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Combined Dislocation of the Carpometacarpal Joint With Rupture of the Radial Collateral Ligament of the Thumb. A Case Study.

Vincent R. Avallone Jr., D.O., Elliot L. Ames, D.O.*

ABSTRACT: The purpose of this case study is to present the combined dislocation of the Carpometacarpal Joint and Complete Rupture of the Radial Collateral Ligament of the Thumb Secondary to Trauma. Successful treatment was achieved by closed reduction and percutaneous pinning of the Carpometacarpal Joint and Primary Repair of the Collateral Ligament of the Metacarpophalangeal Joint.

**Assistant Clinical Professor of Orthopedic Surgery Philadelphia College of Osteopathic Medicine Former Christine Kleinert Fellow in Hand Surgery University of Louisville School of Medicine Louisville, Kentucky*

Isolated dislocations of the carpometacarpal joint or rupture of the radial collateral ligament of the metacarpophalangeal joint of the thumb are not uncommon. However, a review of the English literature for the last ten years failed to uncover any reports of combined injuries in the same digit.

CASE REPORT

E. M., a thirty eight year old, right hand dominant, black male presented to the Emergency Room complaining of pain and swelling of his right thumb due to a basketball injury. He related a "jamming" injury to his thumb. X-rays revealed a dislocation of the carpometacarpal joint of the thumb, which was subsequently reduced by the Emergency Room physician and a thumb spica splint applied. (Figure 1)

On follow up in our clinic, the patient complained of persistent metacarpophalangeal pain. Clinical examination revealed palpatory tenderness over the radial collateral ligament, and instability with adduction stress. Stress X-rays revealed forty-five degrees of gapping consistent with complete rupture of the collateral liagment. (Figure 2)

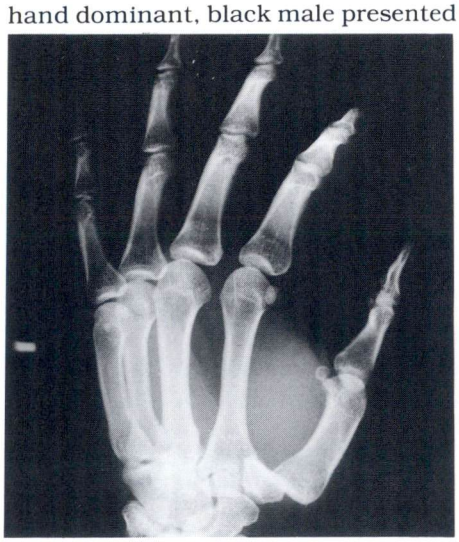

Figure 1: Initial X-rays revealing a dislocation of the CMC Joint of the Thumb.

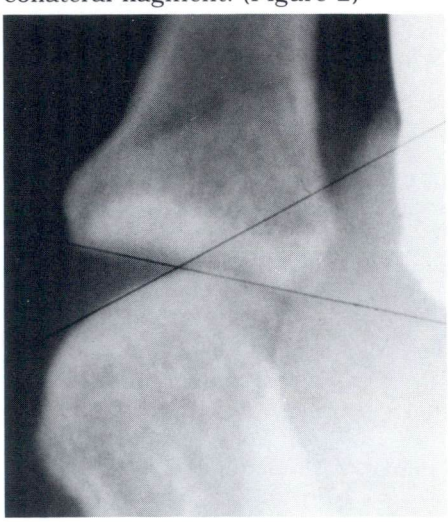

Figure 2: Stress X-Ray of the Metacarpophalangeal Joint revealing a 45 degree gap on the radial side.

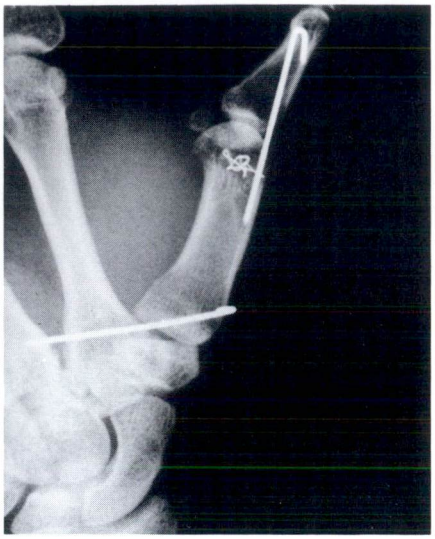

Figure 3: Post-Operative X-rays following primary collateral ligament repair and closed reduction with percutaneous pinning.

The patient subsequently underwent primary repair of the radial collateral ligament of the metacarpophalangeal joint and percutaneous pinning of the carpometacarpal joint of the thumb. (Figure 3).

Post operatively a thumb spica cast was applied at two weeks, following suture removal. Pins and wires were removed at six weeks post-surgery. At two months, casting was discontinued and clinical examination revealed full opposition, with radial collateral ligament and carpometacarpal joint stability of the thumb.

DISCUSSION

The carpometacarpal joint of the thumb is a saddle joint. Dislocations are relatively uncommon in contrast to the more frequent fracture dislocation. The usual mechanism of injury is a longitudinal force applied to a partially flexed metacarpal, which results in dorsoradial dislocation.[1,2,3] Treatment is deceptively difficult. Closed reduction is simple and may initially appear stable, as in this case. However, maintainence of reduction is uncertain, with recurrence of subluxations and dislocations quite frequent. Due to this, it is advisable to secure the reduction with percutaneous pin fixation for four to six weeks.[1]

Rupture of the radial collateral ligament of the metacarpophalangeal joint of the thumb, while less published than its ulnar counterpart, may occur more frequently than earlier studies indicated.[5,6] The postulated mechanism of injury is an adduction stress. Acute treatment of ligamentous ruptures of the radial collateral ligament remains controversial, since most patients present with chronic pain and instability. Some authors suggest immobilization by spica casting acutely with late reconstruction if symptoms persist. Other sources support primary repair of ligamentous structure.[5,6,7,8]

The proposed mechanism of injury in our patient is adduction force with axial stress. The decision to acutely repair the collateral ligament of the metacarpophalangeal joint and percutaneously pin the carpometacarpal joint was based on the injury to adjacent joints of the thumb with its inherent instability and associated disability.

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Band Aid Hip Surgery

Paul G. Bizzle, D.O., Fountain Springs, PA

ABSTRACT: Hip fractures can be treated by a variety of different methods. Presented is a series treated with closed reduction and percutaneous pinning with Knowle's pins. Indications for this procedure are discussed as are the advantages and limitations of such an operation. This less invasive avenue of treatment for appropriately selected hip fractures can lead to extremely gratifying results in these patients.

BAND AID HIP SURGERY

In 1984 a prospective study of patients with hip fractures treated with closed reduction and percutaneous pinning utilizing Knowles' pins was begun. The majority of these were subcapital and transcervical fractures. A small number of basicervical and intertrochanteric fractures were also treated by this method. All other hip fractures treated by open reduction internal fixation, closed intramedullary nailing, or by endoprosthetic arthroplasty were not included in this study.

All patients or their responsible guardians were thoroughly appraised of the treatment options available to them for their respective fractures. Both potential advantages of closed reduction and percutaneous pinning and potential short comings of the procedure were discussed in detail. The vast majority of the patients considered to be potential candidates for this procedure chose the percutaneous route after this discussion.

MATERIALS AND METHODS

From a period extending from December 1, 1984 to January 1, 1989 forty nine patients with fractured hips were treated with closed reduction and percutaneous pinning with Knowles' pins (see chart 1). Follow-up time ranged from six months to four years with a mean time of two years and three months. Forty females and nine males comprised the patient population. Ages from 34 to 95 years old with a mean of 75 years old. The majority, forty two patients, were coherent, rational and able to understand the options given to them prior to deciding on this method of treatment. In the remaining seven confused or disoriented seven patients the nature of the procedure and options were discussed with those holding power of attorney to give consent for the surgery.

Thirty five of the fractured hips were subcapital fractures, six were transcervical, six were basicervical, and the remaining two were intertrochanteric fractures. The majority of these fractures were nondisplaced or impacted fractures. No displaced basicervical or intertrochanteric fractures were treated with percutaneous pinning. Twenty one subcapital fractures were displaced. Two transcervical fractures were displaced.

Of the forty nine patients treated with percutaneous pinning forty two were able to ambulate prior to their fractures. The remaining seven patients did not ambulate pre-operatively. Pre-operatively ten patients had required either walker, cane or other assistive devices for ambulation. Nine patients required these for degenerative joint disease of the hip, knee of both. One patient required a hemi-walker to ambulated due to paralysis from a prior cerebral vascular accident.

A sincere effort was made to surgically treat these fractures as soon as possible with the majority, twenty eight subcapital and six transcervical and four basicervical and two intertrochanteric fractures, undergoing percutaneous Knowles' pinning within 24 hours. Time periods from the incident of fracture to surgical treatment for the remaining nine patients range from two days to three days. Surgery was delayed only when the patient was not medically stable enough to undergo the procedure. Mean time from time of

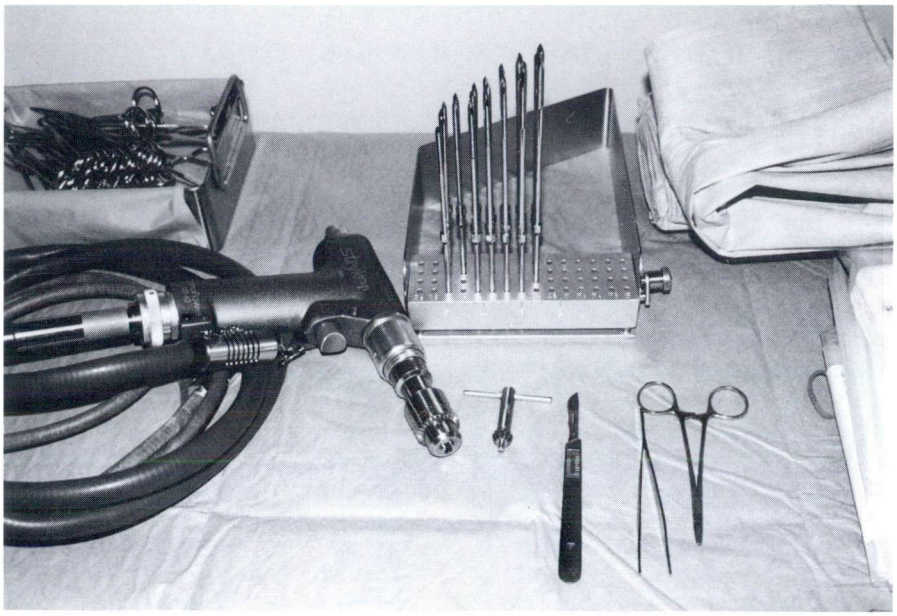

Figure 1—Typical operating room set up for Knowles hip pinning.

fracture until time of surgery was one day.

With two exceptions the patients treated had rather low velocity injuries. Most patients fell in nursing homes, their own homes, or those of relatives. Two of the three younger patients were injured when they fell several stories from roof tops to the ground below. Both sustained displaced subcapital fractures and were treated within several hours after their injury.

PROCEDURE

The procedure was performed in the operating room under either general or short duration spinal block anesthesia. Patients were placed in the supine position on the orthopaedic fracture table and gentle closed reduction performed on those requiring it. C-arm visualization of the fracture was utilized to obtain satisfactory positioning prior to proceeding with the pinning. After proper positioning was achieved the hip was prepped and draped in the standard manner, including the C-arm image intensifier.

Instruments required were few (see figure 1) including scalpel, Knowles' pins, pin driver, needle holder and suture scissors. After determining the approximate Knowles' pin size and level of insertion the first pin is placed through a small one inch incision. It is placed in either superior or inferior position, either anteriorly or posteriorty. The C-arm imaging is utilized to place these pins. Following pin placement in three to four four of these positions reduction and fixation is checked throughout the pinning procedure and the pins are placed such that rotational stability is provided for the fracture. The pins are inserted at an angle of 135° to 150° to allow for controlled subsidence of the fracture during healing. When pinning is completed the Knowles' pins are broken at the hex nut, the small wound irrigated, and the wound then closed with a subcuticular closure of absorbable suture material. Skin closure strips are then applied and a transparent biocclusive dressing applied over this. Alternatively a large band aid can be utilized.

THE POST-OPERATIVE PROTOCOL

Early weight bearing ambulation was encouraged in all patients with subcapital and transcervical fractures who had been ambulators preoperatively. Intertrochanteric and basicervical fractures were treated with nonweight bearing early ambulation. The patients were advanced from walk-

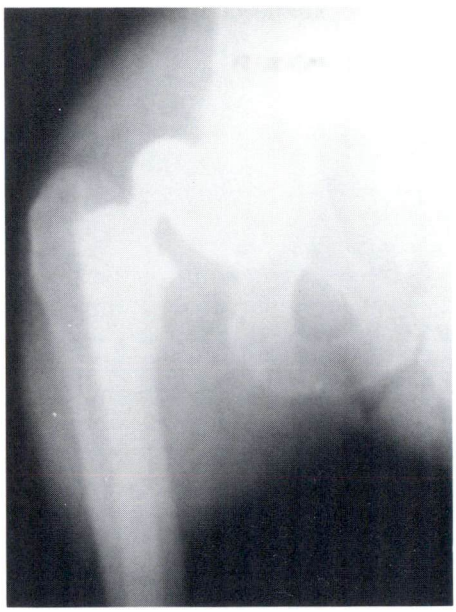

Figure 2—Disarticulation of bipolar hip prosthesis two years post-operatively.

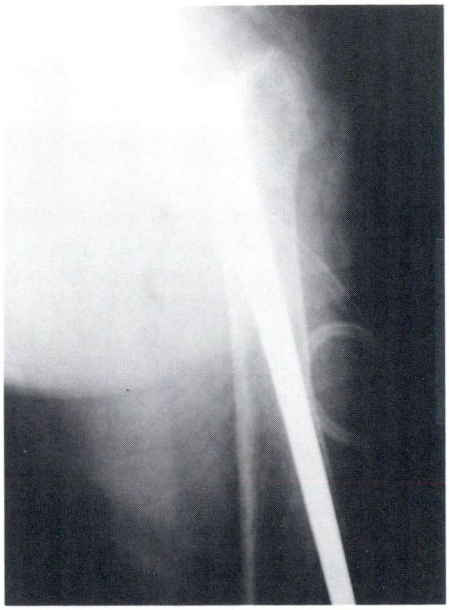

Figure 3—Post-operative fracture of femur in elderly patient with bipolar Austin Moore hip prosthesis.

er or crutches to a quad cane, if possible, at one month. At two months they were encouraged to graduate to a regular cane or no assistive devices at all.

Quadriceps, hamstring, and gluteal strengthening exercises were begun on the first post-operative day and continued until the patient had achieved their pre-operative functional level. Obviously this study included patients who were confused and disoriented. These patients were incapable of carrying out any structured exercise program and often times were not able to ambulate pre-operatively.

RESULTS

Of the forty nine patients treated with closed reduction and percutaneous Knowles' pinning of their hip fractures only two patients required revision of their surgery. These were for nonunion of their subcapital fractures. They were revised to bipolar hip arthroplasties. More commonly re-operation was required for tenderness in the greater trochanteric bursal area due to irritation from the hex heads of the Knowles' pins. This procedure was carried out on an out patient basis with local anesthetic and sedation. Pin removal was necessary in only six of the forty nine hips treated with this procedure.

In the forty nine patients treated with this procedure malunion occurred in three hips. These were all nondisplaced intertrochanteric or basicervical fractures which initially appeared satisfactory but subsequently went into a varus positioning. Leg length discrepancy occurred in these individuals averaging three quarters of one inch. This was treated with a shoe lift. These patients had no complaints of either hip or back pain and were pleased with their post-operative result.

Deep vein thrombosis occurred in two of the forty nine hips in this study. Superficial phlebitis post-operatively was identified in thirteen patients. All patients were treated post-operatively with low dose aspirin for deep vein thrombosis prophylaxis.

There were no intra-operative deaths and no immediate post-operative mortalities. Those patients who did die post-operatively did so from medical problems. The average time from operation to reported mortality was nine months after their reduction and internal fixation.

Blood loss was minimal with much less than 5cc lost in each of these cases. No post-operative infections occurred. All patients received antibiotic prophylaxis for 48 hours post-operatively with one gram of Cefazolin being administered every eight hours.

All patients or their responsible guardians relayed that they were pleased with their choice of surgical options. The two patients requiring re-operation were disappointed with their nonunions but were appreciative that a more conservative approach had been employed first.

Ambulatory and activity status changed in only two patients. As noted previously, several patients required assistive devices prior to their fractures. Seven patients also were not ambulating prior to their fractures.

Post-operative hospital time ranged from three to twenty one days with a mean of ten days. Patients who were not capable of ambulation were discharged back to their prior residence within seven days.

Only the two patients who had required revision of their Knowles' pinning to a bipolar hip arthroplasty due to nonunion did not secure relief of their pain from their hip pinning. These were evaluated by either patient or care person questioning and physical examination of the patient in the office. The vast majority, thirty six patients, related that they experienced no hip or thigh pain. The remaining six coherent patients experienced intermittent thigh or groin pain of a mild degree. They, however, relayed that this was minimal and did not significantly impair their activities of daily living.

DISCUSSION

Knowles' pins have been utilized for the treatment of hip fractures for many decades, however, have generally been used in open reduction procedures. In the majority of the reported cases decisions were strongly influenced by the minimal nature of the described surgery itself. Advantages included decreased anesthesia time, minimal blood loss (5cc or less), and minimal incision and tissue dissection. Another benefit of the procedure is decreased expense due to the need for fewer instruments, less expensive implant devices and even supplies such as suture and dressings are kept to a minimum. Also, an assistant is rarely if ever needed.

Several authors[1-3,9,10,13-16,18,19,21-29,32-34] have advocated primary endoprosthetic replacement for treatment of femoral neck fractures. This technique is certainly successful in allowing early weight bearing ambulation. Intra-operative and post-operative morbidity is also certainly greater than with closed reduction and percutaneous pinning. Post-operative complications not seen with pinning include loosening of the prosthesis, dislocation of the prosthesis (see figure 2), and post-operative fracture at the prosthetic tip (see figure 3). Time of operation is greater with hip arthroplasty. Dissection is more extensive. Blood loss is also elevated when compared with percutaneous pinning.

Reports by others[4-8,11,12,17,20,30,31] of a relatively high (up to 43%) incidence of either nonunion or avascular necrosis with pinning of the femoral neck fractures has not been born out in this series. Although the patient population is small (49 hips), only two percutaneous hip pinnings did not go on to bony union and none developed avascular necrosis. Both of these patients felt that the more minimal procedure was worth while and that the potential benefits outweighed the risks significantly.

Small incision size and minimal dissection appear to psychologically benefit the patient. They are usually surprised and pleased with the cosmetic result and seem to be less afraid of, and more interested in, participating in their rehabilitation period. This technique is felt to be quite worthwhile in the treatment of femoral neck fractures. Although basicervical and intertrochanteric fractures can also be treated by this means both patient and surgeon must understand that malunion and varus may occur. In these patients the advantages of this more minimal-

ly invasive procedures should be weighed closely against this disadvantage. Unless the patient is not an ambulator or is in poor medical condition these fractures are probably better treated with compression hip screw or similar fixation devices.

Overall, closed reduction with percutaneous Knowles' pinning in femoral neck fractures appears to be a viable treatment alternative which offers significant advantages to both surgeon and patient. Although failures do occur, the incidence seems to be less then previously reported.

