior, detailed medical descriptions of injuries received, and biomechanical analyses of mechanisms of injury are being performed. To this point, 15 cases of isolated severe femur injuries have been identified. The approximate peak axial force acting at impact on the femur was estimated , in these cases, to be at least 2500 lbs. This is well beyond the peak permissible dashboard loading. The problem may be that dashboard stiffness varies and is greater in corners such as junctions with the door, sterring wheel or center console where many of these contacts take place. In contrast, testing of dashboard impact force with crash dummies is usually done in the center of the dashboard. Using a biomechanics approach , we are focusing on the locations of contact of these femur fracture cases and testing the load capacity of the dashboard in these areas. Ultimately, we will propose redesign of these stiff areas of the dashboard to reduce knee contact loads. (Funded by the National Highway Transportation Safety Administration , David Grossman, M.D., P.I.)

Prevention of injuries in falls by the elderly

Falls are a significant source of injury in the elderly, accounting for the majority of fractures of the distal radius and the hip in this population. These injuries have been reported to account for up to 50% of all hospital beds used for fracture care. We hypothesized that characteristics of the faller's shoes may be partly responsible for the fall. In particular, there is a range of shoe-floor interface friction below which the interface is too slippery and may cause a slip, and above which, is too sticky, and may cause a stumble. Using an epidemiological approach, a large group of elderly, healthy people is being followed. These people have had extensive screening for cognitive and medical function as part of a larger study. When a fall is reported, a biomechanical survey is performed of the site, the shoe wear, and the shoe/floor interface at the site of the fall. These measurements include; (1) shoe/floor dynamic frictional coefficient, (2) shoe sole stiffness, (3) shoe sole contact area, (4) shoe lateral stability, and (5) floor impact characteristics. A total of 400 falls are being surveyed along with a matched control group. We may be able to identify characteristics of shoes that are more likely to result in falls. In an adjunct study, a new type of energy absorbing flooring is being studied as an alternative fall injury prevention approach. This floor system consists of two rigid tiles separated by vertical rubber columns (made of recycled shoe sole and tire rubber) which retain normal stiffness under normal loading but collapse in buckling under injury causing loads. This flooring is currently being tested for its ability to attenuate impact loads from jumping in basketball and may find use in nursing homes where falls are prevalent.

(Funded by the National Institute on Aging, NIH, Marsha Wolf PhD , PI, the Washington Technology Center, and by SATECH Inc, Kirkland, WA).

Failed Acromioplasty: Investigation of 74 Cases

David G. Duckworth, M.D., Kevin L. Smith, M.D., and Frederick A. Matsen III, M.D.

Anterior acromioplasty is now one of the commonest surgical procedures performed on the shoulder. While the literature describes general satisfaction with this procedure, approximately one in ten of the patients in the published series sustain an unsatisfactory result.

The goal of this report is to characterize the common features of a group of patients who were unsatisfied with their result following acromioplasty.

Materials and Methods

This study concerned 74 consecutive patients who presented to our consultation service between June of 1993 and April 1998 because of dissatisfaction with their shoulder at least one year after an acromioplasty. Essentially all of the acromioplasties in this series had been performed by open surgery. Patients with acromioplasty carried out as part of other surgical procedures (such as cuff repair) were not included in this series.

There were 40 males and 34 females in the study with an average age of 45 ± 11 years. Seventy six percent of the cases were covered by workers' compensation insurance. Fifty-three percent of the patients' occupations included heavy manual work. The average patient smoked two packs of cigarettes per week. Nineteen percent had a distal clavicle excision at the time of their acromioplasty.

Each patient was evaluated to determine factors associated with the failure, such as postoperative stiffness, surgical complications and diagnoses not treated by acromioplasty. Standardized anteroposterior, scapula outlet and axillary radiographs were performed to judge the adequacy of the acromioplasty and to seek additional pathology.

Each patient completed the Simple Shoulder Test inventory of shoulder functions and the SF-36 health status assessment.

Results

These patients with failed acromioplasty had poor self-assessed health status; the average SF 36 score for physical role function was only 22% of age and gender matched controls while the comfort score was 36% of controls. They also had poor shoulder function as documented by the Simple Shoulder Test (Table I). Only 4% could sleep comfortably. On average these patients could perform only 3.5 ± 2.7 of the 12 standardized functions.

Our clinical assessment of these 74 patients revealed a number of factors frequently associated with patient dissatisfaction following acromioplasty (see Table II). Aside from workers' compensation coverage, the most common was significant limitation of motion - especially internal rotation and cross body adduction. Failure of a deltoid reattachment was present in 13%. A substantial number of patients had diagnoses not treated by the acromioplasty. In some patients, multiple factors were present. No patient had clinical or radiographic evidence of an inadequate acromial resection. Eleven percent of the patients demonstrated a diffuse chronic pain syndrome around the shoulder which we could not explain.

Table I

Simple Shoulder Test Function	Percent able
Is your shoulder comfortable while sleeping?	4%
Can you lift 8 lbs to shoulder level?	8%
Can you toss a softball overhand 20 yards?	9%
Can you carry 20 lbs at your side?	19%
Does your shoulder allow you to work?	19%
Can you toss a softball underhand 20 yards?	27%
Can you wash your opposite shoulder?	31%
Can you lift 1 lb to shoulder level?	41%
Is your shoulder comfortable at rest?	42%
Can you reach your back to tuck in your shirt?	49%
Can you place your hand behind your head?	50%
Can you place a coin on a shelf?	50%

Discussion

In 1972 Neer originally described the resection of the anterior undersurface of the acromial process and the coracoacromial ligament to treat what he referred to as 'impingement syndrome,' which included a variety of pathologies of the subacromial bursa and rotator cuff. Open and more recently arthroscopic acromioplasty has become the surgical procedure most frequently performed on the shoulder.

The most common feature of this group of patients with failed acromioplasty was coverage of the shoulder condition by workers' compensation insurance. This association has been noted by Ogilvie-Harris, Hawkins and others. It serves to remind us that individuals who do physical shoulder work and who are hurt on the job have complex occupational and economic issues which cannot be easily separated from their shoulder condition and its management.