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Patient	Sex	Age	Type of Fracture	Able to Ambulance Pre-Operatively
ZC	M	51	Displaced subcapital	Yes
CH	F	81	Displaced subcapital	Yes
RG	F	81	Displaced subcapital	No
MB	F	72	Transcervical	Yes
MB	F	73	Subcapital	Yes
NM	M	80	Subcapital	Yes
MH	F	78	Subcapital	Yes
AS	F	72	Displaced subcapital	Yes
HS	F	51	Displaced subcapital	Yes
GR	M	85	Subcapital	Yes
AO	F	80	Subcapital	Yes
PH	F	69	Basicervical	No
JB	M	95	Displaced subcapital	No
MM	F	83	Intertrochanteric	No
EC	F	86	Pertrochanteric	Yes
HS	F	90	Subcapital	Yes
HM	F	74	Intertrochanteric	Yes
PK	F	68	Pertrochanteric	Yes
MH	F	88	Displaced subcapital	Yes
MC	F	62	Pertrochanteric	Yes
ST	F	79	Subcapital	No
LZ	F	85	Displaced subcapital	Yes
MW	F	77	Subcapital	Yes
RM	M	67	Displaced subcapital	Yes
MJ	F	84	Displaced subcapital	Yes
DF	F	66	Displaced subcapital	Yes
MD	F	88	Displaced subcapital	Yes
LW	M	81	Transcervical	Yes
HB	F	79	Displaced subcapital	No
IL	F	75	Basicervical	Yes
JM	F	57	Displaced subcapital	Yes
SD	F	77	Subcapital	Yes
JB	M	69	Displaced subcapital	Yes
KS	F	83	Subcapital	Yes
KN	F	85	Displaced transcervical	Yes
BT	F	76	Displaced transcervical	Yes
VW	F	79	Displaced subcapital	No
LY	F	71	Subcapital	Yes
WS	M	70	Transcervical	Yes
DR	F	58	Transcervical	Yes
LP	F	90	Basicervical	Yes
EP	F	60	Displaced transcervical	Yes
HY	F	87	Displaced transcervical	Yes
GM	F	77	Subcapital	Yes
FM	F	84	Displaced subcapital	Yes
BD	F	85	Displaced subcapital	Yes
AH	F	74	Subcapital	Yes
BK	F	83	Subcapital	Yes
MD	M	34	Displaced Subcapital	Yes

Comparison: Arthroscopic Anterior Suture Capsulorrhaphy & Open Capsular Shift Procedures for Anterior Shoulder Subluxation/Dislocation

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This study is a comparison of fourteen (14) arthroscopic anterior suture capsulorrhaphies and twenty-two (22) open capsular shift procedures done in conjunction with Dr. William L. Smith in Phoenix, Arizona.

The purpose of this paper is to compare the results of the arthroscopic suture capsulorrhaphies with those of the open capsular shift to determine if the arthroscopic surgery is an alternative to the open procedure.

There have been 14 arthroscopic anterior suture capsulorrhapies and 22 open capsular shifts performed from 1986 to present. The average age for the arthroscopic patients was 25.79 and ranged from 16 to 41. The open shift patients averaged 24.23 years and ranged from 17 to 37. The arthroscopic patients were 10 male, 4 female, with 9 athletes and 5 non-athletes. The open shift patients were 16 male, 6 female with 19 athletes, 3 non-athletes. All patients were right-hand dominant and the injured shoulder was 9 right, 5 left, in the arthroscopic group, and 12 right, 10 left in the open group.

SEE TABLE 1-A and 1-B

The Center for Sports Medicine and Orthopedics was the site for preoperative and postoperative patient evaluations. All patients were evaluated subjectively (questionnaire and/or direct questioning) and objectively (physical examination). All patients went through physical therapy postoperatively and progressed to muscular rehabilitation and weight training at the Center for Sports Medicine and Orthopedics.

INTRODUCTION

Arthroscopic surgery of the shoulder has made great strides in recent years, from diagnostic to operative correction of many shoulder pathologies. Shoulder arthroscopy has been used for diagnosis and treatment of the following: Impingement syndrome (resection of the coracoacromial ligament and subacromioplasty); Glenoid labrum pathology (debridement and suture repair); Rotator cuff pathology (debridement); Synovitis/bursitis; Adhesions; Degenerative changes of the glenohumeral and acromioclavicular joints (debridement); Loose body removal, and most recently for suture repair of capsular laxity, tears of the glenohumeral ligaments and glenoid labrum tears (suture capsulorrhaphy).

The arthroscopic capsulorrhaphies and repairs of Bankart and S.L.A.P. lesions have been performed utilizing staple, screw and suture techniques.[*2]

The traditional surgical treatment for patients with shoulder subluxation/dislocation has been one of the following: Modified Bristow, Magnusen-Stack, Putti-Platt, and Bankart procedures. More recently the capsular shift procedure has come into vogue. This was described by Charles Neer, II, M.D. and some modifications of his original description have been utilized by many surgeons in performing the capsular shift procedure.[*11]

PATHOLOGY

The patients in our study experienced anterior subluxation or dislocation at some time that caused anterior capsular laxity and/or glenoid labrum pathology. Most reported an incident that caused the affected extremity to be placed in a position of abduction and external rotation at the time of the injury. As described in the literature, this position is that which causes

stretching of the anterior capsule and muscles as well as causing glenoid labrum pathology as the humeral head subluxates or dislocates. Once these anterior stabilizing structures become damaged by a subluxation/dislocation, they are less effective restraints and predisposed to future episodes of subluxation/dislocation when the abducted-externally rotated position is encountered.

Studies have shown that at zero (0) degrees of abduction, the subcapularis muscle is the primary restraint; at 45 degrees of abduction the subscapularis, middle and inferior glenohumeral ligaments all contribute to stability; and at 90 degrees of abduction the inferior glenohumeral ligament and anterior glenoid labrum are all that prevent dislocation.[*3]

It is easy to see that in abduction and external rotation, the stability of the shoulder is decreased anteriorly.

Turkel, et al, showed that clinically most recurrences of anterior shoulder dislocation occur with the shoulder abducted more than 90 degrees with an applied external rotation force.[*4] The forces applied in this position overcome the restraints (the inferior glenohumeral ligament and anterior glenoid labrum) and damage occurs to these structures as subluxation/dislocation occurs.

The inferior glenohumeral ligament blends into the glenoid labrum anteriorly to form a complex support structure. However, the glenoid concavity only averages 2.5 mm in depth and the inferior glenohumeral ligament-anterior labral complex structurally only adds an additional 2.5 mm depth to the glenoid fossa to provide anterior stability. These structures can be overcome most easily when the shoulder is abducted and externally rotated, thus causing the named Bankart lesion (separation of the inferior glenohumeral ligament-anterior labral complex from the anterior glenoid rim and scapular neck).[*3]

The presence of a Bankart lesion renders the inferior glenohumeral ligament nonfunctional at 90 degrees of abduction and allows subluxation/dislocation to occur more easily.

The typical procedure for repairing the Bankart lesion has been by open means. The procedure is technically difficult due to exposure and obtaining drill holes in the anterior glenoid for capsular fixation. Alternate methods for repair have been tried, i.e. use of screws, staples, plates, wires, and sutures. The use of metallic devices in the shoulder has led to some well-known complications, i.e. loosening, migration, improper placement, resulting in pain and an unsatisfactory result.[*5,6]

Due to these factors, many arthroscopists have directed their attention to arthroscopic suture capsulorrhaphy to repair the Bankart lesion (ligament-labrum pathology.)

Dr. William Smith and I have directed our attention to the undirectional subluxation/dislocation and have utilized the arthroscopic anterior suture capsulorrhaphy technique performed by Dr. Richard Caspari of Richmond, Virginia as our method of treatment for those patients treated arthroscopically.[*7]

For our patients treated nonarthroscopically, we have adopted a modification of the Charles Neer, M.D. and Frank Jobe, M.D. techniques for the open capsular shift procedure.[*11,13,14]

MATERIALS

This study involves 14 patients who had arthroscopic anterior suture capsulorrhaphies and 22 patients who had open capsular shifts.

All 36 patients had anterior shoulder capsular laxity and/or glenoid labrum tears. The patients had experienced anterior shoulder subluxation or dislocation at some time and had capsular laxity and/or glenoid labrum pathology secondary to this.

The patients were all examined preoperatively and many had x-ray (Hill-Sach lesion), arthrogram and CT scans confirming capsular laxity and glenoid labrum pathology. The results were obtained by postoperative history and physical examination and questionnaire.

The 14 patients treated arthroscopi-

cally were all told about the arthroscopic surgery alternative to the standard open Bankart repair and agreed to follow through with the arthroscopic anterior suture capsulorrhaphy. The 22 patients treated with the open capsular shift procedure were not given the option of the arthroscopic procedure because it was felt that their injuries were more severe and would benefit from a more invasive procedure (open capsular shift).

TECHNIQUE

All the arthroscopic surgeries were set up in the same manner. The patients were given a general anesthetic and then had both shoulders examined under anesthesia. The patient was then placed in the lateral decubitus position with the affected shoulder up and rotated 30 degrees posteriorly to align the glenoid with the floor. The affected arm was suspended with a rope-cable-pulley system with ten pounds of weight.

The shoulder was first injected posteriorly with 30 cc of 0.5 percent Marcaine to insufflate the joint. The posterior portal was then established (2.0 cm down and 1.0 cm medial to the posterolateral corner of the acromion), and then the arthroscope was advanced anteriorly into the subscapularis recess to transilluminate the skin and allow establishment of the anterior portal by the passage of a Wisinger rod. A third (superior or Navaiser) portal was established under direct arthroscopic vision with entry between the scapula and the distal clavicle.

All cases began with a systematic examination of all intra-articular structures. Once this was completed, special attention was directed to the pathologic area. In this study, the anterior capsular structures (capsule and glenohumeral ligaments), and anterior glenoid labrum were the areas of interest.

The intra-articular shaver was utilized to clean up any debris (torn loose labral pieces, synovitis), and was then used to clean the anterior glenoid neck area prior to using the burr.

The high-speed burr was then used to burr down to the bleeding bone, the scapular-glenoid neck from as far anterior-inferior as possible to anterior-superior in the area of the bicipital tendon attachment. This was done in the hope of bettering the tissues chance of scarring down to bone.

A Steinmann's pin is passed through the anterior portal and drilled through the scapular neck about 3.0 mm below the glenoid surface. The site of drilling is superior to the glenoid notch on the anterior glenoid and the drill is passed out the scapular neck posteriorly below the scapular spine until it tents the skin. A stab wound allows the pin to be pulled through the posterior aspect of the shoulder.

The Caspari punch is inserted through its cannula in the anterior portal and used to grasp some of the anterior capsular tissue (capsule, glenohumeral ligaments), as well as a portion of the glenoid labrum. The punch allows suture (#0 PDS) to be passed through the soft tissues. This was done in three or four different areas of the anterior capsular and labral tissues. These sutures were then fed through the eye of the Beathe pin. The Beathe pin was inserted through the anterior portal and passed through the hole in the glenoid that was drilled with the Steinmann's pin. The Beathe pin with the sutures passed through its eye is then pushed out through the hole in the glenoid and the sutures are pulled through the skin on the posterior aspect of the shoulder below the scapular spine.

An incision is made along the inferior border of the scapular spine and the sutures are found and pulled through the incision. The sutures are pulled taut, and while arthroscopically viewing the anterior capsular structures and labrum, the sutures are tied over a fascial bridge.

The incision is closed in a routine fashion and the arthroscopy portals are left open. A sterile dressing is applied and a shoulder immobilizer is used.

All of our open capsular shifts were set up in the same manner. After a general anesthetic was administered, both shoulders were examined under

anesthesia. The patients were placed in the supine position with a sand bag behind the operated side scapula. The head of the bed was elevated about 25 degrees to a semi-beach chair position. The arm was draped free.

An anterior approach is used with the skin incision from the anterior axillary fold to a few centimeters distal to the coracoid process.[*12] The cephalic vein is found in the deltopectoral groove and is retracted laterally. The deltopectoral groove is held open with retractors. The coracoid process is found and if more exposure is needed the conjoined tendon is released a few millimeters laterally to allow further medial retraction. A good tendonous cuff is made so adequate repair can be accomplished.

The musculocutaneous nerve should be avoided. It usually is located from 3 to 8 cm from the tip of the coracoid process. The subscapularis muscle is then found and a stat is placed under its inferior margin to elevate it off the capsule. The leash of vessels is located at the inferior margin of the subscapularis muscle and realization that the axillary nerve is close by is made. No cutting below the leash of vessels is made.

The electrocautery hot knife is used to make a longitudinal incision in the subscapularis muscle about 1.0 to 2.5 cm medial to its insertion. This cut is made in a good tendonous portion of the muscle to provide a good substance to repair. The edges of the subscapularis muscle are tagged with #0 Vicryl suture and the muscle is elevated off the capsule medially and laterally.

The capsule is then incised longitudinally at the edge of the glenoid labrum. A T-plasty is then made with the transverse incision extending from medial (glenoid) to lateral. This produces an inferior and a superior leaf that can be shifted to tighten up the lax capsule. The inferior lateral leaf is first pulled and advanced superior medially to the top of the glenoid and sutured in place. This will help obliterate any anterior-inferior translation. The superior leaf is then pulled and advanced inferior medially and sutured down over the superior-medially shifted leaf.

The subscapularis muscle is then repaired. We have sutured the muscle end-to-end as well as overlapping it a bit (Putti-Platt). We decide this based on the amount of laxity noted with our examination under anesthesia. If we have a throwing athlete, a direct end-to-end repair is preferred over a Putti-Platt.

A routine skin closure is performed and drains are utilized as is a shoulder immobilizer.

Postoperatively, the patient does hand-wrist-elbow range of motion exercises starting the day of surgery. Shoulder pendulum exercises and isometric exercises keeping the arm adducted at the side and not allowing external rotation past the neutral anatomic position are done starting postoperative day one.

The patients enter postoperative physical therapy at the Center for Sports Medicine and Orthopedics within a few days of surgery. Therapy is gentle range of motion to the hand-wrist-elbow, including supination-pronation of the forearm, shoulder pendulum exercises, and passive stretching. The shoulder is held in the adducted and internally rotated position in the shoulder immobilizer for three weeks at all times except when exercising in therapy. From three to six weeks, the patients discard the immobilizer; this is patient specific. There is a gradual increase in range of motion and strength exercises from three to six weeks. At six weeks a more aggressive therapy is instituted with light dumbbell work and surgical tubing exercises. Patients are not taken beyond the neutral external rotation position until four to six weeks postoperative and then only with gradual stretching and range of motion.

Patients continue to gradually increase their weight and workload in therapy over the next few weeks and then are advanced into muscular rehabilitation in the weight room between eight to ten weeks. Here, they continue to increase strength in a

certain range of motion dictated by the physical therapist and strength trainer. Patients continue with this therapy until the results obtained are acceptable. Many patients have chosen to stay in weight training indefinitely.

RESULTS

Results were rated excellent, good, fair or poor and were determined by the following criteria:

Excellent--Asymptomatic --No pain
--Function --Full range of motion, what existed prior to injury/surgery
--No instability

Good --Mild pain
--Function --Not quite full range of motion, almost what existed prior to injury/surgery
--No instability

Fair --Moderate pain
--Function --Decreased range of motion, only slightly better than prior to injury/surgery
--Some instability-subluxation

Poor --Moderate to severe pain
--Function --Decreased range of motion, no better than prior to injury/surgery

RESULTS Table 1C
Arthroscopic suture capsulorrhaphies (14)

Excellent:	7	(50 percent)
Good:	6	(42.9 percent)
Fair:	0	(0)
Poor:	1	(7.1 percent)

Anterior capsular shift procedure (22)

Excellent:	12	(54.5 percent)
Good:	6	(27.3 percent)
Fair:	1	(4.5 percent)
Poor:	3	(13.7 percent)

RESULTS

All the patients were examined prior to the writing of this paper to obtain current data. All patients also were sent a questionnaire that most of them filled out. The examination entailed a subjective assessment on the patients' part as to how they were doing, and allowed them to discuss the pain, range

RESULTS Table 1A
ARTHROSCOPIC SUTURE CAPSULORRHAPHIES

AGE	SEX	ATHLETE	SHOULDER	FOLLOWUP	RESULTS
33	M	Yes	Left	16 mo.	Excellent
16	M	Yes	Right	22 mo.	Excellent
19	M	No	Left	23 mo.	Excellent
29	M	Yes	Right	28 mo.	Good
41	M	No	Right	23 mo.	Poor
17	F	Yes	Right	14 mo.	Good
23	M	No	Left	33 mo.	Good
24	F	Yes	Left	19 mo.	Excellent
38	M	Yes	Right	10 mo.	Good
23	F	No	Right	14 mo.	Good
21	M	Yes	Right	5 mo.	Excellent
41	F	No	Left	9 mo.	Good
18	M	Yes	Right	19 mo.	Excellent
18	M	Yes	Right	3 mo.	Excellent
25.79avg	**10 male**	**9 athletes**	**9 right**	**17 mo avg**	
	4 female	**5 non-athletes**	**5 left**		

RESULTS Table 1B
ANTERIOR CAPSULAR SHIFT PROCEDURE

AGE	SEX	ATHLETE	SHOULDER	FOLLOWUP	RESULTS
26	M	Yes	Right	25 mo.	Excellent
37	M	Yes	Left	30 mo.	Excellent
18	M	Yes	Right	20 mo.	Excellent
27	M	Yes	Left	29 mo.	Good
27	M	No	Left	14 mo.	Excellent
18	M	Yes	Left	11 mo.	Excellent
21	M	Yes	Left	17 mo.	Poor
30	M	Yes	Left	10 mo.	Excellent
18	M	Yes	Right	14 mo.	Excellent
19	M	Yes	Right	4 mo.	Excellent
34	M	No	Right	17 mo.	Good
21	M	Yes	Right	10 mo.	Poor
20	F	Yes	Left	2 mo.	Fair
18	M	Yes	Left	25 mo.	Excellent
26	M	Yes	Right	9 mo.	Excellent
17	F	Yes	Right	4 mo.	Excellent
20	M	Yes	Left	6 mo.	Excellent
26	F	Yes	Right	7 mo.	Good
23	M	No	Right	4 mo.	Good
28	F	Yes	Right	6 mo.	Good
28	F	Yes	Left	16 mo.	Good
31	F	Yes	Right	17 mo.	Poor
24.23avg	**16 male**	**19 athletes**	**12 right**	**13.5 mo avg**	
	6 female	**3 non-athletes**	**10 left**		

of motion, strength and overall feelings of their current status. Then an examination was done in both standing and supine positions. First, the non-affected shoulder was taken through range of motion (flexion, extension, abduction, adduction, internal and external rotation), then was tested for strength of deltoid, rotator cuff, biceps and triceps muscles. Various tests were then done: Flexion impingement test, adduction impingement test, supraspinatus test (Jobe test), apprehension test, speed test, and then the suluxability/dislocatability was determined. Once this was done, the operated shoulder was then examined and compared to the non-operated side and the results recorded.

Results were based on both the patients' subjective information via questionnaire and during examination as well as the objective data from the examination.

The findings were as follows:

Arthroscopic suture capsulorrhaphies — Seven of fourteen had excellent results (50 percent); Six of fourteen had good results (42.9 percent); No fair results; One of fourteen had poor results (7.1 percent).[*1]

Anterior capsular shift procedure — Twelve of twenty-two had excellent results (54.5 percent); Six of twenty-two had good results (27.3 percent); One of twenty-two had fair results (4.5 percent); Three of twenty-two had poor results (13.7 percent)[*1]

In the arthroscopic suture capsulorrhaphy group the one poor result was a very noncompliant patient who did not engage in therapy as he should have. He had continued moderate pain and his range of motion was no better than prior to surgery. He had no instability, however.

In the anterior capsular shift group, there were three (3) poor and one (1) fair result. One of the poor results has redislocated four to five times and feels unstable. He does have full range of

motion and no pain. Another of the poor results has not subluxed or dislocated but has chronic impingement syndrome with bicipital tendinitis that has restricted activities. The one fair result is only two months postoperative and has continued moderate gain and has not reached full range of motion. This patient is so early that we feel she will improve with time.

The average followup for the arthroscopic suture capsulorrhaphies was 17 months and for the capsular shifts was 13.5 months. These times are fairly good and make this study credible, but one year from now the data will be more important. It is commonly noted that you need a two-year followup to have a good study. We will reevaluate these patients at a later date to see how they compare to other shoulder studies with a longer followup time. I feel that with continued rehabilitation it is possible for even more patients to obtain an excellent result in time.

COMPLICATIONS

There were no infections, no vascular injuries, no neurologic injuries (suprascapular nerve injuries have been reported with suture capsulorrhaphies and axillary and musculocutaneous nerve injuries have been reported with capsular shifts). Failure of the procedure is also considered a complication and in our study we had two patients who subluxed or dislocated after their surgery (both were capsular shift patients).

DISCUSSION

In the past few years, several orthopedists have reported preliminary clinical results of arthroscopic anterior capsular stapling procedures done for recurrent anterior glenohumeral instability.[*8,9,10] The early results showed a disappointing 15 to 20 percent redislocation rate and complication related to use to metal staples in the shoulder (10-20 percent). Due to these findings, many orthopedists have gone to performing suture capsulorrhaphies in an attempt to perform the surgery arthroscopically, and to avoid the problems of intra-articular stapling. Many preliminary reports have been favorable with this technique.[*3] Those reports as well as our results in this study are very encouraging at this time. We must continue to follow these patients over time to see how they hold up.