The second most common feature was persistent shoulder stiffness. In his 1934 book, The Shoulder, Amory Codman spoke of the subacromial area as being 'in constant use. It is in fact a joint without articular cartilages but quite as indispensable. When its surfaces are thoroughly adherent, half of the extent of elevation is lost....' (see figure 1). If surgery is performed in this area, it seems essential to assure the smoothness of these articulating surfaces and to initiate immediate postoperative motion before restrictive adhesions begin to form.

Table II

Associated condition	Prevalence
Workers' compensation claim	76%
Stiffness	69%
Deltoid Failure	13%
Rotator cuff tears	10%
Persistent Subacromial Roughness	10%
Cervical spine pathology	7%
Glenohumeral Arthritis	6%
A-C Joint Instability	4%
Biceps/Labral Pathology	3%
Inadequate acromial excision	0%

The third most common association of failed acromioplasty was failure of deltoid reattachment. This complication can be functionally devastating and is very difficult to manage because of difficulty in achieving secure purchase on the retracted muscle. This complication is avoided by using the 'deltoid-on' approach and by minimizing the amount of the deltoid origin that is resected. In this regard it is important to note that in none of these case of failed acromioplasty was the amount of acromial resection found to be inadequate.

Finally, failures were associated with diagnoses not treated by acromioplasty. This observation speaks to the importance of a thorough preoperative evaluation of all patients with shoulder pain before a surgical procedure is carried out.

Conclusion

This investigation provides insight into conditions which are commonly associated with patient dissatisfaction following acromioplasty. It suggests that attention to patient selection, complete preoperative evaluation, careful surgical technique, and immediate postoperative mobilization of the shoulder may help minimize similar failures in the future.

Recommended Reading

Neer C.S., Anterior Acromioplasty for the Chronic Impingement Syndrome in the Shoulder. J Bone Joint Surg.1972;54A:41-50.

Neer C.S., Impingement Lesions. Clin Orthop. 1983;173:70-77.

Ogilvie-Harris D.J., Wiley A.M., Sattarian J., Failed Acromioplasty for Impingement Syndrome. J Bone Joint Surg. 1990;72B:1070-1072.

Seltzer D.G., Wirth M.A., Rockwood C.A., Complications and Failures of Open and Arthroscopic Acromioplasties. Operative Tech Sports Med. 1994;2(2):136-150.

Hawkins R.J., Chris T., Bokor D., Kiefer G., Failed Anterior Acromioplasty: A Review of 51 Cases. Clin Orthop. 1989;243:106-111.

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

Codman, E .A The Shoulder, Krieger Malabar, Florida 1934

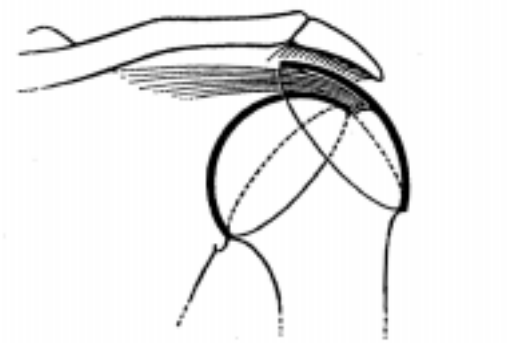

Figure 1: Codman drawing from his book The Shoulder. Permission granted by Krieger Publishing Company.

The Position of Prosthetic Components in Failed and Successful Shoulder Arthroplasties

Michael J. Moskal, M.D., Barry Campbell, B.S., Kevin L. Smith, M.D., and Frederick A. Matsen III, M.D.

Biomechanical studies have suggested that non-anatomic positioning of the humeral articular surface can adversely affect glenohumeral kinematics. Identification of simple surgical targets and landmarks for prosthesis position could potentially decrease the incidence of non-anatomic prosthesis placement. As part of our ongoing effort to identify and minimize factors which contribute to the failure of shoulder arthroplasty, we implemented a clinical and radiographic analysis of the position and orientation of the glenoid and humeral prosthetic components in successful and failed shoulder arthroplasties. Further, we attempted to indentify simple surgical targets for prosthesis placement. We postulate that the tuberosity offers an accessible guide to correctly judging the height of the humeral component, and the glenoid centerline offers an accessible guide to correctly judging the version of the glenoid component.

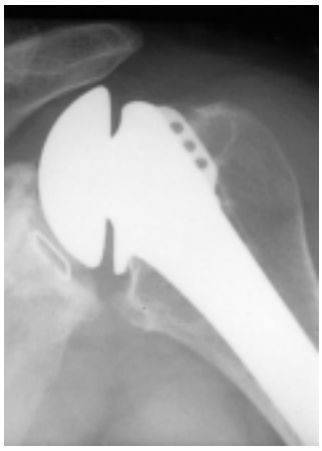

Figure 1A: Radiograph showing a humeral prosthesis more than 5 mm above the greater tuberosity.

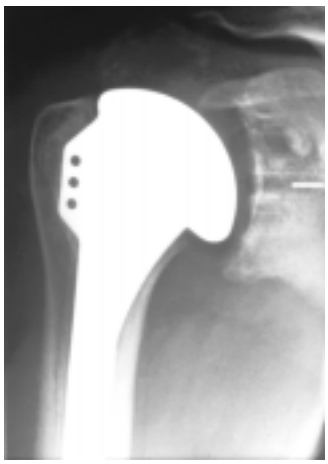

Figure 1B: Radiograph showing humeral prosthesis within 5 mm of the greater tuberosity.

Materials and Methods

The inclusion criteria for the "success" group were (1) a total shoulder arthroplasty performed by the senior author AND (2) a follow-up evaluation that included excellent self-assessed shoulder function—specifically, the patient's opinion that he/she could perform at least ten of the twelve functions of the Simple Shoulder Test (SST). The inclusion criteria for the "failed" group were 1) a previous shoulder arthroplasty (by any surgeon) AND 2) patient dissatisfaction with the functional outcome from the previous shoulder arthroplasty prompting referral to our shoulder service.

The average patient age in the success group was 60 (range, 48 to 72) years and in the failure group was 62 (range, 49 to 73) years. In the success group, there were 67 men and 13 women, with 46 right and 34 left operated shoulders. In the failure group, there were 55 men and 45 women, with 54 right and 46 left operated shoulders. All of the cases in the success group were total shoulder arthroplasties. In the failure group, 53 were total shoulders and 47 were hemi-arthroplasties.