It is promising that our arthroscopic suture capsulorrhaphy patients faired quite well with 50 percent excellent and 42.9 percent good results for an overall 92.9 percent satisfactory result. These results are with a 17 month followup and are very encouraging to us.

Our anterior capsular shift patients were 54.5 percent excellent and 27.3 percent good for an overall 81.8 percent satisfactory result. These results are with a 13.5 month followup and are also quite encouraging to us because we feel with time these patients will improve.

We realize that those patients treated arthroscopically were not as unstable as those treated with the open capsular shift procedure and thus to compare these two groups may be misleading. It is important, however, to realize that good results can be obtained arthroscopically if careful patient selection is performed. If the patient is a subluxator and/or occasional dislocator that does not have severe capsular laxity and instability, an arthroscopic suture capsulorrhaphy appears to be a viable alternative to the open procedure.

Our arthroscopic patients had full range of motion where some of the open patients have not obtained this yet and may never obtain this due to the surgical procedure. By shifting the capsule to rid the patient of capsular laxity we do not necessarily expect a decreased range of motion. However, by cutting the subscapularis muscle in addition to cutting and shifting the capsule, we realize a certain amount of external rotation is lost. This is all right in many cases because it does not allow the patient to get into that vulnerable position where anterior subluxation/dislocation occurs. If the patient never again dislocates, but has some loss of external rotation, most people would be satisfied. If, however, the

patient had near full range of motion and never again dislocated almost everybody would be ecstatic. We do not know if this can be obtained with the open capsular shift because the anterior tissues are cut and sutured causing some shortening and scarring, but we think it can be obtained with the arthroscopic suture capsulorrhaphy.

The question of stability over a longer followup is still not quite answered because our followup of 17 months is shy of 2 years that we would like to see. Our results to date are very encouraging to us because if we can obtain results that equal those of the open procedure by arthroscopic technique, we feel this will be a major advantage. It will offer less postoperative morbidity, decreased loss of motion, less pain, and is more cosmetically acceptable.

COMMENTS

Many questions arose after examining these patients and evaluating our results. Here are some interesting things we must think about:

Can the arthroscopic procedure give us the long-term results we all have noted with the open procedure?

Will the arthroscopically treated patients be as stable as the patients treated by open means?

Will the athletes treated arthroscopically be more susceptible to redislocation/subluxation when they return to their sport than those treated open?

Can we use the arthroscopic procedure on severely unstable shoulders or must we continue to carefully select patients for this procedure?

In the future, as more arthroscopic suture capsulorrhaphies are performed and more long-term followup is obtained, the answers to many of these questions will be found.

CONCLUSION

In our study of 36 patients with anterior shoulder laxity secondary to subluxation/dislocation causing a Bankart-type lesion and capsular laxity, we obtained 92.9 percent satisfactory results (50 percent excellent, 42.9 percent good) with the arthroscopic suture capsulorrhaphy technique and 81.8 percent satisfactory results (54.5 percent excellent, 27.3 percent good) with the open capsular shift technique.

We feel that even though the arthroscopic suture capsulorrhaphy is a new technique, it appears to be a viable alternative to the open capsular shift/Bankart repair in the hands of an experienced shoulder arthroscopist if the patients are carefully selected. In time as our skill in performing this procedure improves, we hope to improve on patient results. We still must continue longer followup on these patients to adequately compare the arthroscopic and open procedures utilized for the treatment of anterior shoulder subluxation/dislocation.

TABLE IIA
ARTHROSCOPIC SUTURE CAPSULORRHAPHY

AGE/ SEX	ATHLETE	SHOULDER	FOLLOWUP	RESULT	DIAGNOSIS	SURGERY
33/M	Yes	Left	16 mo	Excellent	Subluxator Torn ant. glen. labrum	Suture rep. lab., suture cap.
16/M	Yes	Right	22 mo	Excellent	Ant. Dislocator Torn ant. lab.	Suture rep. lab., Suture cap.
19/M	No	Left	23 mo	Excellent	Recurrent sublux torn ant-inf lab cap.	Suture rep. lab., Suture
29/M	Yes	Right	28 mo	Good	Recurrent sublux torn ant. labrum	Suture rep. lab., suture cap.
41/M	No	Right	23 mo	Poor	Torn ant. glen. lab, subluxator	Suture rep. lab., suture cap.
17/F	Yes	Right	14 mo	Good	Torn ant. lab. Ant. cap laxity	Suture rep. lab., suture cap.
23/M	No	Left	33 mo	Good	Torn ant. lab. Capsule tear	Suture rep. lab., suture cap.
24/F	Yes	Left	19 mo	Excellent	Torn ant. lab. Ant. Subluxator	Suture rep. lab., suture cap.
38/M	Yes	Right	10 mo	Good	Recurrent ant-inf dislocator, cap laxity	Suture cap.
23/F	No	Right	14 mo	Good	Torn ant-inf lab, recurrent subluxator	Suture rep. lab., suture cap.
21/M	Yes	Right	5 mo	Excellent	Recurrent ant-inf dislocator	Suture cap.
41/F	No	Left	9 mo	Good	Recurrent ant. dislocator	Suture cap.
18/M	Yes	Right	19 mo	Excellent	Torn ant-inf lab & subluxator	Suture rep. lab., suture cap.
18/M	Yes	Right	3 mo	Excellent	Recurrent ant. dislocator, torn ant-inf lab.	Suture cap. suture rep lab.

TABLE IIB
ANTERIOR CAPSULAR SHIFT

AGE/ SEX	ATHLETE	SHOULDER	FOLLOWUP	RESULT	DIAGNOSIS	SURGERY
26/M	Yes	Right	25 mo	Excellent	Recurrent ant. dislocator	Cap shift Putti-Platt
37/M	Yes	Left	30 mo	Excellent	Ant. cap laxity Instability Tear rot. cuff	Cap shift Putti-Platt Repair cuff
18/M	Yes	Right	20 mo	Excellent	Recurrent ant. dislocator	Cap shift Bankart rep
27/M	Yes	Left	29 mo	Good	Ant. dislocator Torn labrum	Cap shift Putti-Platt
18/M	Yes	Left	11 mo	Excellent	Recurrent dislocator	Cap shift
21/M	Yes	Left	17 mo	Poor	Recurrent ant. dislocator	Cap shift
30/M	Yes	Left	10 mo	Excellent	Ant-inf laxity Subluxator Torn rot. cuff	Cap shift Rep cuff
18/M	Yes	Right	14 mo	Excellent	Recurrent ant-inf Dislocator Bankart	Cap shift Putti-Platt Bankart rep
19/M	Yes	Right	4 mo	Excellent	Recurrent ant. dislocator Bankart, fx scap neck	Cap shift Bankart rep
34/M	No	Right	17 mo	Good	Ant-inf cap lax S.L.A.P. lesion	Cap shift Putti-Platt
21/M	Yes	Right	10 mo	Poor	Recurrent ant. subluxator, cap	Cap shift
20/F	Yes	Left	2 mo	Fair	Ant-cap lax Subluxator	Cap shift Putti-Platt
18/M	Yes	Left	25 mo	Excellent	Recurrent ant. dislocator, torn labrum	Cap shift Mangnusen-Stack
26/M	Yes	Right	9 mo	Excellent	Recurrent ant. dislocator Deficient lab.	Cap shift Bankart rep Putti-Platt
17/F	Yes	Right	4 mo	Excellent	Ant-inf cap lax	Cap shift
20/M	Yes	Left	6 mo	Excellent	Recurrent ant. dislocator, multi dir. instability	Cap shift Putti-Platt
26/F	Yes	Right	7 mo	Good	Ant-Inf cap lax Recurrent ant. dislocator	Cap shift Putti-Platt
23/M	No	Right	4 mo	Good	Recurrent ant. dislocator S/P suture cap	Cap shift Putti-Platt
28/F	Yes	Right	6 mo	Good	Cap laxity	Cap shift Putti-Platt
28/F	Yes	Left	16 mo	Good	Chronic ant-inf laxity	Cap shift Putti-Platt
31/F	Yes	Right	17 mo	Poor	Ant-inf cap lax Rot. cuff tear	Cap shift
27/M	No	Left	14 mo	Excellent	Recurrent ant. dislocator Bankart, cap lax.	Cap shift Bankart rep

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Results of a Modified Jones Procedure For Stabilizing The ACL Deficient Knee

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ABSTRACT: From September 1977 through February 1985 the senior author performed 54 modified Jones procedures in which a 1 centimeter wide strip of quadriceps aponeurosis, central one-third patellar tendon, patellar bone wedge, intrapatellar tendon and tibial tubercle bone block was used to perform an intra-articular reconstruction or augmentation of the ACL. The quadriceps aponeurosis portion of the autograft provided an extra-articular lateral tenodesis. 36 patients were subjectively evaluated post-operatively at a minimum of 2 years follow-up by 2 previously published rating systems. 27 patients were clinically evaluated by examination, radiographs, and the MEDmetric arthometer KT-1000.

On clinical examination 85% had negative Lachman's tests, negative pivot shift tests, and a normal range of motion. 78% had a good or excellent objective result at a minimum of 2 years follow-up, as judged by previously published criteria. Using the two different subjective rating scales we had 72% and 76% satisfactory results. Recent modifications in the procedure, such as paying careful attention to an adequate notchplasty, isometric placement of the ACL autograft, and leaving the anterior defect unclosed promise the possibility of seven more reliable clinical and subjective results. We feel this previously unreported procedure meets the biological and biomechanical requirements necessary to effectively stabilize the ACL deficient knee.

We are presenting a previously unreported procedure, which utilizes a 1 centimeter wide strip of quadriceps aponeurosis, central one-third patellar tendon, patellar bone wedge, infrapatellar tendon and tibial tubercle bone block in order to provide an intra-articular reconstruction or augmentation of the ACL and an extra-articular lateral tenodesis.

Many have reported the downward spiral of joint disruption associated with the symptomatic ACL deficient knee.[15,20,25,30] In an attempt to prevent this from occurring many procedures have been used in an attempt to provide stability to the ACL deficient knee.[5,9,21,26,29,32,34,36] Our subsequent post-operative care is also based the currently understood biological requirements of tissue healing.[3,8,14,16,28,31]

Using previously published objective criteria we had 78% satisfactory results at a minimum follow-up time of 2 years.[32] Using two previously published subjective evaluations, we had 72% and 76% satisfactory results.[30,34] We feel, however, that as the procedure is currently performed one can expect at least a 85% success rate in providing the patient with a stable, functional knee.

MATERIALS AND METHODS

From September 1977 through February 1985, the senior author performed 54 modified Jones procedures in which a 1 centimeter wide strip of quadriceps aponeurosis, central one-third patellar tendon, patellar bone wedge, infra-patellar tendon and tibial tubercle bone block was used to perform an intra-articular reconstruction or augmentation of the ACL.[21] The quadriceps aponeurosis portion of the autograft was used to provide an extra-articular lateral tenodesis. This pre-

viously unreported procedure, its results, and complications are reported here.

PATIENT SELECTION

Patients with a positive anterior drawer sign at 20° of knee flexion and a history of a tense effusion following a luxating phenomenon of the knee who are "at risk" for future symptomatic instability were considered as candidates for this procedures.[35] Many factors help determine which patients are "at risk" including age, sex, severity of injury, occupation and associated or prior damage to the knee, and the competitive level of the particular sport(s) at which they desire to participate. We have tended to recommend reconstruction or augmentation for the young, athletic individual who desires to engage in sports requiring rapid acceleration-deceleration maneuvers, such as running with a football, playing basketball or volleyball, or performing in gymnastics. In contrast, older, more sedentary individuals with ACL deficient knees are often not "at risk" due to their decreased activity levels. However, older patients whose occupation or avocation requires strenuous use of their knees are counseled to consider surgical intervention. In these recommendations we are not unlike those before us.[34]

In addition to the above recommendations, we feel we must add one more group for whom surgery should be considered. Patients with an ACL deficient knee and a torn meniscus should be considered for surgical intervention, as we feel that the meniscal tear is probably due to knee instability secondary to the ACL deficiency. In all patients who have a peripheral meniscal tear repaired in an ACL deficient knee, the ACL should be repaired and augmented or reconstructed, as studies by DeHaven, and by DiStefano and Bizzle have shown unacceptable rates of recurrent meniscal tears following meniscal repair in ACL deficient knees.[6,11] DeHaven reported a 30% failure rate for meniscal repair in the ACL deficient knee. Other authors have reported successful repair of peripheral meniscal tears when combined with an intra-articular stabilization procedure.[9]

All patients had a positive anterior drawer sign at 20° of flexion and history of a subluxating phenomenon in their affected knee. Most also had a positive pivot shift sign present at their examination under anesthesia in the operating room.[17,24] All of the patients who had this procedure performed had the diagnosis confirmed by arthroscopic examination, either by the referring orthopaedic surgeon or by the senior author.

From October 25, 1977 through February 18, 1985, 54 ACL deficient knees in 54 patients were reconstructed or augmented using this procedure. Thirty-seven patients were males and 17 were females. Of these 54 patients, 8 had acute lesions, having occurred within 3 weeks of surgery, and 46 had chronic lesions. Twenty-three had had diagnostic arthroscopic performed prior to their admission for this procedure. Five had had lateral meniscectomies, 10 had had medial meniscectomies, 2 had had intra-articular reconstructions, and 2 had had failed extra-articular procedures. At the surgery reported here, 30 required 32 meniscectomies, 13 required 14 meniscal repairs, and 3 required medial collateral ligament repairs.

OPERATIVE PROCEDURE

Following induction of satisfactory general or spinal anesthesia, examination of the knee was performed. The limb was then prepped and draped free, following placement of a proximal thigh tourniquet. If prior diagnostic arthroscopy had not already confirmed an ACL deficiency an arthroscopic examination was performed. During arthroscopy, the tourniquet is only inflated if it is absolutely needed to maintain a clear visual field, as most meniscectomies in the senior author's hands can be completed without the use of a torniquet. If a repairable peripheral meniscal tear is noted, it is repaired through the arthrotomy performed for the reconstruction or augmentation.[4,10,11,12] Following completion of the arthroscopic portion of the procedure, the surgeon and as-

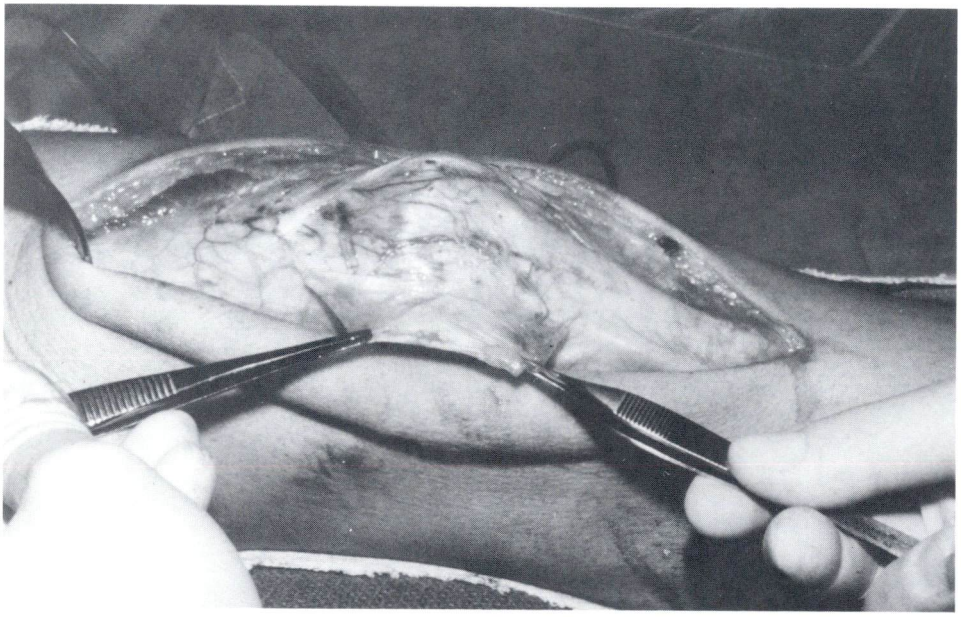

Figure 1: Prepatellar retinaculum has been grasped with forceps and retracted laterally.

sistant change gowns and gloves.

A gram of cefazolin and 20 mg. of Decadron are given intravenously on call to the operating room. The limb is exsanguinated and the tourniquet inflated to 300 to 350 mm. of mercury. An incision is started on the lateral aspect of the thigh just proximal to the posterior flare of the lateral condyle, continued distally to just distal to the inferior pole of the patella, then swung medially and distally to a point on the proximal tibia, just medial and distal to the tibial tubercle. A median parapatellar incision is then made for the arthrotomy. Following confirmation of the ACL disruption, a primary repair is performed if the tear is acute and the stump is excised if the tear is chronic.

Attention is then turned to harvesting the autograft. The pre-patellar retinaculum is first dissected from the extensor retinaculum laterally and turned medially. **Fig. 1.** A one centimeter wide strip of quadriceps aponeurosis, patellar tendon, anterior patellar bone wedge, infrapatellar tendon, and tibial tubercle bone block is then harvested by sharp dissection. **Fig. 2.** An oscillating saw is used to procure the anterior patellar wedge and tibial tubercle bone block. The soft tissues of the graft are then tubulated by suturing the edges together. Interrupted sutures of #3-0 Vicryl are used.

Sharp dissection is then used to develop a surgical plane between the subcutaneous tissues and the underlying fascia laterally. The iliotibial band should be incised in line with its fibers. A Steinmann pin is then drilled from the anatomic attachment site of the ACL to a point on the lateral femur, just anterior to the intermuscular septum and just proximal to the flare of the condyle. This correlates to the femoral isometric point described by Krackow and Brooks.[23] Retractors are used to hold the tissues away from this area, thus allowing the surgeon to visualize the Steinmann pin as it exits the femoral cortex. The guide is then overdrilled with an appropriately sized reamer, creating the femoral tunnel. From a point 2 centimeters distal to the tibial plateau and 2 centimeters medial to the tibial tubercle, a second Steinmann pin is drilled posterolaterally and proximally, to exit into the knee joint at the tibial anatomic attachment site of the ACL. This is then overdrilled with an appropriately sized reamer, creating the tibial tunnel. The edges of the tunnels are then chamfered with a dental burr, thus decreasing the possi-

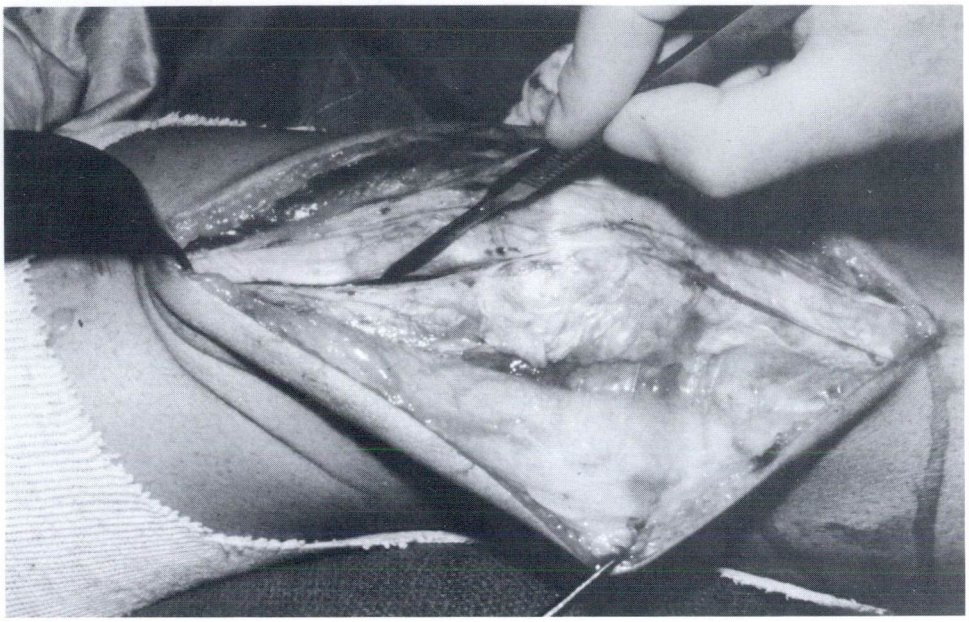

Figure 2: The proximal portion of the graft has been extended through the quadriceps aponeurosis to the muscle fibers of the rectus femoris.

bility of graft abrasion at the tunnel exit and entrance sites. The bone procured while drilling the tunnels is saved.

A notchplasty is then created by removing 5 to 7 mm. of the medial aspect of the lateral femoral condyle with an osteotome. A wire loop is then passed retrograde through the femoral tunnel, joint, and tibial tunnel. The graft's tubulating sutures through the quadriceps aponeurosis are tied to this loop, and the graft is pulled through the tunnels, placing the tibial tubercle bone block within the tibial tunnel, the infrapatellar tendon portion within the joint, the patellar bone wedge within the femoral tunnel and the quadriceps aponeurosis portion laterally to serve as a lateral tenodesis. **Fig. 3,4,5.** A staple is used to hold the tibial tubercle bone block within the tibial tunnel. The knee is flexed to 20°. The quadriceps aponeurosis portion of the graft is then brought down to a scarified region of the tibial cortex just anterior to Gerdy's tubercle, gently placed on tension and stapled in place. A gentle drawer test with the knee flexed to 20° is then performed. It should be negative, if the graft is correctly tensioned. At this point, the knee should be capable of a passive range of motion from complete extension to near complete flexion, which is restricted by the surgical drapes and tourniquet. Twenty mgs. of Decadron is then repeated intravenously. The tourniquet is then deflated and hemostasis obtained.

The femoral tunnel exit site and the distal placement of the lateral tenodesis are important. If correctly placed, they should correspond to the isometric points described by Krackow and Brooks.[23] Thus, the tenodesis should not be stretched out with knee motion.

Prior to closure, the bone obtained from drilling the tunnels is placed into the defect in the patella. The prepatellar retinaculum is then sutured back in place over it. The defect in the extensor mechanism, capsule, and iliotibial band are repaired with interrupted sutures of #1 Vicryl. A lateral release is performed in an effort to decompress the patellofemoral joint. The subcutaneous tissues are closed with a running subcuticular suture of #3-0 Prolene. Steri-strips, sterile dressings, and a cylinder cast with the knee at 20° of of flexion were then applied.

POST-OPERATIVE CARE

Post-operatively, patients received a gram of cefazolin intravenously every 8 hours for 3 doses, and 4 mgs. of Decadron orally every 6 hours for 4 doses.

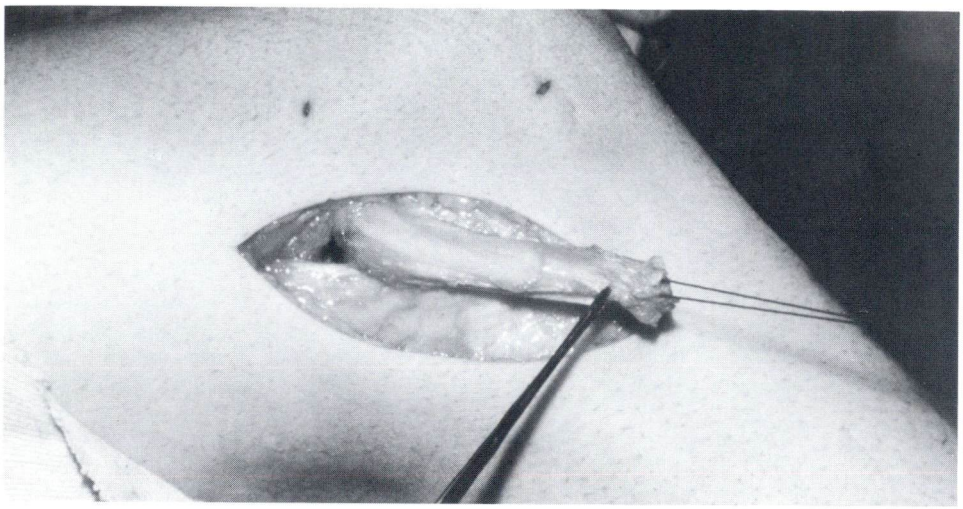

Figure 3: The quadriceps aponeurosis is used as a lateral sling (placed through a separate lateral incision in this photo).

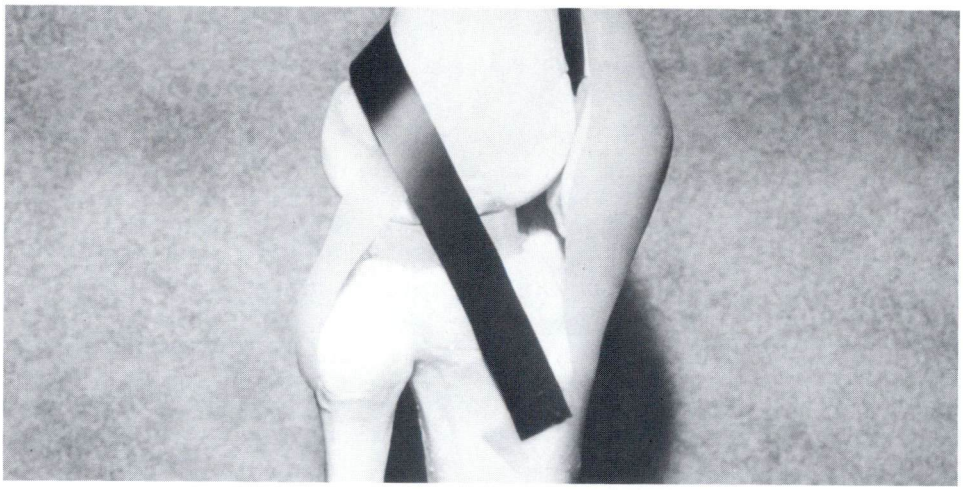

Figure 4: Knee model with black tape representing lateral sling portion of ACL graft.

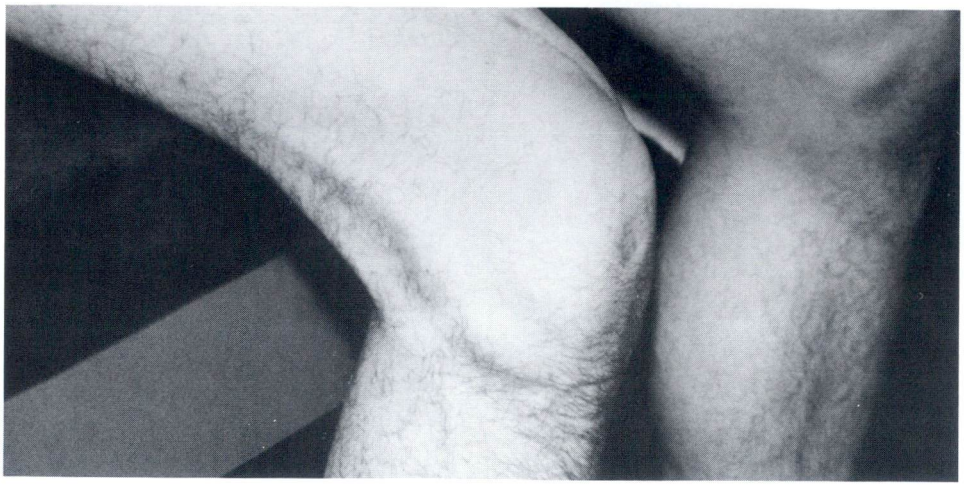

Figure 5: Lateral sling as seen post-operatively.

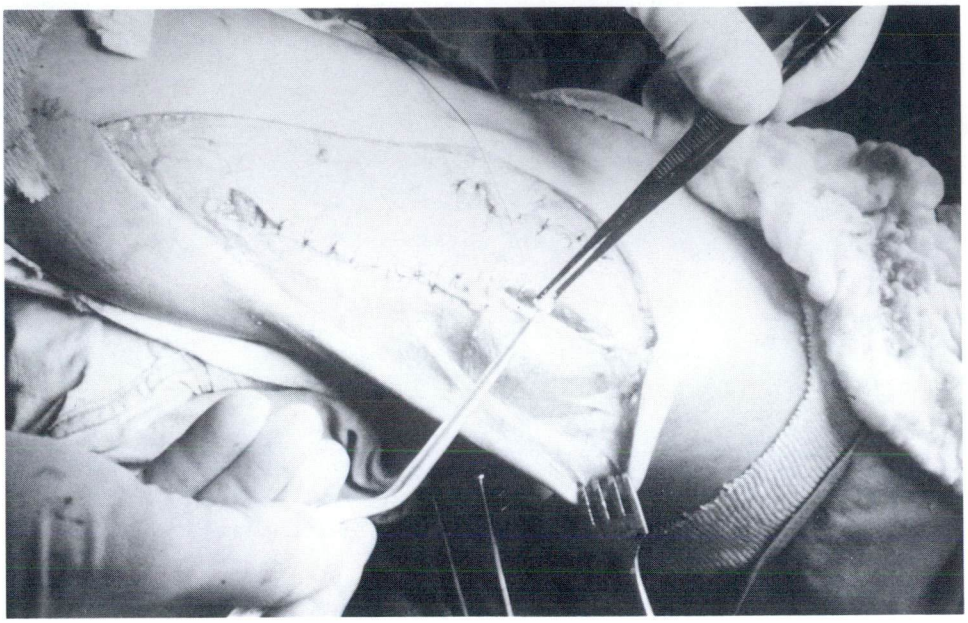

Figure: 6: Bone chips being packed into patellar donor site. Patellar retinaculum will be repaired over the top of the chips.

The limb was kept elevated with ice bags packed around it for 24 hours. The patient who had been trained in crutch walking pre-operatively was allowed to have bathroom privileges immediately. On the second day, patients were allowed non-weight bearing ambulation with crutches as tolerated. When the patient was using only oral medications for pain relief and was ambulating well with crutches, he was discharged.

The patient returned to the office two weeks post-operatively for suture removal and a cast change. The patients remained non-weight bearing for six weeks. In patients later in the series, a cast brace allowing a limited range of motion replaced the first cast at two weeks. More recently, a constant passive motion machine set at 20° to 50° has been used immediately post-operatively, followed by cast bracing, allowing a limited range of motion. This is done to decrease the effects of immobilization, to improve nutrition of the articular cartilage, and enhance the ligamentous healing.[31,33]

Six weeks following surgery, the cast or cast brace was removed and the patient sent to the physical therapist for initiation of a carefully monitored rehabilitation program. Whirlpools and deep heat modalities were used, followed by active assistive range of motion exercises, carefully avoiding the terminal 10° of knee extension. Stationary biking, with the seat set to limit knee extension to minus 50° is started. Isometric quadriceps and hamstring exercises within 50° to 90° range of motion is started. Hip isometrics and progressive resistive exercises with the knee at a 60° flexion arc are started. The early therapy, which includes stationary bicycling is aimed at restoring knee flexion and regaining muscle tone. At six weeks post-operatively, the patient begins weight bearing and full weight bearing is allowed by 8 weeks. Patients are specifically warned to avoid all quadriceps resistive exercises.

At 10 or 12 weeks post-operatively, full arc extension progressive exercises are started. At 6 months, if the patient had attained 75-80% quadriceps strength as measured on the isokinetic dynamometer, straight-away running was allowed. Patients begin by running one-quarter mile, followed by a one-quarter mile walk, followed by a one-quarter mile run, until they can run for a total of one mile. At this point

they may run one-half mile, followed by a one-half mile walk, until they can run a total of two miles. Once they can run two miles, they may run straight away as they wish. When patients can run one mile without their knees swelling, they are encouraged to begin the backward running also. When they can run backwards well, they started running figure-eights, starting at 50 yards at half speed, progressing to 25 yards, then to 10 yards. When they can run it at 10 yards well, they run 50 yard figure-eights at full speed and work back down to 10 yards. Finally, cutting drills are performed.

With proper rehabilitation, patients are encouraged to wait a full year prior to competing in any sporting event. This is because of the slow return to full tensile strength of the autograft, which has been suggested to take as long as 12 to 18 months.[29]

SUBJECTIVE EVALUATION

Patients who had had this procedure performed were contacted by phone or mail during November and December 1986. Thirty-six patients responded, 27 by returning for clinical evaluation, radiographs, and subjective evaluation by questionnaires, and 9 by returning questionnaires. The questionnaires used were as previously put forward by Snydor and Andrews, and by Noyes.[30,34]

Using the functional rating system of Noyes, et. al. Patients were asked to rate their operated knee for levels of pain, swelling, giving way, and activity level at which they could function, in comparison to varying levels of intensity of activity.[30] The subjective rating scale set forth by Snydor and Andrews also had the patient rate their operated knee in relation to level of pain, giving way, activity levels, and whether or not their athletic performance had been altered by the procedure.[34] However unlike the rating system set forth by Noyes, et. al., this second scale did not specifically question the function of the knee at each varying level of athletic intensity.

CLINICAL EVALUATION

Clinical examination was as delineated by Roth, Kennedy, et. al.[32] Clinical examination included evaluation of stability by use of the anterior drawer sign at 20° and at 90° of knee flexion, the pivot shift sign, and by quantitative assessment of anterior tibial subluxation on the femur, using the KT-1000 arthrometer at 15 and 20 pounds and maximal displacement forces. The patellofemoral joint was examined for tenderness and crepitance. The comparative range of motion of the knee and post-rehabilitation muscular development at 10 centimeters proximal and 10 centimeters distal to the patella were determined. The post-operative time range from 24 to 87 months, with the average time being 54 months. R.A. examined all of the patients.

The Model KT-1000 arthrometer (MEDmetric, San Diego, CA) was used to evaluate the stability of the knee at 15 pounds, 20 pounds, and maximal forces in 25 of 27 knees that were able to be clinically evaluated during this study. The results of the KT-1000 arthrometer testing were compared to our results by objective evaluation.

X-RAYS

The radiographs taken for evaluation were AP, lateral, tunnel and sunrise views. These were evaluated for post-operative degenerative joint disease changes.

CRITERIA FOR RESULTS

Criteria for an excellent objective result included having an excellent objective evaluation of drawer signs and negative pivot shift test. The patient must have no swelling, tenderness, or significant atrophy and must have lost less than 5° of full extension and less than 10° of full flexion. A good result was indicated by having a good objective evaluation of anterior drawer signs at 20° and 90° of knee flexion, a pivot shift of 1 + or less only mild swelling, mild tenderness, or thigh atrophy of 0.5 inch or less, and extension loss of only 5° to 10°, and flexion loss of only 15° or less.[34] We were very strict in our evaluation, and if a patient did not meet all of the objective criteria for a given rating, his results were assessed at the next lower rating.

A score of 100-91 points, on Noyes functional rating system was considered an excellent result, 90-81 points a good result, 80-71 points a fair result and less than 70 points a poor result.[30] An excellent subjective result on Snydor and Andrews rating scale was a knee that had no pain, did not give way, did not limit athletic activity and allowed the patient to return to his pre-injury levels of athletic performance. A good result left the knee with mild and infrequent pain, an occasional sensation of instability, fatigue, or infrequent giving way, only mild activity limitations, and with only a mild decrease in athletic ability. A poor result was scored if the patient felt he had significant knee pain, frequent symptomatic instability, significant limitations of his activity, and significant inability to perform at his prior level of athletic performance.[34]

RESULTS

Of the 27 patients who were able to return for an examination 5 had excellent, 16 had good, and 6 had poor objective results. One poor result was due to graft rupture, one due to a lack of the terminal 15° of knee extension, one due to a loss of 15° of flexion, one due to an unstable knee, and two due to thigh atrophy of 0.5 inch or more as compared to their opposite limb.

Of the 36 who responded to questionnaires, 5 scored 100-91 points, 14 scored 90-81 points, 7 scored 80-71 points, and 10 scored 70 or fewer points of Noyes subjective functional rating system.[30] Using Andrews' subjective rating system, 3 had excellent, 24 had good, and 9 had poor results.[34]

Post-operatively, 5 arthroscopic examinations have been performed, with two revealing evidence of chondromalacia patella, two showing the graft impinging on the intercondylar notch in full extension, and one revealing a torn meniscus. Two of these patients subsequently had notchplasties performed, thus eliminating their impingement.[22,27] Symptomatic staples were removed in 14 patients. Two patients have had manipulation of their knees under general anesthesia. One subsequently developed a full range of motion, and the other demonstrated a persistent 15° flexion contracture when last examined. This patient, however, had returned to his job in Saudi Arabia immediately post-operatively and had not sought physical therapy until six months post-operatively.

Six patients had poor objective results. One patient obviously had ruptured his graft at examination 84 months post-operatively. Upon questioning, he related that he had had a very stable knee allowing him to confidently participate in sports at his pre-injury levels until the summer prior to this study when, while swinging for the bleachers during a baseball game, he heard a pop in his knee. He had had an effusion within hours, and had had an unstable knee since that time. This patient had been operated on early during this series, prior to the inclusion of a notchplasty. Perhaps if he had had one performed, he may not have ruptured his graft. This patient is currently considering another reconstructive procedure to stabilize his knee.

One patient had lost terminal extension of the knee of greater than 15°, however, he was very happy with his knee as it had allowed him to play quarterback at a major university. He scored a good rating on the Andrews' scale and 89 points on the Noyes' scale. This patient also complained of a "clunking" sensation in his knee at full extension. He also had not had a notchplasty, and clunking was thought to be due to graft impingement.

One patient with a poor result had a loss of full extension. He had not sought any physical therapy for the first six months post-operatively, instead refusing therapy to return to his job in Saudi Arabia.

One patient with a poor result, had a loss of 2 cm. of thigh girth and a positive drawer at both 20° and 90° of flexion. This patient had previously had a medial collateral ligament repair and an intra-articular repair and augmentation, an open medial mensicectomy, and a pes anserinus transfer.

Two patients were objective failures simply because of diminished thigh girth, measuring at least 0.5 inch less

than the opposite side. However, one felt that his knee worked well. We feel that minimal thigh atrophy does not preclude a good functional result though knees with this finding must be classified as objective failures under the criteria we chose to rate our objective results.[34] It must be noted however, that the rating system of Snydor and Andrews is based on an extra-articular procedure in which the extensor mechanism is left undisturbed.

There were nine subjective failures, using Snydor and Andrews' subjective scale.[34] Three simply had never attempted to use their operated knee enough to reach pre-injury levels, out of fear of re-injury. Return to pre-injury levels figured heavily in both subjective scales used in this study. Four patients had poor subjective results due to swelling or giving way, though their knees appeared stable on examination.

Using Noyes' subjective scale 5 scored 100-91 points, 14 scored 90-81 points, 7 scored 80-71 points, and 10 scored 70 or fewer points.

All of the patients questioned felt that their knees functioned better postoperatively with the exception of the patient who had ruptured his graft. He felt that he had had six years of full athletic ability from his knee following his one year rehabilitation, before he had re-injured himself.

COMPLICATIONS

Complications included 1 case of superficial phlebitis, 1 infected hematoma, 1 area of wound dehiscence, 1 patient with an allergic reaction to Benzoin used for the Steri-strips, 1 with an allergic reaction to the cast brace material, and 6 patients with a clunking sensation in terminal extension, one of whom eventually ruptured his autograft. One other complication occurred, but was actually related to the meniscal repair performed. This was a pressure sore under bolster over which the suture for meniscal repair were tied. Since we have gone to burying the sutures for meniscal repair under the skin, this problem has been eliminated.

DISCUSSION

The rationale for augmentation of the acutely injured ACL or reconstruction of the chronically deficient ACL knee is to improve functional stability of the knee. Clinical studies of ACL primary repair alone have been conflicting, therefore we recommend repair and augmentation in all acute ACL ruptures that will be treated surgically, in order to return normal knee biomechanics to the injured joint and prevent meniscal tears of degenerative changes that occur secondary to the knee's instability.[13,14,15,20,25,26] This procedure appears to have given these knees greater stability, as 23 of 27 knees examined in this study showed negative drawer signs at 20° and 90° of knee flexion and had negative pivot shift tests. All of 23 of these knees also have a complete functional range of motion. Thus, 85° of our patients had a stable knee with a functional range of motion post-operatively.

Sixty of 61 menisci retained after this procedure have gone without further surgery, only one requiring arthroscopic partial meniscectomy at a later date. Of thirteen menisci which were repaired at this surgery, none are known to have been retorn. We feel that by stabilizing the knee, we have contributed to maintaining the menisci of these knees intact.