Both groups of patients had standardized radiographic views of their shoulder arthroplasty, including an anteroposterior (AP) of the glenohumeral joint in the plane of the scapula, an AP of the humerus in 35∞ of external rotation, and a true axillary lateral view. Each patient's radiographs were evaluated by a single observer using standardized criteria.

Humeral component positions were compared for all patients in each of the two groups. Each humeral prosthetic component was characterized as having the superior aspect of its articular surface either five millimeters below, within five millimeters, or five millimeters above the greater tuberosity. Each prosthetic component was evaluated for gross anteversion or retroversion.

Glenoid component positions in the 53 failed total shoulder arthroplasties were compared to the glenoid component positions in the 80 total shoulders in the success group. The glenoid components were evaluated in the axillary projection in terms of their version in relation to the plane of the scapula. Glenoids were classified as either more than zero degrees of anteversion, between zero and 20∞ of retroversion, or more than 20∞ of retroversion with respect to the plane of the scapula.

Unstable articulations were those in which the radiographs showed either a frank dislocation or translation of the humeral head center more than five millimeters away from the glenoid center. The direction (anterior, posterior, superior, inferior or anterosuperior) of glenohumeral instability was noted.

The frequency of the different observations between the success and failure groups was statistically analyzed using the nonparametric Mann-Whitney U test for unmatched groups.

Results

Our results indicated that the patients in the failure group could perform an average of only 2 (range, 0 to 4) of the twelve functions of the SST, whereas the patients in the success group could perform an average of 11 (range, 10 to 12) functions ($p<0.0001$). Each of the individual patient's responses on the SST was significantly

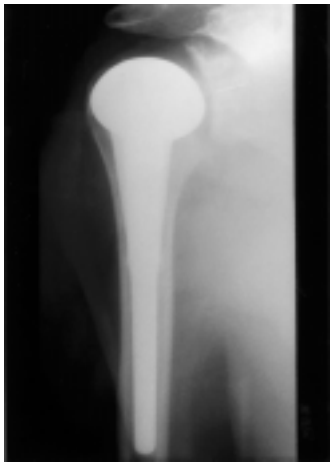

Figure. 2A: Radiograph of the humerus is taken in 35∞ of external rotation relative to the radiographic beam. Lateral fins of the humeral prosthesis are not seen.

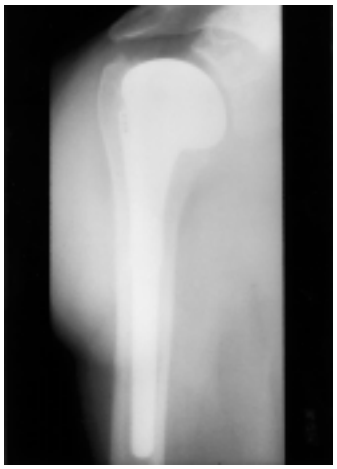

Figure 2B: In this radiograph, the patient's arm is further rotated internally, relative to the radiographic beam, to reveal the fins, thus demonstrating the gross humeral anteversion..

different between the two groups ($p<0.0001$). The greatest differences were in strength (lifting a coin to shoulder level, lifting a pound to shoulder level, lifting eight pounds to head level), range of motion (placing hand behind head with the elbow at the side), and comfort (sleeping comfortably).

The failed arthroplasties were three times more likely (59 %) to have the humeral head more than five millimeters above the tuberosity than in the successful arthroplasties (20 %) ($p<0.0001$) (Fig. 1). Gross humeral malversion (ante- or retroversion) was present in 18 % of the failures and in 4 % of the successes ($p<0.05$) (Fig. 2). Lucent lines were noted in 60 % of the failures and in 39 % of the successes ($p<0.005$).

The glenoid components of failed arthroplasties (n=53) were malverted (angled more than zero degrees anterior or more than 20 degrees posterior to the plane of the scapula) in 46 % of cases, whereas none of the glenoid components was malverted in the success group ($p<0.0001$) (Fig. 3). Of the failed arthroplasties, glenoid components had lucent lines in 76 %, were loose in 66 %, and had moved in 26 % in contrast to 29 %, 0 % and 0 %, respectively, in the successful arthroplasties ($p<0.0001$). Glenohumeral instability was present in 43 of the 100 failed cases. Of these, 35 % were posterior, 28 % anterior, 33 % anterosuperior, 5 % superior and 0 % inferior. The correlation coefficients for anterior glenohumeral instability with anterior glenoid and humeral component malversion were 0.75 and 0.58, respectively. The correlation

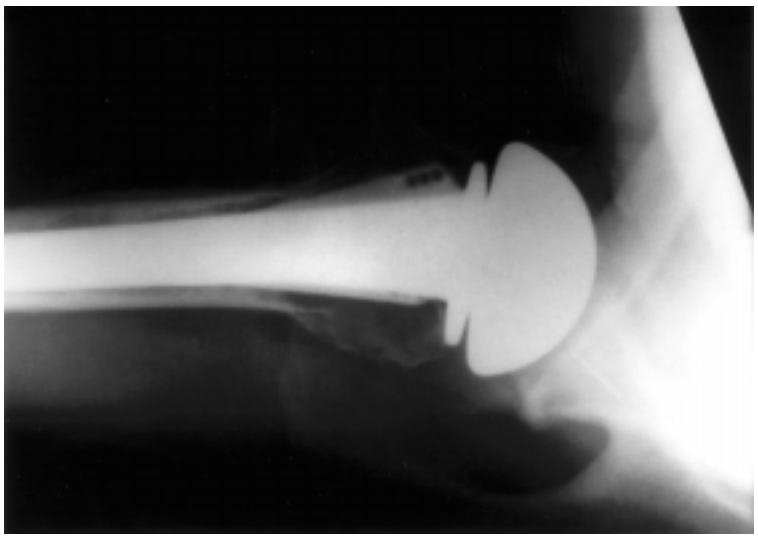

Figure 3A:. Radiograph of an anteverted glenoid component.