The autograft was chosen over other potential grafts for several reasons: it is stronger than other available tissues, it allows bone to bone healing, and its extension into the quadriceps aponeurosis usually allows a long enough graft to be obtained to provide a lateral tenodesis without disturbing other structures around the knee. The autograft chosen has been reported to be 174% as strong as the ACL, while semitendinosus, gracilis, distal iliotibial band, and pre-patellar retinaculum are 75%, 44%, 36%, and 20% as strong as the normal ACL, respectively.[28] The bone to bone healing allows for a stronger fixation than does tendon to bone healing.[5,16,28,29] The bone-patellar tendon-bone autograft also allows for earlier re-vascularization, which is almost complete by 8 weeks postoperatively. This is due to the overwhelming contribution to the graft revascularization by endosteal ves-

sels.[1,2,8] In other vascularization studies by Arnoczky et. al., no osseous tunnels were created, thus eliminating the possibility of endosteal vessels contributing to the graft re-vascularization. In their studies, it took 16 to 20 weeks for the graft to revascularize.[3]

The lateral tenodesis was felt to be important for providing additional stability to the knee. Computer studies have shown that it increases resistance to internal rotation, especially as flexion increases, thus reducing the possibility of pivot shifting occurring.[18] It may also serve to protect the intra-articular graft, allowing it to reach its full strength, while it appears that an extra-articular tenodesis may allow full activity within 6 or 7 months.[34]

Potential problems with this choice of an autograft are post-operative patellar tendon rupture and increased patellofemoral joint forces, which possibly contributed to the postoperative complaints of patellalgia.[7] Lateral retinacular release was added during the evolution of the procedure, due to the author's feelings that the post-operative patellofemoral crepitus he noted in many of his patients may have been due to increased patellofemoral forces. However, of those responding to the questionnaires, 11 had been treated without a lateral retinacular release and 25 with one. Of those who did not have one performed, 5 (45%) had never had a complaint of sub-patellar pain at some time during their rehabilitation period, while 6 (55%) had. Of those who had had a release performed, 10 (40%) had no patellar complaints and 15 (60%) had complained of sub-patellar pain at some time during their rehabilitation.

The lateral retinacular release had not solved the problem of post-operative patellofemoral pain. The procedure had been further modified by deleting closure of the extensor mechanism defect caused by the autograft harvest. This appears to have decreased the incidence of sub-patellar pain.

Another recent change in the surgical procedure aimed at decreasing the incidence of post-operative patellofemoral pain has been limiting the proximal extent of the medial arthrotomy to the level of the lower one-third of the patella. This allows excellent visualization of the intra-articular contents of the knee, without undue disruption of the extensor mechanism. The senior author has performed intra-articular ACL reconstructions arthroscopically, but has now returned to this limited medial arthrotomy, as he feels it allows better visualization for the notchplasty, the isometric placement of the femoral tunnel, and the final tensioning of the autograft.

We feel a notchplasty is necessary for all intra-articular reconstructions, as intercondylar eminence impingement may have led to ACL rupture in the first place. There has been some evidence that the intercondylar eminence in some patients is very narrow, predisposing them to ACL rupture. One surgeon has suggested the future possibility of prophylactic notchplasty in these patients.[19]

Another recent modification of the procedure appears to offer the promise of a more reliable satisfactory subjective result. We had recently been leaving the anterior defect caused by autograft harvest unclosed. Patients are reporting post-operative patellar pain less frequently now.

A comparison of the results of the patients who had had acute ACL disruptions to those that had had chronic lesions revealed that of the knees with acute tears, all had good or excellent results on the Andrews' subjective rating scale.[34] All scored 76 or more points on the Noyes' subjective rating scale.[30] Objectively, of four knees with acute lesions examined in this study, 3 had good results and one had an excellent result.[32] Of those patients who had had a reconstruction for a chronically ACL deficient knee, 2 had an excellent result, 19 had good results, and 9 had poor results on Andrews' scale, while 3 scored greater than 90 points, 10 scored 81-90 points, 7 scored 71-80 points, and 10 scored less than 71 points on Noyes' subjective scales.[30,34] Of the 23 chronically ACL deficient reconstructed knees examined in this study, 5 had excellent, 13 had good,

and 5 had poor objective results.[32] Though it appears that early primary repair and augmentation of acute ACL tears offers the possibility of a better prognosis than does reconstruction of a chronically ACL deficient knee, the small number of acute lesions studied here cannot allow us to make a definitive statement to that effect. Whether it is the primary repair with augmentation that is an intrinsically superior procedure to the reconstruction, or whether the apparently superior results in the acutely treated knees were due to a lesser amount of associated pathology, has not been determined.

However, the 7 acute lesions reviewed here had only 3 associated TCL ruptures, 1 medial meniscal tear requiring meniscectomy, 2 lateral meniscal tears requiring partial meniscectomies, and 2 medial meniscal tears requiring repairs. The 27 knees with chronic lesions reviewed here had required 24 meniscectomies, 5 meniscal repairs, 2 prior failed intra-articular repairs, and 2 TCL repairs. All repaired menisci in these knees have remained intact to date. This contasts sharply to the senior author's experience in repairing meniscal tears in ACL deficient knees where the instability is not surgically addressed. He had experienced an unacceptable rate of recurrent tears in knees in which the ACL was not reconstructed. We therefore strongly suggest that any meniscal repair in an ACL deficient knee be accompanied by a procedure to restore stability to the knee. The preceding data also shows that in this study, less than 50% of the acutely repaired and augmented knees had suffered the loss of a meniscus. This may be a factor in the apparently superior results seen in treating the knees with acute tears.

In looking at the results of the KT-1000 arthrometer testing, we found that 20 of the 21 patients reviewed here who had good or excellent results, had differences in anterior tibial excursion on the femur between their two knees of 3 mm. or less. One patient with a good objective result, had a KT-arthrometer reading of 4 mm. for his operated knee, as compared to his normal knee. However, we found that 5 of our knees with poor objective results also had differences of 3 mm. or less, as compared to their non-operated knees, while one poor result had a 6 mm. difference at 15 and 20 pounds and at maximal displacement force. Therefore, in this study we cannot say that the KT-1000 arthrometer results necessarily correlate with the objective results.

COMPARISON OF SUBJECTIVE RATING SCALES

We compared the two subjective rating scales to each other.[30,34] Twenty-one of 36 patients scored equivalent scores if the scores of 100-91 on Noyes' scale is scored considered an excellent result, if a score of 90-81 is considered a good result and if 80-71 points are considered fair. Of the fifteen times equivalent scores are not recorded, 8 times the Andrews' scale rated the patient's results higher than the Noyes' scale did: 7 times the converse occurred. In all cases but one, the subjective scores only varied by one classification, i.e. one scale rated the result excellent, one scale rated the result good. However, one patient scored an excellent result on the Andrews' scale and a poor result on the Noyes scale. We feel that the Noyes' scale allows clearer identification of where an individual patient is having specific problems.

CONCLUSION

We feel that this procedure in its present state of evolution, can offer a patient with a ACL deficient knee at least an 85% chance of a stable knee, with a full, functional range of motion. Attention must be paid to the details of the operative procedure, especially in placing isometric tunnels, in performing an adequate notchplasty, in leaving the donor site in the extensor mechanism unclosed, in using early post-operative motion, and especially in allowing a sufficient period of protected rehabilitation before a return to full competitive activities. We feel that if all of the details are looked after, future patients who have this procedure performed should have even higher rates of satisfactory results.

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Init.	Age	Objective Result	Acute vs. Chronic	Subjective Noyes	Results: Andrews	Mechanism of Injury	Previous Surgery	Concomitant Surgery	Follow-up	Subsequent Surgery	KT-Arthrometer Results
J.M.	17	Excellent	Acute	Exc. (100)	Exc.	Rugby	None	Lateral Meniscectomy	87 Mo.	Manipulation Under	1 mm. difference at 15, 7, 20 and max. force
D.S.	21	Excellent	Chronic	Fair (79)	Good	Football	Arthrotomy	None	86 Mo.	None	1 mm. difference at 15, 20 and max. force
B.J.	23	Good	Acute	Exc. (94)	Good	Torsional Weight-Bearing	None	Lateral Meniscectomy	85 Mo.	None	0 mm. difference at all force levels
G.B.	18	Poor-Ruptured Graft	Chronic	Poor (63)	Poor	Basketball	Medial Meniscectomy ACL Stump Debridement	Reconstruction Posterior Oblique Lig. Pes Transfer	84 Mo.	None, Currently Considering Goretex Prosthesis	6 mm. difference at all force levels
P.B.	18	N.A.	Acute	Good (83)	Good	M.V.A.	Arthroscopy	T.L.C. Repair	84 Mo.	None	N.A.
D.G.	18	Good	Acute	Good (82)	Good	Football	None	Medial Meniscectomy	84 Mo.	None	1 mm. difference at all force levels
C.C.	18	Excellent	Chronic	Exc. (94)	Good	Football With ACL Debridement	Arthroscopy	None	83 Mo.	Staple Removal	1 mm. difference at all force levels
D.S.B.	18	N.A.	Acute	Good (84)	Good	Skiing	None	None	82 Mo.	None	N.A.
W.B.	24	Good	Chronic	Good (81)	Good	Basketball	None	Medial Meniscectomy, Pes Transfer Reconstruc-tion Posteromedial Capsule	82 Mo.	Staple Removal	1 mm. all force levels
M.H.	18	N.A.	Chronic	Good (85)	Good	Football	None	Lateral Meniscectomy	80 Mo.	None	N.A.
G.P.	18	Excellent	Chronic	Exc. (91)	Good	Baseball	Arthroscopy	None	67 Mo.	None	0 mm. difference at all force levels

Init.	Age	Objective Result	Acute vs. Chronic	Subjective Noyes	Results: Andrews	Mechanism of Injury	Previous Surgery	Concomitant Surgery	Follow-up	Subsequent Surgery	KT-Arthrometer Results
M.A.Y	17	N.A	Chronic	Poor (55)	Good	Torsional Weight-Bearing	Arthroscopy	Reconstruction Posterior Oblique Ligament, Pes Transfer, Medial Meniscectomy, Lateral Meniscectomy	67 Mo.	Diagnostic Arthroscopy; Staple Removal	N.A.
N.S.	16	Good	Chronic	Good (85)	Good	Gymnastics	None	Lateral Meniscal Repair	66 Mo.	None	1 mm. difference at all force levels
D.C.	22	Poor — Loss of 15° Fexion	Chronic	Good (89)	Good	Snow Sledding	None	None	83 Mo.	Notchplasty; Staple Removal	1 mm. difference at 15, 2 mm., at 20, and 3 mm. at max. force
A.P.	18	Good	Acute	Good (86)	Good	Football	None	TLC Repair, Pes Transfer, Lateral Release, Medial Meniscal Repair	65 Mo.	None	3 mm. difference at all force levels
J.M.	20	Poor — Loss 0.5 Inch Thigh Girth	Chronic	Good (81)	Good	Basketball	None	None	60 Mo.	Staple Removal	1 mm. difference at all force levels
A.H.	17	Good	Chronic	Good (83)	Good	Basketball	Medial Meniscectomy Pes Transfer	Reconstruction Posterior Oblique Ligament	67 Mo.	Staple Removal	N.A.
L.F.S.	24	Good	Chronic	Poor (69)	Poor	Gymnastics	Arthroscopy Open Medial Meniscectomy	Lateral Release	54 Mo.	Medial Retinaculoplasty; Staple Removal	1 mm. difference at all force levels
R.N.	19	N.A.	Chronic	Fair (78)	Poor	Basketball	Arthroscopy Twice	Lateral Release	52 Mo.	None	N.A.

Init.	Age	Objective Result	Acute vs. Chronic	Subjective Noyes	Results: Andrews	Mechanism of Injury	Previous Surgery	Concomitant Surgery	Follow-up	Subsequent Surgery	KT-Arthrometer Results
L.P.	19	N.A	Chronic	Fair (78)	Good	Hurdling	Medial Meniscectomy	Lateral Release	50 Mo.	None	N.A.
S.C.	15	Poor — 0.5 inch loss of thigh girth	Chronic	Poor (55)	Poor	Hockey Check	None	Lateral Meniscal Repair, Lateral Release	47 Mo.	Staple Removal	2 mm. difference at 15 and 20, and 0 mm. difference at maximal force
S.S.	28	Poor — Loss 15° Extension	Chronic	Fair (71)	Poor	Baseball	Medial Meniscectomy	Lateral Meniscectomy, Lateral Rel.	47 Mo.	Manipulation Under General Anesthesia	1 mm. difference at all force levels
A.M.	20	Good	Chronic	Poor (67)	Good	Gymnastics	Arthroscopy	Medial and Lateral Meniscal Repairs, Lateral Rel.	42 Mo.	None	0 mm. difference at all force levels
E.S.	19	Good	Chronic	Good (82)	Good	Valgus Stress	Arthrotomy	Lat. Meniscectomy; Lat. Release Notchplasty	38 Mo.	Staple Removal, Partial Medial Meniscectomy	2 mm. difference at all force levels
C.M.	30	Excellent	Chronic (10 years)	Poor (62)	Poor	Skiing	Medial Meniscectomy TCL Repair	Lateral Release; Notchplasty	37 Mo.	None	1 mm. difference at all force levels
B.T.	27	Poor — Loss 20° Flexion	Chronic	Fair (75)	Poor	Unknown	Open Medial Meniscectomy	Lateral Release	30 Mo.	None	2 mm. difference at all force levels
C.A.	22	N.A.	Chronic	Poor (48)	Poor	Unknown	Intra-articular Reconstruction; Medial and Lateral Meniscectomies	Lateral Release	30 Mo.	None	N.A.

Init.	Age	Objective Result	Acute vs. Chronic	Subjective Noyes	Results: Andrews	Mechanism of Injury	Previous Surgery	Concomitant Surgery	Follow-up	Subsequent Surgery	KT-Arthrometer Results
K.M.	20	Good	Chronic	Good (82)	Good	Basketball	Arthrogram	Lateral Release; Medial and Lateral Meniscectomy, Pes Transfer, Notchplasty	41 Mo.	None	2 mm. difference at all force levels
D.G.	21	Good	Chronic	Poor (68)	Good	Football	ACL Repair, Med. and Lat. Meniscecto-mies, Scope With ACL Debridement	Lateral Release Notchplasty	41 Mo.	None	0 mm. difference at all force levels
J.D.	19	Good	Chronic	Poor (63)	Poor	Football	TCL and ACL Repairs, Med. Meniscectomy, Second TCL Repair, Staple Removal	Lateral Release, Medial Menis-cectomy, Notchplasty	41 Mo.	None	2 mm. difference at all force levels
H.R.	21	N.A.	Acute	Fair (76)	Good	Work	None	TCL Repair, Lateral Release, Medi-al Meniscal Repairs	30 Mo.	Notchplasty	N.A.
N.C.	20	N.A.	Chronic	Good (82)	Exc.	LaCrosse	Medial Meniscectomy	Lateral Release	30 Mo.	Staple Removal	N.A.
A.P.	25	Excellent	Chronic	Poor (62)	Exc.	Work	Arthroscopy	Partial Lat. Meniscectomy; Lateral Release	27 Mo.	None	3 mm. difference at 15, and 4 mm. difference at 20 & maximal force
A.E.	21	Good	Chronic	Exc. (92)	Good	Baseball	Lat. and Medial Parital Meniscec-tomies	Lateral Release	26 Mo.	Staple Removal	N.A.

Init.	Age	Objective Result	Acute vs. Chronic	Subjective Noyes	Results: Andrews	Mechanism of Injury	Previous Surgery	Concomitant Surgery	Follow-up	Subsequent Surgery	KT-Arthrometer Results
M.G.	25	Good	Chronic	Fair (72)	Good	Unknown	Arthroscopy	Medial Meniscal Repair; Medial and Lateral Retinacular Release, Notchplasty	24 Mo.	None	1 mm. difference at all force levels
A.H.	20	Good	Chronic	Good (87)	Good	Racquetball	Arthroscopy	Lateral Release; Medial Meniscectomy; Notchplasty	26 Mo.	None	3 mm. difference at all force levels

The Effect of Lead Intoxication On Bone Fracture Healing Utilizing Tetracycline Labeling

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ABSTRACT: This study reports the changes observed in callus formation and overall bone healing of fractures created in eight-week-old puppies exposed to lead. The puppies were fed 5 mg of lead acetate a day for thirty days before and after the fracture of their left radii. Six puppies, two control and four experimental, were used in the protocol. Tetracycline was given to each at the initiation of the study, at fracture time and at the termination of the study, to facilitate appreciation of qualitative changes in the fracture callus. In the leaded dogs, healing was delayed as were the osseous appositional rates. This study is clinically relevant, as many of the pediatric population, particularly inner city, are often exposed to low or moderate amounts of environmental lead.

INTRODUCTION

The problem of lead intoxication in the pediatric population, particularly in the inner city, continues to be prevalent. Data from the National Center for Health Statistics indicates that in 1980, 4% of childen between 6 months and 5 years of age had elevated blood lead levels of 30 micrograms per deciliter of whole blood or more. It has been shown by various authors that bone growth and development are inhibited by lead.[9,14,20] Little discussion is made in the North American literature, however about the effect of lead on fracture healing. To date, no quantitative histologic data is available concerning fracture healing in the pediatric population with lead intoxication.

Ingestion of leaded paint chips from the walls of homes built prior to 1940 brought attention to the problem of lead intoxication.[2] Since that time, inhaled airborne lead, especially near heavily traveled roadways;[22] lead leeching into infant formula from the solder in can seams;[12] industrial contamination; lead leeching into fluids contained in earthenware containers glazed with leaded glazes;[11] all have been cited as sources of lead intoxication.

Lead is eaten or inhaled and subsequently bound to red blood cells at the intestine or lung. It then develops a dynamic flux with the bone and soft tissue areas of the body. In children, seventy percent of lead which is not excreted in the urine or feces is stored in bone.[18] Hass[9] and Anderson[1] have shown that lead has inhibitory effects on bone growth and development. Chondroclastic activity,[4] along with that of osteoblastic and osteoclastic function, is retarded.

Dragatoiu and Borundel[3] found in a retrospective study from Bucharest, Rumania, that workmen exposed to lead developed a delay in the time needed for consolidation of their fractures. They found an absence of endosteal callus and diffuse decalcification in the fracture focus. Furthermore, they carried out a study utilizing lead intoxicated rabbits. They demonstrated a delay in fracture healing with lead intoxication and a reversal in that delay once EDTA was administered.

Anderson et al,[1] found that appositional rates were slowed in their study of bone remodeling rates in mature dogs without fracture exposed to lead. They strongly state they are unsure how their results from the mature dogs relate to the skeletally immature child with different bone formation dynamics.

This study was designed to demonstrate histology quantitative and qualitative changes in fracture healing

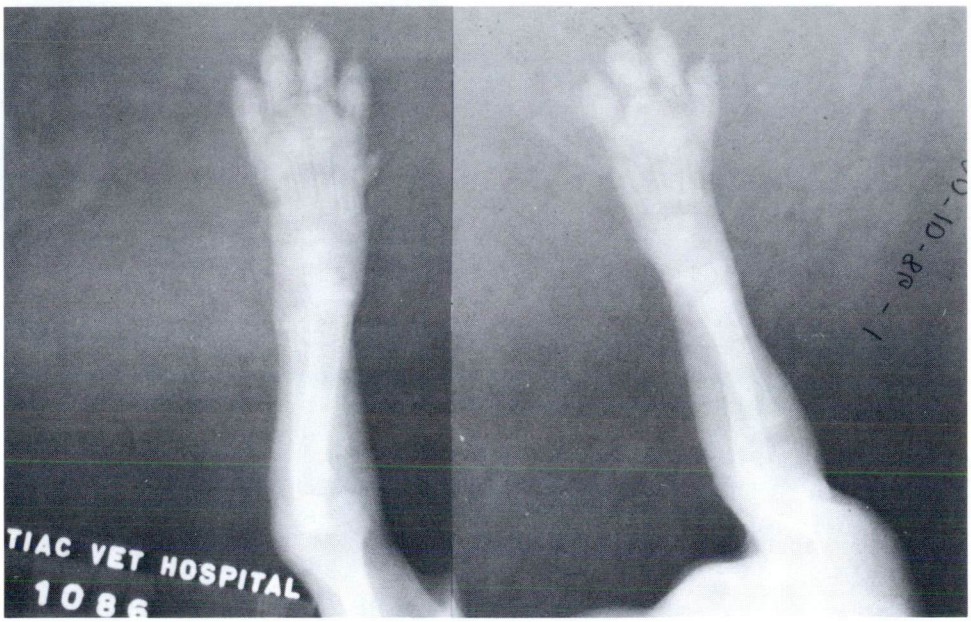


Figure 1: Radii of dog #1 on the right and dog #4 on the left at the outset of the study. The puppies were approximately eight weeks of age at this point.

of dogs with immature skeletons exposed to lead. Tetracycline was administered to label the bone at various points of the study for markers.