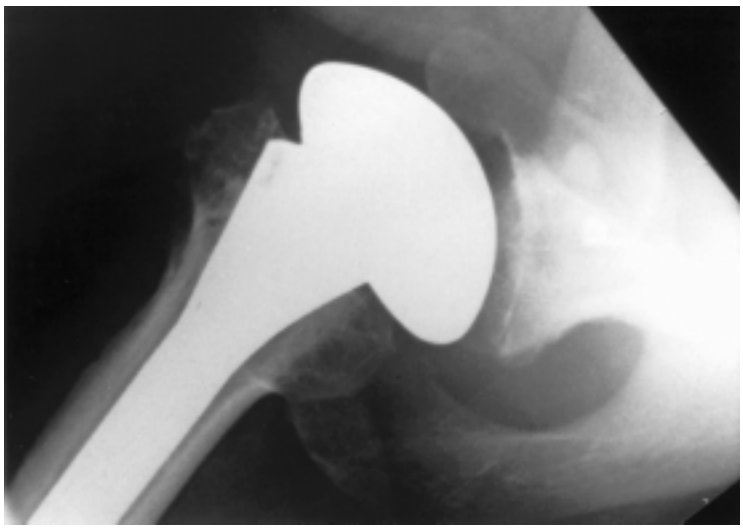

Figure 3B: Radiograph of proper glenoid component orientation.

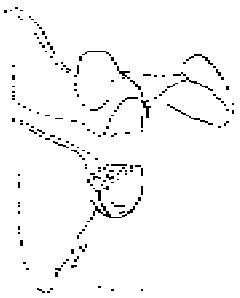

Figure 4A:. Line drawing of scapula cross-section, perpendicular to the glenoid fossa. This cross-section serves as a point of reference for 4B.

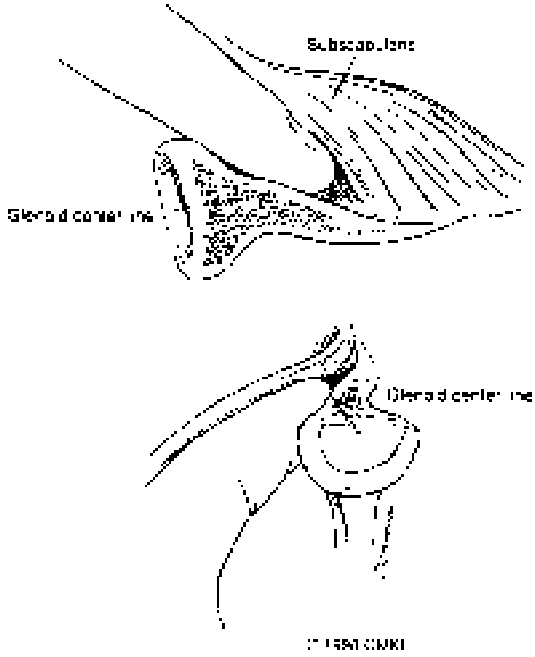

Figure 4B: A line drawing of intraoperative determination of glenoid center line approximately 10 degrees retroverted in reference to the plane of the scapula.

coefficient for posterior glenohumeral instability with posterior glenoid component malversion was 0.5.

Discussion

Suboptimal humeral and glenoid component position was more common in the 100 failed arthroplasties than in the 80 successful ones. These observations are consistent with biomechanical studies which suggest that non-anatomic positioning of the humeral articular surface can adversely affect glenohumeral kinematics. An excessively high humeral prosthesis shifts the center of humeral rotation upwards and lead to excessive soft tissue tension which limits humeroscapular motion. It is also recognized that non-anatomic positioning of the glenoid component predisposes to glenohumeral instability. Excessive tipping of the component increases the risk of instability in the direction of tipping.

This study suggests an important relationship between the functional outcome of shoulder arthroplasty and the position of the prosthetic components. The tuberosity offers an accessible guide to correctly judging the height of the humeral component. The glenoid centerline offers an accessible guide to correctly judging the version of the glenoid component. This centerline is determined at surgery by palpating the glenoid centering point (Fig.4A). Unaffected by arthritis, the glenoid centering point is a point at the junction of the anterior glenoid neck at the lateral aspect of the subscapularis fossa, midway between the upper and lower crura. A line connecting the glenoid centering point to the center of the glenoid fossa is the normalized glenoid centerline which is approximately 10 degrees retroverted from the plane of the scapula (Fig. 4B).

We hope that the use of simple surgical targets such as placing the top of the humeral component within five millimeters of the top of the tuberosity and the version of the glenoid within zero degrees and 20 degrees of retroversion may prove to be useful guidelines for minimizing problems related to suboptimal component placement.

Recommended Reading

Connor, P.M., Levine, W.N., Arroyo, J.S., Ejnisman, B., Pollock, R.G., Flatow, E.L., Bigliani, L.U.: The Surgical Management of Failed Shoulder Arthroplasty. (Abstract) J. Shoulder Elbow Surg. 7 (2):178, 1998.

Lippitt, S.B.; Harryman, D.T.; Matsen, F.A. III.: A Practical Tool for Evaluating Function: The Simple Shoulder Test. In: The Shoulder: A Balance of Mobility and Stability, pp. Edited by F.A. Matsen III, F.H. Fu, and R.J. Hawkins. Rosemont, IL, American Academy of Orthopaedic Surgeons, 1992.

Matsen, F.A. III; Lippitt, S.B.; Sidles, J.A.; Harryman, D.T. II.: Practical Evaluation and Management of the Shoulder. Philadelphia, W.B. Saunders, 1994.

Matsen, F.A. III; Rockwood, C.A. Jr; Wirth, M.A.; Lippit, S.B.: Glenohumeral Arthritis and Its Management. In: The Shoulder, pp. 840-964. Edited by C.A. Rockwood Jr, and F.A. Matsen III. Philadelphia, W.B. Saunders, 1998.

Neer, C.S. II, and Kirby, R.M.: Revision of humeral head and total shoulder arthroplasty. Clin. Orthop., 170: 189-195, 1982.

Wirth, M.A., and Rockwood, C.A. Jr.: Complications of shoulder arthroplasty. Clin. Orthop., 307: 47-69, 1994.

Characteristics of Patients Treated with Proximal Humeral Hemiarthroplasty for Acute Three and Four Part Fractures and the Correlation with Shoulder Function

Richard Rozencwaig, M.D., Shadley C. Schiffern, B.S., John Antoniou, M.D., Hiroshi Takeda, M.D., and Douglas T. Harryman II, M.D.

Fractures of the proximal humerus are common, occurring in 3 of every 10,000 persons. While approximately 90% of proximal humerus fractures are minimally displaced and do well with conservative management, severely displaced proximal humerus fractures can have a devastating effect on upper extremity function. While some authors have recommended open reduction and internal fixation for certain proximal humerus fractures, early techniques were generally unsatisfactory and resulted in poor outcomes. Even with the improved understanding of both the vascular anatomy and biomechanics of the shoulder, the results of open reduction and internal fixation of severely displaced fractures with the more modern techniques and fixation devices are often unpredictable. Prosthetic hemiarthroplasty has become an accepted method of treatment for several well-defined subsets of these fractures, including four-part fractures, fracture-dislocations, head-splitting fractures, and fractures with an impression defect encompassing more than 50% of the humeral head. Also, some patients with three-part fractures may be considered for a hemiarthroplasty as a result of their age, poor bone quality, or extensive comminution.

Several groups have reported the results of humeral head replacement for these injuries. Neer's experience remains the largest in the orthopaedic literature, attesting to the relative infrequency of these injuries and perhaps a general lack of experience in their treatment. The Neer prosthesis has been used most widely for reconstruction of the severely fractured shoulder. However, the results and frequencies of complications following hemiarthroplasty for the treatment of fractures have varied widely. Despite these varied functional outcomes, primary proximal humeral hemiarthroplasty for acute three- and four-part fractures usually prevents the development of a painful shoulder and avoids the potential complications of closed treatment and open reduction with internal fixation.

The purpose of this retrospective study was to characterize the long-term results with Neer prosthetic hemiarthroplasty for three- and four-part proximal humerus fractures. We also assessed the correlation between the various ingo parameters and surgical outcome.

	Mean	Correlation Coefficient	p value
Analog pain scale	3.4 ± 3.1	-0.729	0.0005
# of medications	3.2 ± 2.7	-0.600	0.0095
# of major comorbidities	2.6 ± 1.8	-0.499	0.04
SF-36 Bodily Comfort Score	111.2 ± 34.7	0.654	0.003
SF-36 Mental Health Score	80.4 ± 36.0	0.605	0.0087
Current satisfaction scale (1=least, 5=most)	3.4 ± 1.6	0.540	0.023

Table 1: Correlation of patient characteristics with shoulder function.

Materials and Methods

The records from the University of Washington Medical Center were reviewed revealing 37 patients who had a hemiarthroplasty for an acute three- or four-part fracture of the proximal humerus treated with the Neer prosthesis. Twenty-eight of those 37 patients responded to surveys that assessed personal demographic data, general function, and the presence of standard comorbidities. Furthermore, general health status was evaluated using the SF-36 Health Status Instrument; the function of the injured and contralateral shoulders was determined using the Simple Shoulder Test (SST).

Results

The mean surgical delay was 20 days. The average hospitalization was 5.6 ± 2.6 days. The most common mechanism of injury was a fall (70%) followed by a motor vehicle accident (14%). Ten percent of the injuries involved a legal or industrial claim. Greater tuberosity comminution was noted in 50% of the fractures, while lesser tuberosity comminution was identified in 31% of the fractures. Nineteen percent of the patients sustained a rotator cuff tear at the time of fracture. Extension of the fracture into the calcar region of the proximal humerus was present in 19% of cases.

Two superficial infections were noted postoperatively; these did not negatively influence the outcome of treatment. Heterotopic ossification was identified in 13% of the postoperative radiographs evaluated; greater tuberosity union was noted in only 50% of patients. More than half (55%) of patients felt that they were still improving in their function. Twenty-

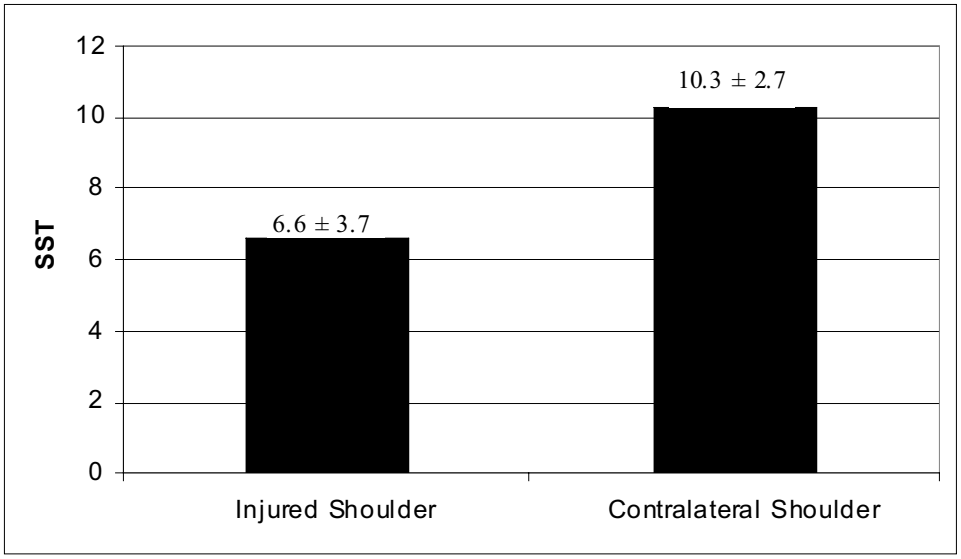

Figure 1: Shoulder function as assessed by the SST.

eight percent of patients stated that they had difficulty with personal hygiene. One half of patients in this study resumed their usual pre-injury work or activities. Eighty-six percent (86%) of the patients in this study were satisfied with the results of their surgery.

Of the twelve shoulder functions assessed with the SST, respondents were able to perform an average of 10.3 ± 2.7 functions with their uninjured shoulder. On the other hand, patients were only able to perform an average of 6.6 ± 3.7 functions with their repaired shoulder ($p < 0.0001$) (Figure 1).

The following six items were found to have statistically significant association with the alteration in shoulder function following fracture treatment: analog pain scale, number of medications, number of major comorbidities, SF-36 Bodily Comfort Score, SF-36 Mental Health Score, and patient satisfaction (Table I).