MATERIALS AND METHODS

Six clinically healthy eight-week-old littermate puppies were utilized. Dogs 4-7 were fed lead acetate in a 5% dextrose solution, 5 mg/kg daily. The solution was delivered orally with a large bore angiocath just posterior to the tonsillar pillars, throughout the entire sixty-day study. Dogs 1-2 were utilized as controls and fed only their normal food allotment. Radiographs were taken of the left front forelimb of all six dogs at the initiation of the study.

Tetracycline 25 mg/kg was given intra-peritoneally on day three and day four. On day thirty, Xylenol Orange was administered intravenously in the amount of 90 mg/kg. The solution utilized was 3% Xylenol Orange (X-15 Fisher Scientific) containing 2% sodium bicarbonate in saline.

On day thirty-two, under sterile conditions, following anesthetization with 5 mg ace promazine maleate and titrated thiamylal sodium, the left radius was fractured in the midshaft area. Under direct visualization, the bone was sectioned transversely with an osteotome. The wounds were thoroughly irrigated, repaired, dressed and the limbs splinted. Penicillin 250 mg was administered orally to each, times two doses. Postoperative radiographs were taken on each. The dogs shed the splints on their own approximately three days after the procedure and all wounds healed uneventfully.

Intravenous oxytetracycline was given on day fifty-seven and day fifty-eight in the amount of 20 mg/kg. Serum lead levels were also taken on day fifty-seven. On day sixty, all dogs were sacrificed using sodium pentobarbitol intravenously and the left forelimbs were re-radiographed.

The specimens were fixed in 70% ethanol. They were then submerged with Villanueva bone stain[21] for seventy-two hours. They were dehydrated and infiltrated with various concentrations of ethanol and acetone and then imbedded in polymethylmethacrylate.[19] The specimen blocks were then trimmed and sectioned. 20 um, 10 um and 6.5 um sections were obtained. Four dry mounts utilizing Haupts Gelatin Adhesive were made.[16] Another four slides for each of the six specimens were also created, utilizing a wet mount procedure. One wet mount slide from each specimen was stained with Gallocyanin-Chrome

Alum Stock Solution.[21] A second wet mount slide was stained with Toluidine blue.

The dry mount slides were than examined for tetracycline marking by fluorescent microscopy using a blue 360 mm wavelength light. The distance between the tetracycline labels were then measured in microns in multiple locations of the bone away from the fracture callus itself.[6] Appositional rate was then calculated in microns per day.

The wet mount slides from each of the dogs, specifically those stained with Gallocyanin, were examined for identification of osteoid seams, boney matrix, osteoid cells and callus formation. Quantitative measurements of bone, marrow and callus were then made utilizing grid morphometry as defined and described by Parfitt.[13] Here, callus is defined as cartilaginous fibrous non-bone, non-marrow healing tissue. The area measured was plotted out 2 mm from the fracture, both distally and proximally, along the entire fracture line on each specimen; dogs 1, 2, 4, 5 and 6. Percent volume of bone and callus were than calculated.

DISCUSSION

There are three basic phases of bone fracture healing. The inflammatory phase, the reparative phase and the remodeling phase.[17] The inflammatory phase involves the formation of a hematoma around the fracture site and subsequent tissue inflammatory response to necrotic debris in the area. The reparative phase involves organization of the hematoma and gradual maturation of the fracture callus, which is comprised of cartilage, fibrous tissue and, later on, immature fiber bone. During the remodeling phase, the body transforms immature bone into mature bone.

The results of this study, using immature skeletal systems, demonstrate a delay in fracture healing time in the lead intoxicated dogs as compared to the control dogs. The increased percent volume of callus versus mature bone in the lead intoxicated bone bears this out when compared to the controls. The control bone fracture sites, at the time

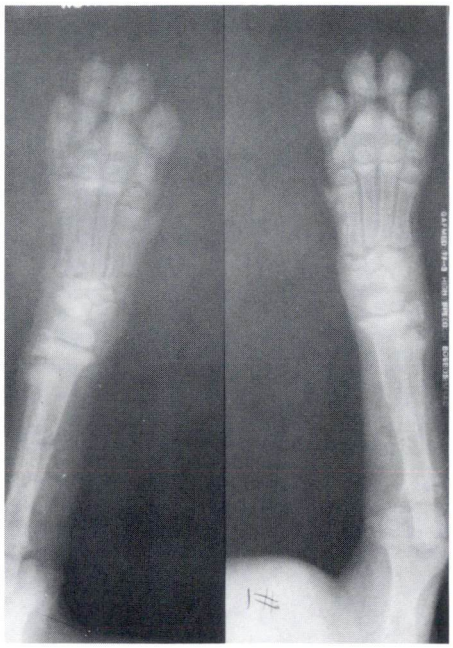
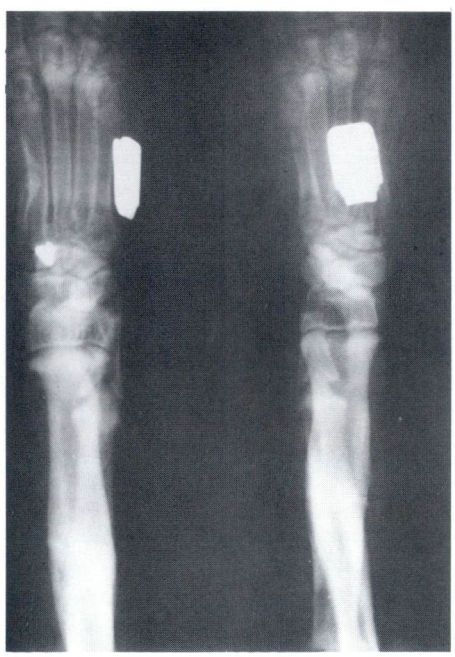


Figure 2: Radii of dog #1 on the right and dog #4 on the left following fracture. This is day thirty of the study. The puppies are approximately twelve weeks of age.

Figure 3: Radii of dog #1 on the right and dog #4 on the left at sacrifice; day sixty of the study. The puppies are approximately fifteen weeks of age.



RESULTS

There were no physical or behavioral differences detected between control and experimental dogs during the study.

1. ***Serum Lead Levels**

DOG NUMBER	LEAD LEVEL (mcg/dl)
1	0
2	0
4	29
5	16
6	17
7	27

*Taken on Day 57 of the Study

2. ****Radiology**

Radiographs of control dog #1 and leaded dog #4 are compared at three different time intervals. The first (fig. #1) demonstrates the left radii at the beginning of the study, (fig. #2) is status-post fracture; and (fig. #3) is a comparison of the left radii after one month of healing. Exuberant callus is noted in both fractures in figure #3. Questionably brighter growth plates are noted in dog #4, possibly exhibiting the beginning of "lead lines".

**See Figures #1 - #3

3. **HISTOLOGY**

a) **Appositional Rate of Bone** (see Figure #4) The appositional rates are presented in graph form with the rates in microns per twenty-four hours. The lines demonstrate one standard deviation of error. Figure #5 is a demonstration of the tetracycline labeling at 320X under fluorescent microscopy.

b) **Percent Volume of Callus, Marrow and Bone** (see Figure #6 and #7) The results are presented in bar graph form. Note that figure #6 compares percent volume of callus only between dogs 1, 2, 4, 5 and 6 and that figure #7 compares all three. Figure #8 is a light scanning micrograph at 80X of the fracture site of dog #1 and figure #9 is that of dog #4. Note the increased cartilage at the fracture of dog #4.

of sacrifice, are in the remodeling phase, while the lead intoxicated fracture sites are still in the reparative phase of healing. Furthermore, the boney appositional rate, or the rate at which mature bone is laid down, is inhibited in the lead fed canines.

Dragatoiu et a,[3] in the only other study of fracture healing in lead intoxication, felt that their data indicated that lead might inhibit revascularization at the fracture site and consequently inhibit healing. Cartilage is formed, as opposed to fibrous bone, in a rapidly developing normal callus when the blood supply is outstripped.[8] Again, increased percent volume of cartilage was noted at the fracture site of the leaded dogs. We may explain the increased volume of cartilage by the inhibition of revascularization by the lead. Furthermore, osteoclasts, which play a critical role in fracture healing, arrive via the blood supply derived from circulating monocytes.[7]

We chose the canine animal model as it closely simulates human bone in terms of remodeling. Frost stated that rodents, notably rabbits as were used in the study of Dragatoiu et al, may not provide valid models of the physiology, pharmacology or pathology of human remodeling.[5] In this light, the results of our study of canine bone growth and fracture healing are more meaningful to the human pediatric population.

Higher serum lead levels might have created greater changes in the appositional rates and percent volume of callus. This was specifically avoided and the recommended dosage was administered[15] for two reasons. First, moder-

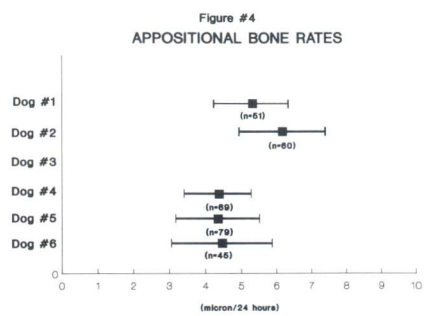


Figure 4: Graph comparing the appositional rates of bone growth amongst all dogs in the study. Dog #7 not included secondary to inappropriate havesting of fracture. "n" is equal to the number of measurements taken from each sample. One standard deviation of error is denoted above and below the average rate for each.

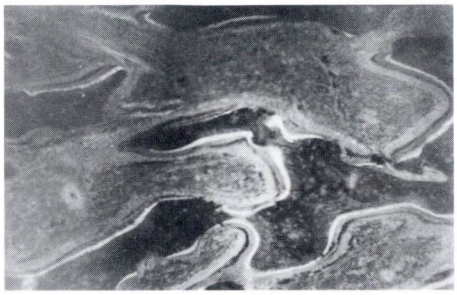


Figure 5: Fluorescent microscopic picture of the tetracycline labeled bone of dog #4 at 320X. Note the double line markers.

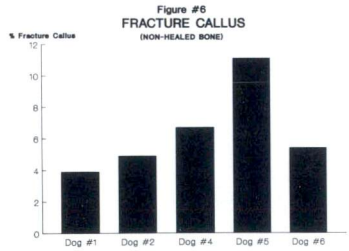


Figure: 6 Percent fracture callus is compared in bar graph form from all five dogs at the completion of the study.

ate to severe lead intoxication might have systemic effects on the animals which might alter their healing rate and introduce a confounding variable. Second, overt lead poisoning in the pediatric population is more clinically obvious; whereas low chronic levels might go unnoticed and, therefore, go untreated.

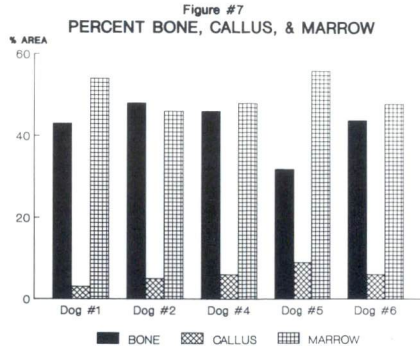


Figure 7: Percent volume of mature bone, callus and marrow is compared in bar graph from all five dogs at the completion of the study.

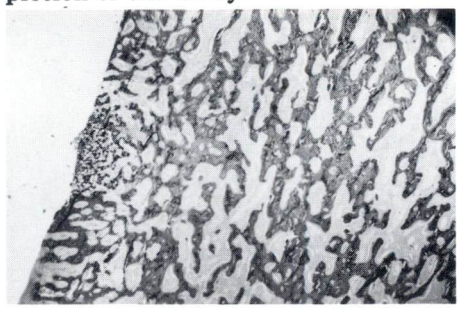


Figure 8: Light scanning micrograph at 80X of the fracture site from dog #1 at the completion of the study.

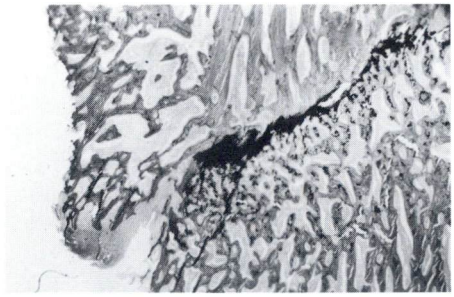


Figure 9: Light scanning micrograph at 80X of the fracture site from dog #4 at the completion of the study.

Further study of the appositional rate of bone and bone formation rate was impaired by the remarkable speed of remodeling in the puppies. The first two tetracycline labels were lost due to remodeling and only irregular patches left behind. The third label was given twice with a twenty-four hour gap in between administration of doses. Measurements were subsequently made at this point.

If a large follow-up study is considered, the time interval between the

tetracycline label administration should be shortened. The remarkable remodeling rate of the immature canine skeleton and subsequent loss of the tetracycline label makes this necessary. In the same light, the allowance of thirty days for healing of the fractures is excessive prior to sacrifice. A subset of puppies, given a larger lead load, could also be considered. This might help magnify the changes induced in the fracture callus by the lead and thereby elucidate the mechanism which shows the fracture healing process.

In conclusion, this study for the first time demonstrates a definite trend that exposure to lead both impairs bone apposition rate and overall fracture healing in the immature skeleton.

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Clinical Evaluation of Decompressive Surgery for Lumbar Spinal Stenosis

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†Brian Van Grouw

INTRODUCTION

Spinal stenosis is a syndrome associated with narrowing of the spinal canal, nerve root canal or the lateral recess by soft tissue or osseous structures resulting in compression of the neural elements.[7] The Anteroposterior diameter (sagittal) of a normal spinal canal is 12 to 22 mm and that of a normal nerve root canal is 5 mm.[29,41,82] In lumbar spinal stenosis, the sagittal diameter of the spinal canal is less than 12 mm and diameter of the nerve root canal is less than 3 mm.[82,94]

Lumbar spinal stenosis is classified using both anatomic and pathologic systems. The anatomic system describes four local areas which are sites for neural compression: central, lateral recess, foramenal, and far-out.

Central refers to a decrease in the dimensions of the spinal canal. Anteroposterior diameters of the spinal canal of less than 12mm or a cross sectional area of less than 100 sqmm are consistent with a diagnosis of spinal stenosis.[10,12,15,81] The normal area of the dural sac is 180 +/- 50 sqmm.[15] The spinal canal is bordered anteriorly by the posterior aspect of the vertebral body or intervertebral disk and posteriorly by the laminae and base of the spinous process.

Lateral recess is an area bordered anteriorly by the posterolateral vertebral body and disc, posteriorly by the superior articular facet and laterally by the pedicle.[35,73] The dimensions of the lateral recess are normally greater than 5mm, though in cases of stenosis, it is typically less than 3mm.[5,20,44,59,89]

Foramenal refers to the neural foramen whose superior and inferior borders are the inferior and superior pedicles. Anteriorly the vertebral body and disc, while posteriorly the pars interarticularis and inferior and superior facets border the foramenal space. Narrowing on CT imaging of the foramenal space is suggested if two or less cuts enter this region.

Far-out designation was suggested by Wiltse.[105] The nerve root is compressed beyond the intervertebral foramen, Although compression of the L5 nerve root is most commonly affected, any nerve root may be involved.[106]

The pathologic classification system is based upon the underlying disease process.[14,25,49,63,97,106] Spinal stenosis is classified into congenital or acquired categories. The causes of spinal stenosis and its pathologic classification system are listed in **table-I.** This adaptation was acquired from Dorart[25] who built upon the framework created by Arnoldi.[7] The most common etiology being degenerative spinal stenosis, which is usually due to osteophyte formation, disk bulging, facet joint hypertrophy or ligamentous thickening.[73]

The first documented decompressive surgery for neurogenic claudication was preformed in 1900 with good results. Many authors have since recommended the practice of extensive decompressive surgery for treatment of lumbar spinal stenosis.[42,79,104] In general, decompressive laminectomy has had good results in 75-85% of cases.[10,14,35,88] The degree of surgical decompression is variable and may include extensive laminectomy, facetectomy, foramenotomy and discectomy. Multilevel laminectomy is usually required. In the series of 68 patients with lumbar spinal stenosis reported by Hall; 4% had single level, 24% had two

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Table I: Pathologic Classification of Spinal Stenosis

I. Congenital/Developmental Stenosis

- **A. Idiopathic**
- **B. Achondroplasia (72)**
- **C. Hypochondroplasia (23)**
- **D. Morquio's Mucopolysaccharidosis**
- **E. Dysplasia associated with lax atlantoaxial joints (9,30)**
  1. **Metatrophic dwarfism**
  2. **spondyloepiphyseal dysplasia**
  3. **Kniest's disease**
  4. **Multiple epiphyseal dysplasia**
  5. **Chondrodysplasia punctata**
- **F. Down's syndrome (C-1 instability) (30)**
- **G. Hypophosphatemic Vitamin D-resistant rickets (18)**
- **H. Klippel-Feil syndrome (46)**

II. Acquired Stenosis

A.Degenerative (51)

1. **Spondylosis and arthrosis (31,32,55,63)**
2. **Soft tissue stenosis (24)**
3. **Isolated intervertebral disc resorption (22)**
4. **Degenerative spondylolisthesis (37)**

- **B. Combined — combinations of congenital or developmental stenosis, degenerative stenosis and protrusions of intervertebral disks**
- **C. Spondylosis — with or without the presence of spondylolisthesis (43)**
- **D. Iatrogenic**
  1. **Post-operative changes**
  2. **Post-fusion**
- **E. Metabolic**
  1. **Paget's disease (4,98,99)**
  2. **Epidural lipomatosis (6,17,18,19,60)**
  3. **Acromegaly (28,34)**
  4. **Fluorosis**
  5. **Calcium pyrophosphate dihydrate deposition disease (Pseudogout) (77)**
- **F. Miscellaneous**
  1. **Ankylosing spondylitis (17,23,39,56)**
  2. **Calcification or ossification of the posterior longitudinal ligament (70,102)**
  3. **Diffuse idiopathic skeletal hyperostosis (Forestier's Disease) (2,76,101)**
  4. **Calcification or ossification of the ligamentum flavum (71)**
  5. **Conjoined origin of lumbosacral nerve roots (33)**
  6. **Spinal tumors (64)**
  7. **Infection (46)**

levels, 43% had three levels, 26% had four levels and 3% had five level decompressions.[42]

Excellent results after surgical decompression are unusual. Most clinical reports classify good and satisfactory results as surgical successes.[65,68,84,92] Postoperatively, patient satisfaction is high though low back pain in long term follow-up is not uncommon.[42] Late failure may be due to inadequate decompression at operation, development of further degenerative changes creating bony stenosis at other levels, progressive epidural or intradural scarring, postoperative instability or attempted regeneration of lamina at the decompressed segments.

As previously mentioned, post-operative instability is a possible etiology for the less than excellent results following surgical decompression for lumbar spinal stenosis.[8] Decompression of the posterior elements has a destabilizing effect on the vertebral segment.[37] It has been shown that the biomechanical support in axial loading, shear, translational and rotational resistance afforded by the posterior elements are significant.[1,61,74] Spinal instability can be created by removal of the posterior support. The extensiveness of decompression is directly related to the incidence of postoperative spondylolisthesis.[50] Overall, the incidence of postoperative spondylolisthesis following decompressive surgery for lumbar spinal stenosis is reported as 10-20%.[84,88,92] Hopp and Tsou reviewed 344 cases of decompressive surgeries for lumbar spinal stenosis and noted an incidence of postoperative spondylolisthesis of 4.6% with the majority (56%) occurring at L4-L5 followed by L5-S1 (25%) and L3-L4 (13%).[3,48,57] In their study, all cases of postoperative spondylolisthesis were within the region of decompression. Other studies have noted the relationship between residual symptoms and postoperative spondylolisthesis.[50,57,104]

Preoperative prognostic factors for postoperative spondylolisthesis include age; degenerated discs; degenerative spondylolisthesis; scoliosis; calcified annulus, capsule and ligamentum flavum; presence of traction spurs, stenosis above the level of L5 or extensive decompression requiring complete facetectomy or pars interarticularis excision.[48]

End stage degenerative disease associated with end-stage disc resorption or calcified ligamentous tissue produces stability at the expense of mobility.[54] Postoperative spondylolisthesis occurred more commonly in the younger patients who underwent decompressive surgery due to the lower degree of stabilizing degenerative disc changes.[40,84,91] Tsou noted that postoperative spondylolisthesis did not occur at any level with extensive degenerative changes.[48] Hence older age and associated end-stage degenerative changes are associated with a decreased risk of postoperative spondylolisthesis. Numerous studies have confirmed the association between improved results with decompression sur-

Table II: Differential Characteristics of Vascular Versus Neurogenic Claudication

VASCULAR	NEUROGENIC
Worse with exercise	May be worse with exercise
Worse on stationary bike	May ride bike in comfort
Relieved with rest	May be worse in bed at night
Better standing	Worse with standing — relief with lying supine
Stocking sensory loss	Bizarre sensory deficits
Decreased pulses and bruits	Normal vascular examination
No change with posture	Worse with hyperextension
Impotence	Urine retention or frequency
Elderly	Elderly
No History of back pain	Usually history of back pain

gery for lumbar spinal stenosis and advanced age.[36,40,58,104]

Preoperative degenerative spondylolisthesis has been statistically shown to be associated with increased rates of further slippage (65%) relative to cases of spinal stenosis without degenerative spondylolisthesis (20%).[50] This observation demonstrates the importance for evaluation of the lumbar spine for areas of degenerative spondylolisthesis defined as displacement greater than 2 mm. Other authors have recommended pre-operative flexion-extension views of the lumbar spine to detect latent instability.[48]

Postoperative spondylolisthesis is associated with degenerative disc disease.[50] McNab noted that traction spurs were evidence of damaged or degenerative discs.[65] Another sign of disc degeneration is loss of disc height. In Tsou's study, all patients with postoperative spondylolisthesis showed either of the above two findings of disc degeneration.[48] 87.5% had associated disc space narrowing with 31% associated with traction spurs.