Discussion

Proximal humeral hemiarthroplasty for the treatment of three- and four-part fractures is a technically demanding procedure. The success following this procedure is party dependent on sound operative technique based on the principles of restoration of humeral length, anatomical fixation of the tuberosities with ultimate healing to the shaft, and placement of the prosthetic component in the appropriate degree of retroversion. Increased attention and tuberosity fixation, bone grafting, and early restoration of motionwill hopefully improve our results in the future.

Recommended Reading

Cuomo F, Flatow EL, Maday MG, Miller SR, McIlveen SJ, Bigliani LU. Open reduction and internal fixation of two- and three-part displaced surgical neck fractures of the proximal humerus. J Shoulder Elbow Surg 1992;1(6):287-295.

Green A, Barnard L, Limbird RS. Humeral head replacement for acute, four-part proximal humerus fractures. J Shoulder Elbow Surg 1993;2(5):249-254.

Moeckel BH, Dines DM, Warren RF, Altchek DW. Modular hemiarthroplasty for fractures of the proximal part of the humerus. J Bone Joint Surg 1992;74A(6):884-889.

Tanner MW, Cofield RH. Prosthetic arthroplasty for fractures and fracture-dislocations of the proximal humerus. Clin Orthop 1983;179:116-128.

Zyto K, Wallace A, Frostick SP, Preston BJ. Outcome after hemiarthroplasty for three- and four-part fractures of the proximal humerus. J Shoulder Elbow Surg 1998;7(2):85-89.

Physical Changes in Polyethylene Glenoid Components After In Vivo Use

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John A. Sidles, Ph.D., James D. Bruckner, M.D., and Frederick A. Matsen III, M.D.

Glenohumeral arthroplasty is an effective procedure for managing conditions in which the normal glenohumeral joint surface is lost. Proper functioning of the arthroplasty depends on the glenoid joint surface retaining the shape in which it was designed. The purpose of this investigation was to characterize the changes in glenoid joint surface which occur after *in vivo* use. This report summarizes our findings on 37 glenoids retrieved from patients at the time of revision surgery for failed shoulder arthroplasty.

Materials and Methods

This study included 19 glenoids retrieved by the authors in their practice of revision arthroplasty as well as 18 glenoids retrieved by other surgeons. Each retrieved glenoid was visually inspected and a standard set of observations were recorded. Each glenoid was then mounted in a holding device, coated to optimize reflectivity and then scanned using a laser scanner accurate to 0.1 mm using a system. The support for the mounted glenoids was motorized by a 2 axis table with a horizontal resolution of ±10 micrometers. The scanner system (fig. 1) measured distances with a nominal resolution of 3 microns and a frequency of 2000 acquisitions per mm.

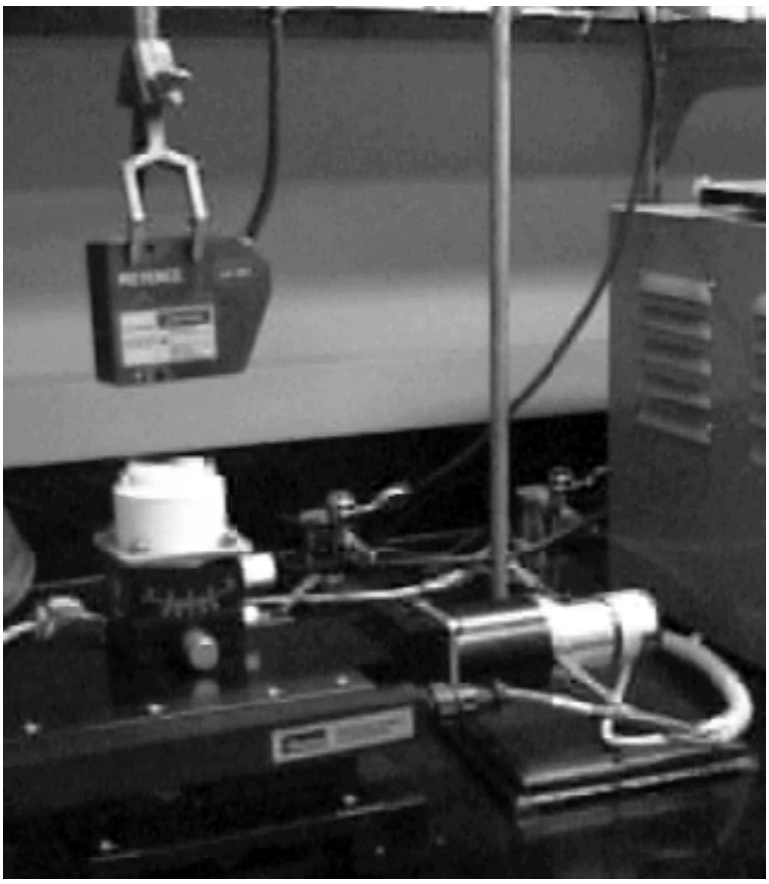

Figure 1: The scanner system used in this experiment.

Scanning data were displayed in graphic form using the LabView software. Contour maps were constructed from the surface scans. The difference between the scanned contour and the spherical contour of a new glenoid was displayed using NIH image. Each glenoid was compared to the shape of an unimplanted component of the same manufacturer and size. The theoretical balance-stability angle (BSA) is defined as the maximal angle that the net humeral joint reaction force can make with the glenoid center line before glenohumeral dislocation occurs (fig. 2). The BSA angle was calculated for each retrieved polyethylene glenoid from the slope of the glenoid surface and plotted as contour lines. The differences between the BSA plots for the new and used glenoids were displayed for each specimen.

Results

The findings in the retrieved glenoids included: (1) surface changes of the polyethylene glenoid (polishing, scratches, pits, delamination, and discoloration) and (2) changes in the shape of the polyethylene glenoid (loss of the glenoid lip, flattening, and fracture). The frequency of the surface and shape changes are graphically displayed in the Figure 3.

The most common surface changes were polishing (33 out of 37) and scratching (28 out of 37). These surface lesions are similar to those described for hip and knee polyethylene components. Delamination was found in 6 cases always being associated with fracture of the components. Discoloration was found in 11 cases.