As previously noted, L4 is the most common site of spinal stenosis and the most frequent level of instability. The degree of instability of L4 has been postulated to arise from the ligamentous support given by the iliotransverse ligaments to L5. With stabilization of L5, stresses are transferred to the adjacent mobile segment. Hence levels above the iliotransverse ligament are subjected to additional stress and increased risk of instability.

The extent of decompression is directly related to the incidence of postoperative spondylolisthesis. Since spinal stenosis is a syndrome which involves a multitude of pathologies and a variety of anatomically affected areas, modern diagnostic techniques must be employed to diagnose the pathologic process and its localization. Preoperative evaluation can isolate, in most cases, the site of the neural compression and thereby assist in the planning of the extent of decompression procedure. The simplest procedure involves a single level decompressive hemilaminectomy. Decompression may be unilateral or bilateral. Further dissection involves facetectomy, discectomy and foramenotomy.[16]

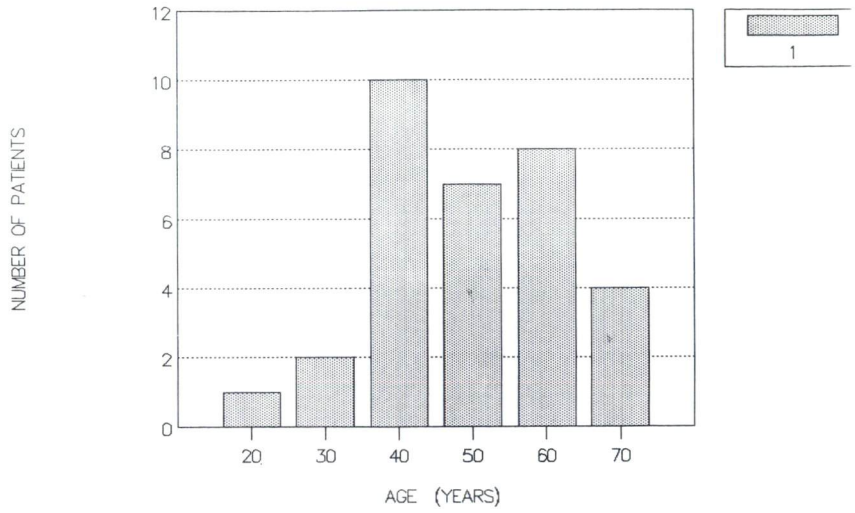
The age of the patient, extent of the decompression, presence of degenerative spondylolisthesis, degree of spondylosis and location of the stenosis are factors that will qualitatively predict the likelihood of postoperative instability. The rule of thumb amongst spinal surgeons is to retain the total of one facet joint at each spinal level in order to retain stability.[16] A bilateral complete facetectomy will produce instability and hence require concurrent fusion. It seems logical that if postoperative instability is predicted from the above mentioned factors then a concurrent fusion should be performed. Studies have supported the improved results associated with concurrent decompression and fusion.[8,48,104] Booth has modified his requirements for fusion to include the excision of more than one facet joint at any spinal level, a patient under the age of 50 years, a patient with a low intercrestal line or a "dynamic spinal stenosis".[16] Dynamic spinal stenosis is present when there exists a complete occlusion upon a myelogram with normalization upon flexion of the lumbar spine. Progressive disk collapse after lumbar decompression in these patients is likely to produce significant spondylolisthesis.

However, most surgeons do not perform fusion with decompression surgery for lumbar spinal stenosis.[10,104] Controversy presently exists in the literature regarding the indications and efficacy of fusion in decompressive surgery for spinal stenosis. The goal of this clinical study is to examine those factors that influence the results of decompressive surgery for lumbar spinal stenosis and establish the basis of further clinical studies. Using these principles, an algorithm for surgical treatment of lumbar spinal stenosis will be suggested.

MATERIALS AND METHODS

Between 1985 and 1988, thirty-two cases of lumbar spinal stenosis treated by decompressive surgery were identified within the tri-divisional hospital system of the University Medical Center — John F. Kennedy Memo-

FIGURE–2: AGE DISTRIBUTION FOR STENOSIS



rial Hospital. Symptomatic spinal stenosis most commonly occurs in men between the ages of 35 and 65 with the majority being greater than 50 years old.[73,107] The mean age at the time of the operation was 54 years (range: 26 - 74) **(Figure 2).** There were 17 females and 15 males. Follow-up periods ranged from 5 months to 45 months and averaged 27 months. Four of the thirty-two cases were lost to follow-up and were excluded from the statistical analysis. Another exclusion criteria was whether the patient's symptoms were predominantly due to disc extrusion.

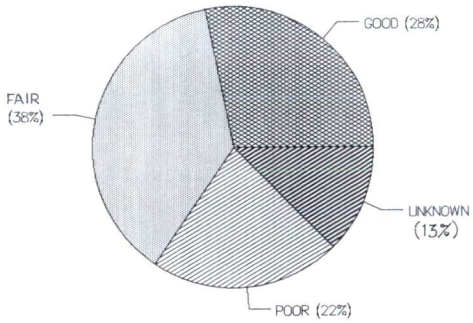
Inclusion criteria was radiographic demonstration of lumbar spinal stenosis. Conventional radiographs, myelography, computerized tomography, and more recently magnetic resonance imaging were used in the diagnosis of the level and location of lumbar spinal stenosis.

Conventional radiographs are initially done to rule out metastatic disease, compression fractures, spondylosis, degenerative disc disease, osteophytosis, spondylolysis, spondylolisthesis or congenital malformations.[5] Lumbar spinal stenosis is suggested by the reduction in the length of the pedicles, decreased interpedicular width, degenerative changes in the apophyseal joints, and narrowing of the disc spaces, and the presence of spondylolysis or spondylolisthesis. Although conventional radiographs are a vital component of the orthopedic examination and do provide much information as stated above, additional radiographic evaluations were usually necessary.

Myelography with computerized tomography is presently the diagnostic method of choice for identifying the extent and location of the lumbar spinal stenosis in the central canal, lateral recess and neural root foramen.[10,52,78] Anteroposterior and transverse diameters of the spinal canal and the shape of the canal are reliable indicators of spinal stenosis.[45,62,69,95,96] Verbiest classified spinal stenosis into two groups based upon the midsagittal diameter of the narrowed portions of the spinal canal. A diameter of 10 mm or less was defined as "absolute" stenosis and between 10 and 12 mm as "relative" stenosis.[81,93] Bolander compared the predictability of computerized tomography verses myelography for surgical findings of lumbar spinal stenosis.[15] Using Verbiest's guidelines, myelography had an 83% predictability while computerized tomography was only 20%. The predictability of computerized tomography improved to 83% when the cross-sectional area of the dural sac was used as the guideline for diagnosis. As men-

tioned previously, central lumbar spinal stenosis is present when the area of the spinal canal is less than 100 sqmm. Most computerized tomography radiologists assess neural element compression subjectively. Stockley used this method of assessment to evaluate prospectively the predictability of computerized tomography verses myelography.[89] Myelography had a predictability of 62% while computerized tomography was 75%. When using the numerical guidelines, metrizamide computerized tomography provides an improved predictability. All of the patients in the study had

FIGURE–1: SURGICAL RESULTS



metrizamide computerized tomographic studies.

Magnetic resonance imaging can be complementary to computerized tomography and replace myelography.[66,67] Modic showed that the predictability of magnetic resonance and computerized tomography used jointly is 96% and the predictability of magnetic resonance alone is 77%.[66] Unfortunately, the literature is sparse of studies that quantitatively support the use of magnetic resonance over metrizamide computerized tomography. However many authors suggest that magnetic resonance imaging is playing an increasing role in the evaluation of lumbar spinal stenosis.[21,41] Five of the patients in the study had magnetic resonance imaging.

Decompressive procedures were planned based upon myelographic and computerized tomographic data. In a few cases electromyographic and magnetic resonance results were utilized. Sixteen cases had disc pathology and required concurrent discectomy with the decompressive surgery. Lateral recess and foramenal stenosis decompression was accomplished by partial or total facetectomy and foramenotomy, respectively. Only one fusion was performed. The results of the surgical treatment were based upon the subjective assessments of the patients and were divided into good (complete relief to mild symptoms), fair (improvement of symptoms), and poor categories (no relief or worsening symptoms).

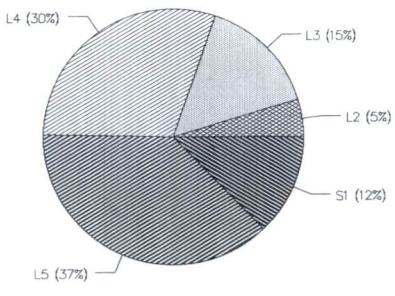
One case was described as having a grade-1 spondylolisthesis preoperatively. Another noted the presence of spondylolisthesis as a post-operative result.

Statistical analysis was accomplished using the 2-way ANOVA method for analysis of variance.

RESULTS

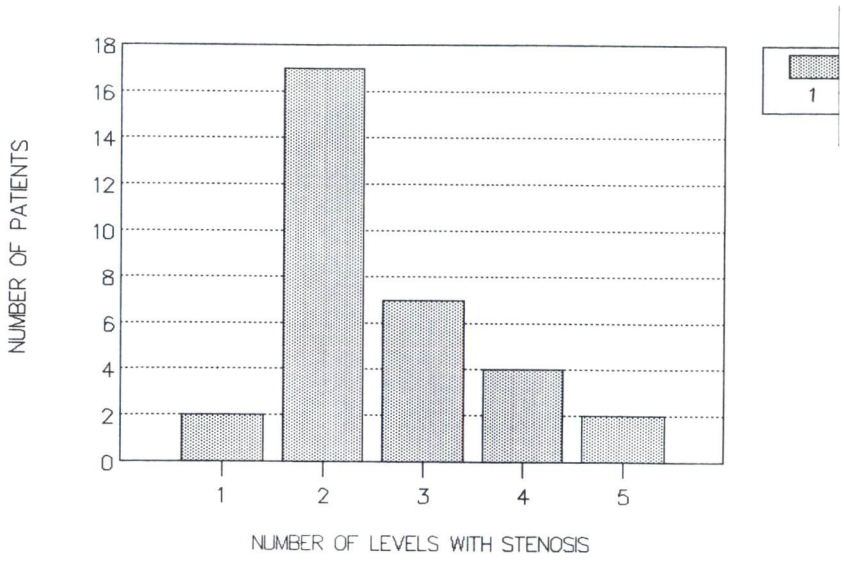
The results of the decompressive surgery are shown in **Figure 1.** Nine of the patients had good, twelve had fair and seven had poor results. The symptoms most common postoperatively were low back pain (40.1%) and lower extremity pain (34.4%) in varying degrees of severity. Patients had complete relief to significant improvement in 75% of the cases. Statistical evaluation of the success of the decompression showed no correlation with the surgical team, the age of the patient

FIGURE–4: INCIDENCE OF STENOSIS AT SPECIFIC VERTEBRAL LEVELS



(Table V), nor the presence of disc pathology. However there existed significance between the number of

FIGURE–3: DISTRIBUTION OF THE NUMBER OF LEVELS WITH SPINAL STENOSIS



stenosed vertebral levels and the surgical results (P = .009) **(Table IV). Figure 3** shows the distribution of spinal stenosis with regard to the number of stenosed levels.

The average number of stenotic levels was 2.6. The most commonly stenosed level was L5. The distribution of spinal stenosis relative to the vertebral level is plotted in **Figure 4.**

Analysis of symptoms and physical findings revealed the high prevalence of low back pain and radiculopathy. There was no statistical correlation between the presence of radiculopathy and the presence or absence of disc pathology. All of the patients with coincident disc pathology had associated positive straight leg raising test, though a positive straight leg raising test was found in sixty-two percent of those patients without disc pathology. The predictability of the straight leg raising test for disc pathology was not statistically significant.

Neurogenic claudication was present in forty-one percent of all the patients. This finding was not associated with any other parameters.

One case was described as having preoperative spondylolisthesis. This patient had a decompressive laminectomy from L2 to L5. The patient presently suffers from persistent lower back pain and her surgical result was regarded as poor.

Another case describes postoperative spondylolisthesis. This occurred in a forty-four year old male at L2-L3 following a laminectomy at L3 and L4 with partial laminectomy of L2 and L5 and discectomy of the L3L4 disc. The patient also had a bilateral foramenotomy of L4. His surgical outcome was regarded as poor.

Another case had bilateral posterolateral fusion performed from L3 to the sacrum. This sixty-six year old female patient was diagnosed as having bilateral lateral recess stenosis and central stenosis of L3 to L5. The patient had a prior history of discectomy of the L4L5 disc. Her surgical treatment also included total laminectomy from L3 to L5 and bilateral foramenotomy. Her surgical result was categorized as being fair.

DISCUSSION

Verbiest was the first to recognize the clinical syndrome that results from a narrow spinal canal and has proposed lumbar spinal stenosis as a cause of significant symptoms.[95,96] The most common symptoms in lumbar spinal stenosis are neurogenic intermittent

claudication (aka: pseudoclaudication) and lumbosciatic pain.[14,42,93] Neurogenic claudication is present in one-third of the cases of spinal stenosis and is usually associated with advanced disease and central neural compression. The claudication usually begins rapidly, intensifies with walking and occasionally by standing. Relief is attained with sitting or recumbency. The quality of the pain is described as a dull ache. The mean distance that neurogenic claudication develops is 180 m.[42] Table-II illustrates the clinical differences between neurogenic and vascular claudication.[36,74] In our study, neurogenic claudication was present in 40% of the patients and was typically described as a vague leg pain exascerbated by lumbar extension and ambulation. The claudication was relieved surgically for all the patients.

Lumbosciatic pain is reported to occur in approximately 65% of patients with lumbar spinal stenosis.[42] The pain is often aggravated by standing, walking or hyperextension of the lumbar spine. Improvement of low back pain is associated with recumbency, sitting or assuming a flexed position. Myelographic data suggests that in extension, the cross-sectional area of the spinal canal narrows and encroachment by bulging disks, ligamentum flavum and approximation of the articular facets are proposed as the mechanisms for the narrowing.[46,52,107] Lumbosciatic pain represented the chief complaint in 74% of the patients in our study. For most patients, the pain was responsive to surgical decompression. Only two patient showed no improvement of lumbosciatic pain.

Burning dysesthesia, morning stiffness, lower extremity weakness, paresthesia and nocturia have been reported. Unusual presentations including disturubances of micturition, sphincteric control, impotence, severe bilateral knee arthropathy, exercise induced weakness of one foot and bilateral hip pain are rare presentations and have not been noted in any of the patients in the study.[11,27,47,83,86,87]

The most common physical examination findings reported are increased pain with extension of the lumbar spine, weakness of the extensor hallacis longus and sensory changes that follow a specific dermatomal distribution.[42,88] Conversely, neurologic examination is usually normal in about half of the patients.[79] Half of the patients show a depressed patellar reflex or absent Achilles reflex. One-third of the patients have weakness of some lower extremity muscle group.[42] However, if the patient ambulates to the limits of their pain positive findings upon neurologic evaluation occasionally surface. The stoop test is an illustration of this principle. The stoop test is performed by walking the patient briskly and as the pain intensifies, the patient will complain of sensory followed by motor symptoms. With continued ambulation, a stooped posture is assumed and symptoms may be relieved. The relationship of posture to physical examination findings and symptoms is also demonstrated by the bicycle test.[85] Claudication and complaints of sciatica result when the patient rides in the erect position and is relieved by forward flexion of the lumbar spine. Our study noted minimal physical examination findings. The predominant findings were lower extremity weakness (56%), decreased range of motion of the lumbar spine (68%), paraspinal spasm (45%), lower extremity paresthesia (24%) and low

Table III: Parameters associated with spinal instability following decompressive surgery for lumbar spinal stenosis.

ABSOLUTE	RELATIVE
1. Excision of more than one facet joint at any spinal level.	1. Age less than fifty years.
2. Pre-operative diagnosis of "Dynamic" stenosis	2. Decompression of levels above the iliotransverse ligament.
3. Degenerative (preoperative) spondylolisthesis	3. Early degenerative disc disease.
	4. Decompressive surgery of three or more vertebral levels.

Table IV: Number of patients with a specific number of stenotic levels verses the surgical outcome

# STENOSED LEVELS	SURGICAL OUTCOME		
	GOOD	FAIR	POOR
ONE LEVEL	2	1	1
TWO LEVELS	3	6	4
THREE LEVELS	3	4	2
FOUR LEVELS	1	1	0

back pain exacerbated by extension of the lumbar spine (16%).

Radicular pain is the least common manifestation of spinal stenosis.[42] The straight leg raising test is usually negative, producing back pain in only 10% of the patients.[42] A positive straight leg raising test is usually associated with herniated disk.[20] One of the exclusion criteria was the presence of a predominate disc extrusion. Sixteen of the cases that were choosen for this study demonstrated disc pathology that required surgical attention. Statistically the presence of disc pathology did not alter the surgical outcome. This was an expected result since the patient's predominant symptoms were not suspected to be due to disc pathology. This was supported by demonstrating no statistically significant relationship between disc pathology and a positive straight leg raising test or the presence of radicular symptoms.

Surgical decompression for lumbar spinal stenosis has been well documented to suffer from less than excellant results. Like many other studies our percentage of successful surgical results (good and fair) was 75%. Success rates from other studies have been reported from 75-85%. Surgical results are determined by the patient's latest examination. The goal was to describe the late surgical results of each case. The degree of follow-up averaged 26 months. The duration of time for sufficient follow-up is not known.