The changes in shape revealed by the laser scanner were not always obvious to the naked eye. The radius of curvature of used glenoids was always greater than that of unused glenoids of the same size. *In vivo* use often transformed the spherical shape of the glenoid into an ellipsoidal shape. In many cases the changes in the joint surface were of sufficient magnitude to

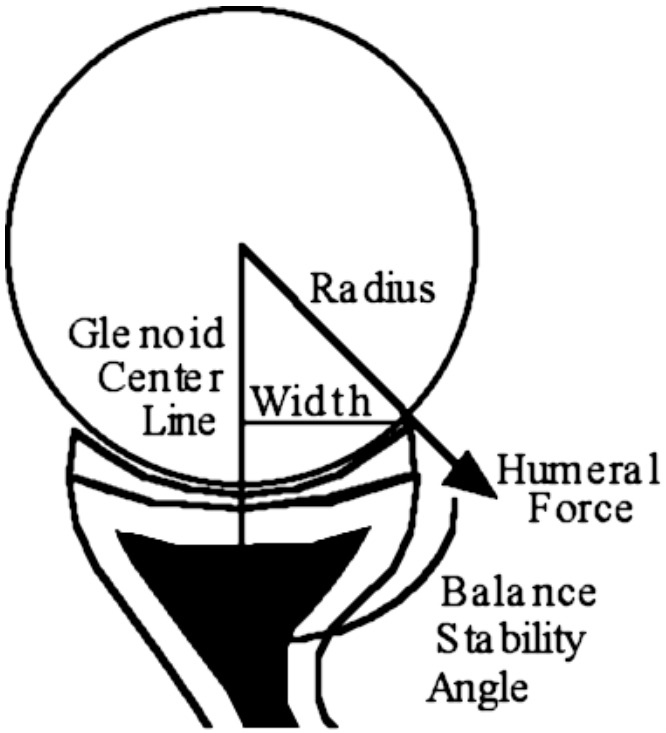

Figure 2: The BSA angle was calculated for each retrieved polyethylene glenoid from the slope of the glenoid surface and plotted as contour lines.

affect the calculated balance stability angle.

Figure 4 (a, b) shows the findings for an unused glenoid. Figure 5 (a,b,c) shows the changes in a used glenoid as represented by a) inspection, b) laser-scanner, c) the BSA. The deviation from sphericity and the modified BSA are apparent.

Discussion

Substantial literature describes the changes in of polyethylene components in hips and knees, but changes the polyethylene of shoulder arthroplasty have not been thoroughly described. This study presents the surface and shape changes for a group of glenoid components retrieved after *in vivo* use. While the observed changes in the glenoid surface were similar to those seen in hip and knee components (polishing, scratches, pits, delamination, and discoloration) these changes would appear unlikely to alter the function of the polyethylene component unless there was an accompanying change in glenoid shape. The shape changes were sometimes

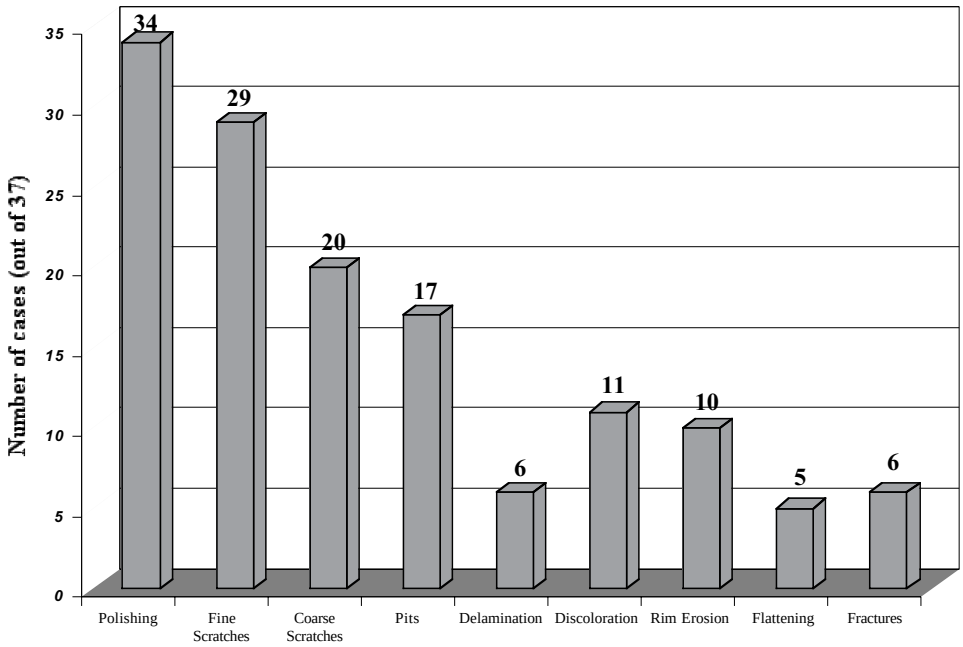

Fig 3 : Physical changes in the glenoid surface and shape

Figure 3: The frequency of the surface and shape changes are graphically displayed.

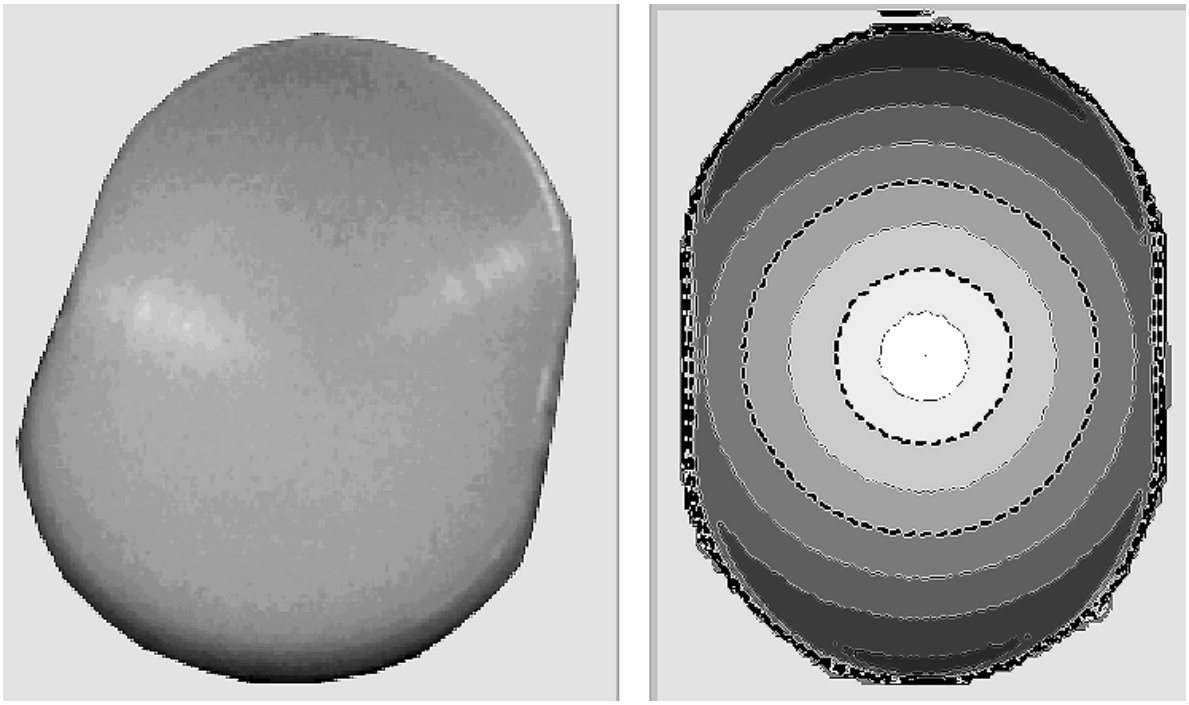

Figure 4 (a, b): The findings for an unused glenoid.

obvious to the eye and at other times were sufficiently subtle that they were only detectable by the laser scanner. In virtually all cases there was a loss of sphericity which was frequently of a sufficient magnitude to change the theoretical balance-stability angle calculated from the surface contour. The importance of the balance-stability angle data lies in the demonstration of the potential mechanical consequences of the changes in shape.

This study was limited by our inability to collect clinical data on many of the specimens. As a result we were unable to correlate the changes in surface and shape with clinical use, patient symptoms, duration of implantation, and other important attributes.

The strength of this investigation lies in the fact that it is the first quantitative observation of changes in shape occurring in polyethylene glenoids after in vivo use. This study has indicated that 1) these glenoid components which had spherical surfaces when they are implanted usually did not have spherical surfaces when they were retrieved after *in vivo* use, 2) the changes in glenoid surface shape were often not evident on visual inspection, 3) the magnitude of the changes in shape may be sufficient to affect the stability offered by the glenoid components.

Figure 5 (a,b,c): The changes in a used glenoid as represented by a) inspection, b) laser-scanner, c) the BSA. The deviation from sphericity and the modified BSA are apparent.

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1999 Department of Orthopaedics Incoming Faculty

Christopher Allan, M.D.

Dr. Allan received his medical degree from Northwestern University in 1992 and completed his training in orthopaedic surgery at the University of Chicago in 1997. He pursued subspecialty training in hand surgery and microsurgery at Baylor College of Medicine with Dr. David Lichtman, an internationally known leader in surgery of the wrist. Dr. Allan has an interest in wrist problems, as well as in general hand and microsurgery. He is also active in research aimed at improving wound healing after injury.

Dr. Allan sees patients at University of Washington Medical Center, UWMC-Roosevelt, Harborview Medical Center, and Children's Hospital and Regional Medical Center.

Carlo Bellabarba, M.D.

Upon completion of his one year Spine Fellowship at Northwestern University in Chicago, Carlo Bellabarba will be joining the University of Washington as an Assistant Professor specializing in spine surgery.

Dr. Bellabarba received his B.Sc. in Biochemistry from McGill University in Montreal, Quebec, Canada, where he also attended medical school. His internship and residency were spent at Rush-Presbyterian-St. Luke's Medical Center in Chicago.

As well, he has completed a fellowship with the Orthopaedic Trauma Service of Tampa General Hospital in Tampa, Florida.

Dr. Bellabarba sees patients at the University of Washington Medical Center, at UWMC-Roosevelt, Harborview Medical Center, and Veteran's Hospital.

Graduating Residents
Class of 1999

Craig Boatright, M.D., has accepted a position as a fellow in spine surgery at Emory University in Atlanta, Georgia.

Jeff Garr, M.D., will be travelling to Daly City, California where he will participate in a one year Spine fellowship.

John Michelotti, M.D., will be travelling to Vail, Colorado where he will participate in a one year Sports Medicine fellowship and thereafter begin private practice in Montana.

Tom Chi, M.D. and his family will be going to Kenya to work at a non-profit hospital, the Kikuyu Orthopedic Rehabilitation Center, for six months. Afterward, he will start a six month foot and ankle fellowship in Birmingham, Alabama.

Julie Switzer, M.D., will be spending a year in Vail, Colorado with Vail Orthopaedics on a fellowship specializing in sports.

Incoming Residents

Ben DuBois: Ben attended Oregon State University where he received his B. S. in biology. He received his medical degree from the University of Southern California. He is currently finishing his internship under the direction of the Department of Surgery at the University of Washington. His outside interests include weightlifting, running, basketball and photography.

Guy Schmidt: Guy attended Brown University where he received a B. S. in biochemistry. He received his medical degree from Johns Hopkins University. He is currently completing his surgical internship at the University of Washington. His interests include rock climbing and alpine skiing.

Brian Shafer: Brian received his B. S. in chemistry from the University of California at San Diego. He attended Johns Hopkins University where he earned his medical degree. He is currently a surgical intern at the University of Washington. Brian enjoys sports in his spare time.

Andrew Howlett: Andy attended the University of Wisconsin at Madison where he obtained a B.S. in biochemistry. He attended the University of Washington Medical School where he received his medical degree. He is currently a surgical intern at the University of Washington. Outside interests include fly fishing, running and basketball.

Emma Woodhouse: Emma attended Stanford University where she received a B. S. in biology. Following her undergraduate education she entered the University of Southern California where she received her medical degree. She is currently a surgical intern at the University of Washington. Personal interests include tennis and hiking.

Contributors to Departmental Research and Education

MAY 1998 THROUGH APRIL 1999

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 offer 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.

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The Shoulder Function and Health Status of Individuals with Documented Rotator Cuff Tears Before and After Treatment: A Multicentered Prospective Study
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