Our series did not show any relationship between surgical outcome and patient's age. However, other studies have noted that age less than 50 years is related to increased probability of post-operative spondylolisthesis and spondylosis and therefore worse surgical results. As a consequence of the association between post-operative spondylolisthesis and age, Booth had noted age to be a factor to be considered in determining the necessity for a concurrent fusion.[16]

In our study, six of the seven poor surgical outcomes occurred with two or more stenosed levels. It was statistically validated that the surgical outcome was related to the number of stenosed vertebral levels. The average number of stenosed levels was 2.6. Previously, we have related extensive decompression with post-operative spinal instability and late surgical failure. The degree of decompression to produce significant instability has yet to be enumerated in both the review of the literature and in our study. In the 56th annual meeting of the American Academy of Orthopedic Surgeons, the issue of post-decompressive spinal instability was addressed and highlighted by Steven Fontain.[38] He expressed the need for a

Table V: Number of patients within an age group versus the surgical outcome

AGE	SURGICAL OUTCOME		
	GOOD	FAIR	POOR
20-29	1	0	0
30-39	0	1	1
40-49	4	2	4
50-59	1	3	1
60-69	3	3	1
70-79	0	3	0

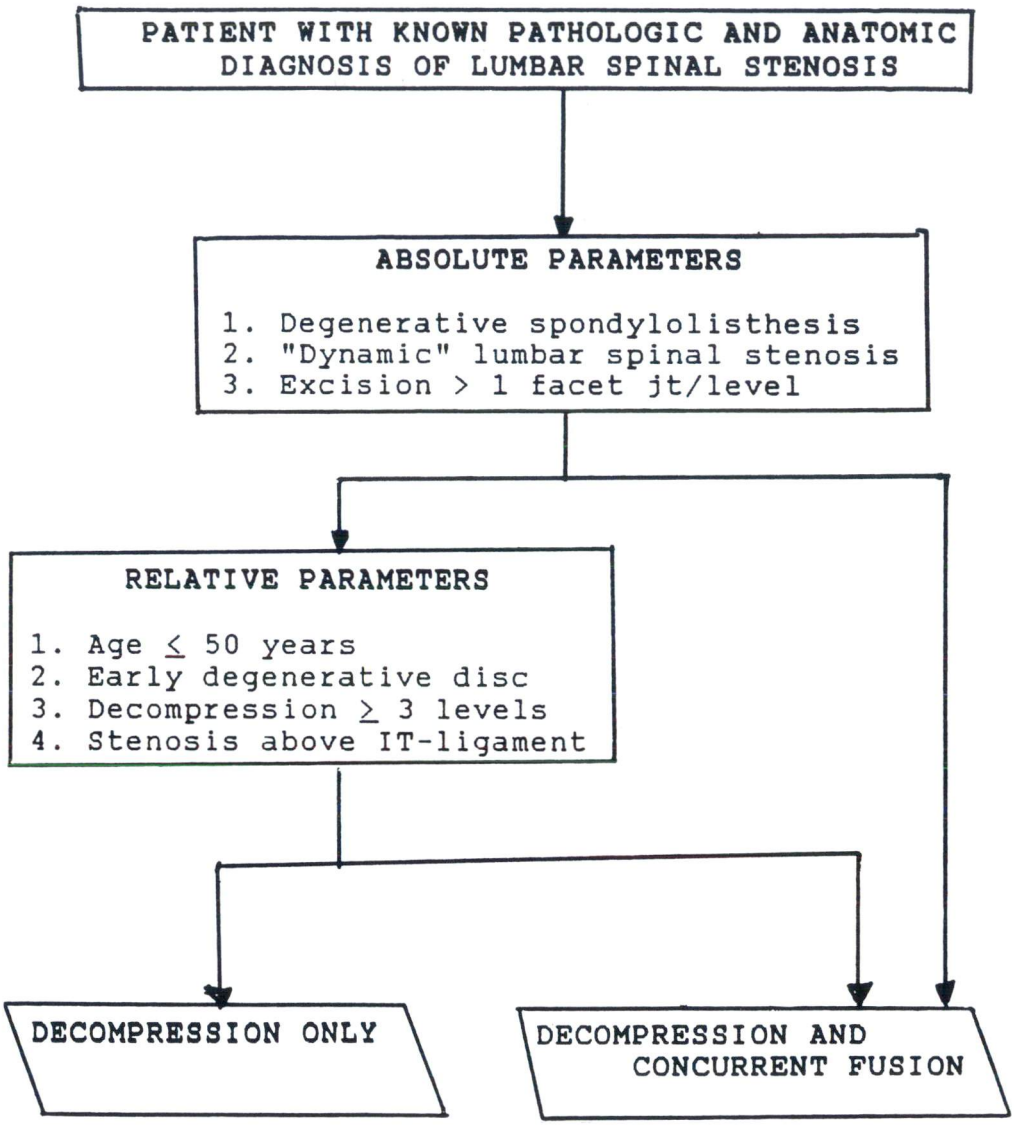


Figure 5: Algorithm for Concurrent Decompression and Fusion for Lumbar Spinal Stenosis

prospective study to assess the indications for concurrent fusion. **Figure 5** proposes an algorithm for fusion with decompression. The algorithm contains seven parameters. From the clinical and literature review these parameters have been associated with surgical outcome and postoperative instability. Three of the parameters are considered absolute indications for concurrent fusion, while the others are regarded as relative indications. **Table III** lists the parameters and separates them into absolute and relative. There exists sixteen possible combinations of the relative parameters. No study has yet to enumerate the significance of these parameters. It would be a true extrapolation of our results to suggest that any combination of these relative parameters would be an indication for decompression with concurrent fusion. Still it is reasonable that without any absolute parameter being satisfied that a concurrent fusion would be indicated by a subset of the relative parameters.

In summary, our study described the

retrospective analysis of 28 patients treated surgically for lumbar spinal stenosis. These patients demonstrated similar epidemiology, physical findings and symptomatology relative to other studies. Our study varified statistically the relationship between the degree of decompression and surgical outcome. It did not show any statistical significance between the patient's age nor the presence of early degenerative disc disease with surgical outcome. We have proposed those studies which should be done in the work-up of those patients. We have noted the clinical presentations that should be evaluated and documented. Finally, we identified seven parameters and have incorporated them into a preliminary algorithm. The significance of these parameters need yet to be established. Additional studies need to be undertaken to elucidate the principles of the surgical treatment for spinal stenosis.

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Posterolateral Fusion as Treatment: Severe Dysplastic Spondylolisthesis

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ABSTRACT: The treatment of severe dysplastic spondylolisthesis is controversial. Because of its proven success rate with low morbidity, we believe the treatment of choice is intertransverse posterior spinal fusion from L-4 to S-1. Seven patients having grade III, IV or V spondylolisthesis were evaluated pre and postoperatively. Six of the seven achieved arthrodesis with one procedure. The one pseudoarthrosis did well after refusion. All patients were improved following fusion and six were asymptomatic. There was no neurologic injury or prolonged morbidity.

Key Words: Spondylolisthesis Posterolateral Spinal Fusion
Abbreviated Title: Posterolateral Fusions for Dysplastic Spondylolisthesis

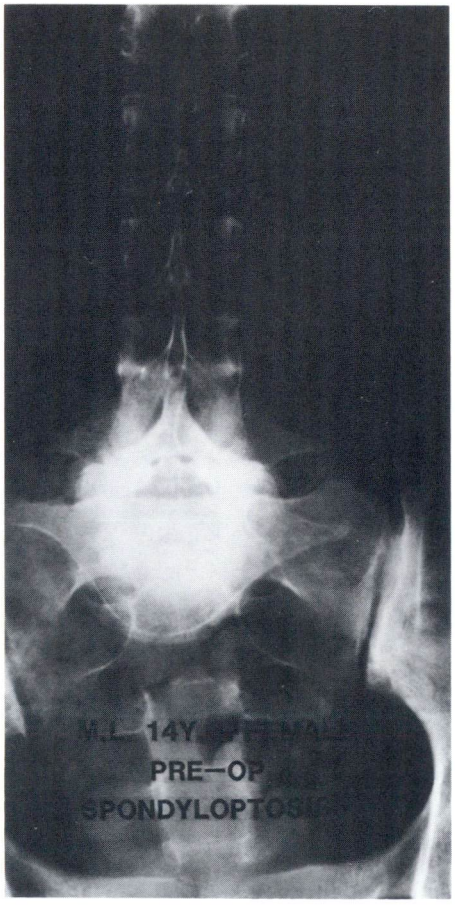
INTRODUCTION

Spondylolisthesis is the most common cause of low back pain in children and adolescents.[1] It has been recognized as a clinical entity since first described by Herbiniaux, a Belgian obstetrician in 1782.[2] The period during which slippage most often occurs is adolescence.[3] Meyerding developed a grading system based on percentage of slip.[4] Slippage greater than 50% is considered a high grade, or severe slip. Slippage greater than 100% has been called spondyloptosis.[5]

Wiltse, Newman and McNab have classified spondylolisthesis into five types: dysplastic, isthmic, degenerative, traumatic and pathologic.[6] In the dysplastic type there is congenital dysplasia of the upper sacrum or the neural arch of the fifth lumbar vertebra. The pars interarticularis may remain unchanged, however, usually it elongates, or comes apart.[6] Even though the dysplastic type is often not associated with a break in the pars interarticularis, the degree of slip is often severe.[7,8]

Patients with high grade slips can be asymptomatic, but more often have low back and occasionally radicular pain.[9] Symptoms are often aggravated by strenuous activity and decreased with rest.[8] Physical examination may show an altered gait, flattening of the buttocks, and hamstring tightness.[8,9,10]

The goal of treatment is to relieve and prevent progression of deformi-



ty.[8,11] Surgical intervention has been the standard of care in severe spondylolisthesis.[1,9,12] However, the procedure of choice continues to be controversial. In situ posterolateral arthrodesis from the fourth lumbar to the first sacral vertebra, with or without removal of the loose posterior element of the fifth lumbar vertebra has been the accepted standard for surgical treatment.[7,9,10,13,14] Yet, because of persistent cosmetic deformity,[13] pseudoarthrosis rate[1,9,15] and persistent slippage following in situ arthrodesis[1,7,14,15] other techniques have been advocated.

Scaglietti et al[16] have advocated a cast technique of reduction and fusion. Bradford[17] has advocated a combined approach with traction and reduction techniques. Other techniques include Harrington rod reduction and fusion,[18] anterior fusion with tibial strut graft,[11] and combined approaches.[19] However, these techniques are demanding for physician and patient, and complications have been frequent[16,17,18]

Because of consistent rates of fusion, low complication rates and consistent relief of symptoms, it is our belief that fusion in situ remains the standard of care in the treatment of severe spondylolisthesis. The purpose of this paper is to evaluate the results of posterolateral in situ fusion in patients having severe spondylolisthesis of the dysplastic type.

MATERIALS AND METHODS

Seven patients were evaluated. All had posterolateral fusions for grade III, IV or V spondylolisthesis. All slips were of the dysplastic type. We did not include patients with age greater than twenty-five upon presentation to eliminate those whose pain was degenerative in origin. There were six females and one male. Age at time of fusion ranged from twelve to twenty-three, with mean being fifteen years eight months. Patients averaged three years of symptoms prior to surgery. Length of follow-up ranged from one to six and one half years with mean being four years. Most patients suffered mild low back pain preoperatively. However, symptoms varied from one patient who was asymptomatic to another patient with radicular pain and foot drop. Roentgenographic evaluation showed four patients had grade III, one grade IV, and two grade V spondylolisthesis.

Patients were treated by a single surgeon (D.H.). Each underwent an intertransverse posterior spinal fusion with autogenous bone grafting from L-4 to S-1. In one patient the fusion extended to L-3. A Gill procedure was performed in two patients. There was one patient who developed a pseudoarthrosis and required a second fusion one year after the first. Postoperatively, the patients wore a hip spica cast three months, and then a lumbosacral corset for three months.

Each patient was requested to return for complete evaluation. This included completion of a questionnaire, physical examination and lumbar roentgenograms.[20] Roentgenographic measurements included percent slip and slip angle. These were compared against previous films. Five patients returned for a full examination. The other two patients were interviewed over the telephone.

The questionnaire recorded both the patient's and physician's perception of the patient's pain and disability. Patients were also asked to compare their symptoms at follow-up with preoperative symptoms. Physical examination included range of motion, leg raising tests and neurologic testing.

RESULTS

At follow-up six of the seven patients were asymptomatic. The seventh complained of occasional low back pain and foot weakness. The patients had no complaints of disability or limitation of activities. When asked to compare the symptoms at follow-up, all patients were improved from preoperative status. None of the patients required medication of any sort.

All patients had excellent range of motion of the spine. All were able to bend down and touch the floor. No patient had pain with hyperextension. All were neurologically intact. One patient had mild weakness dorsiflexing both feet which was improved from preoperative.

Six of seven achieved arthrodesis

with the operative procedure. The one pseudoarthrosis was diagnosed after a return of symptoms, and progressive radiographic slip. The patient did well after refusion, and is now asymptomatic four years later.

Roentgenographic measurements were evaluated in six patients.[12] In one patient there was a progressive slip of 15% without change in slip angle. No other progression was seen.

DISCUSSION

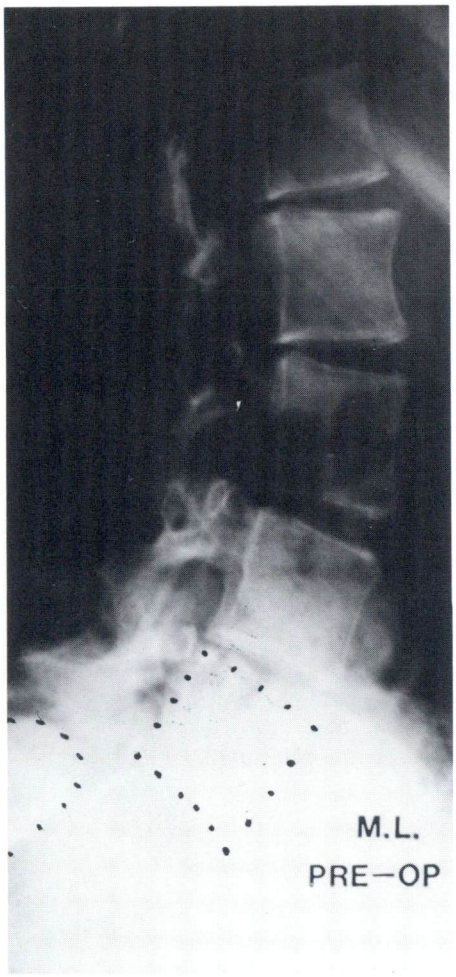
Spondylolisthesis can be of many types. When severely displaced, it is most commonly due to congenital dysplasia of the lumbosacral junction. The treatment of severe displacement is controversial. Harris and Weinstein have shown that when treated nonoperatively, these patients remain active and require only minor adjustments in their lifestyle.[21]

Operative treatment has been supported by most surgeons.[1,9,12,21] Arthrodesis in situ,[9,13] reduction with posterior fusion,[16,18] and combined approaches[17,19] have been advocated. The reduction and combined techniques are technically demanding, involve prolonged traction and casting of patients, and have been associated with complications. The use of Harrington rods has been associated with increased thoracic lordosis,[14] worsened lumbosacral kyphosis,[17] and cauda equina syndrome.[22] Scaglietti reported trouble with infection and noted that a good radiographic result did not always accompany a satisfactory clinical one.[16] Bradford's combined approach led to L-5 root injury in three of ten cases.[17]

We are reported the results of treatment of severe spondylolisthesis using posterolateral intertransverse fusion from L-4 to S-1. Its advantages are that it involves one surgery with proven success, low morbidity and complication rate.[1,7,9,13,15,21]

We have demonstrated excellent results in seven patients, all severe slips, without the use of reduction techniques. Six patients were asymptomatic at follow-up and the seventh was much improved. There was no neurologic injury or prolonged morbidity. There was one pseudoarthrosis, an incidence of 14% in this series. This patient underwent refusion, and progressed to an excellent clinical result. Progression of slip occurred in one patient and did not affect the clinical outcome.

In summary, the method of treatment in severe dysplastic spondylolisthesis remains controversial. Reduction techniques have led to complications in many hands. We believe that posterolateral in situ fusion is the treatment of choice.



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Complications Associated With Intramedullary Nailing of Femur Fractures

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ABSTRACT: Intramedullary nailings done in a community hospital setting between 1981 and 1987 were retrospectively reviewed. Twenty four patients with 25 femur fractures comprised the study group. Nine of twenty four patients experienced a complication due to the procedure. The pit falls and complications associated with intramedullary nailing are reviewed and solutions are discussed.

INTRODUCTION

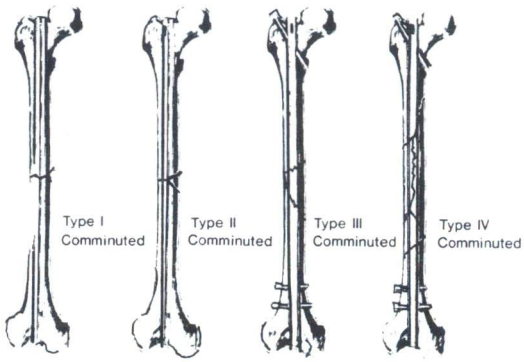
Treatment of the patient with femoral shaft fractures has been problematic for the orthopedist. The high incidence of complications associated with skeletal traction are well known and documented throughout the orthopedic literature.

The management of femoral shaft fractures has changed dramatically over the years. The first recorded attempt at internal fixation of a fracture with a metal rod was by Lambott in 1907.[11] Kuntscher in 1940 reported his experience with an intramedullary rod for femurs. The complications associated with intramedullary nailing are primarily in three general categories, technical, mechanical, and biological failures. The purpose of this paper is to review our initial experience with our first 25 intramedullary nailings with a minimum of two year follow up report on the pitfalls, errors, and complications associated with our experience. Included in this will be a review of the literature concerning this topic.

MATERIALS AND METHODS

This study reviews 24 patients in whom 25 femoral fractures occured over the period 1981-1987. Intramedullary nails used were initially the Kuntscher rod, followed by the Grosse-Kempf, and finally the Russell-Taylor intramedullary nail. The fracture table used during this study was the Amsco. From 1981 to 1984, nine Kuntscher nails and two Schneider nails were used. From 1984 to 1986, nine Grosse-Kempf intramedullary nails were used and in 1987, five Russell-Taylor nails were used. Age range was 16 through 76. Sixteen patients were male, eight were female. The three most common causes of the fracture were motorcycle accidents, motor vehicle accidents, and pedestrian motor vehicle accidents. No infections were present in this group. There was one delayed-union with a Grosse-Kempf nail that was placed in the dynamic mode. Time until full weight bearing ambulation was 12 to 26 weeks. Healing time range was three to twelve months with an average of approximately five months. Operative time ranged from 20-300 minutes, average 145 minutes. Blood loss was 300 cc. to 1800 cc., average 700 cc. Knee motion was greater than 110 degrees in all patients by six months post-operatively. Twelve femurs were nailed by closed technique, 13 femurs required open nailings. Thirteen femurs were nailed in the static mode, two in the dynamic mode, and 10 femurs were nailed unlocked. Out of 24 patients, 10 patients returned to work. Utilizing the Winquist and Hansen classification scheme, there were 5 type I fractures, 6 type 2, 9 type 3, and 5 type 4.

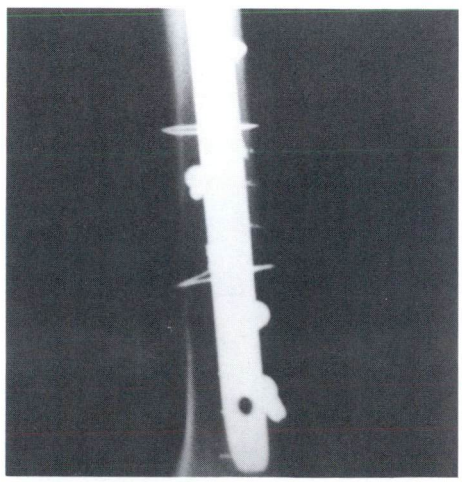
Classification of Femoral Comminution:
By Winquist and and Hansen



The Winquist and Hansen classification of femoral comminution. Type I: there is a small fragment of comminution at the site of the fracture that is not important for stability of the fracture. Type II: there is slightly more comminution than in Type I, but more than 50% of abutting cortical contact at the site of the fracture. This cortical opposition is sufficient to control shortening, rotation, and translation. Type III: there is less than 50% of abutting cortical surfaces at the site of the fracture. These injuries are unstable to rotation, translation, and shortening. Type IV: there is extensive comminution, and no cortical buttress at the site of the fracture. These injuries are unstable to shortening, rotation, and translation.

RESULTS

Of the 24 patients with 25 femoral fractures, complications associated with intramedullary nailing either of a mechanical, technical or a biologic nature were encountered in 9 patients. Of the complications encountered, there was one procedure where one of the distal locking holes was missed with the locking bolt **(picture 1).** There was one episode where the C-arm broke at the beginning of the case prior to skin incision with the patient anesthetized on the fracture table. Although not actually a complication of the procedure the patient did receive an unnecessary anesthetic. There was one episode with the Grosse-Kempf nail where we encountered severe torsional stress to the nail during it's insertion and despite the comminution of the fracture type which would have required locking of the nail, we were unable to do so due to 90 degree torque of the intramedullary nail **(picture 2).** There were two patients that developed compartment syndromes which required fasciotomies. One of the patients with the compartment syndrome had an associated laceration of his femoral artery which required vascular surgical intervention initially with a reverse saphenous vein graft which failed and was then converted to a Gortex graft. This patient ultimately developed gangrene of his forefoot and required a below knee amputation. We had one episode of superficial perineal skin necrosis. This occurred in the patient with the bilateral femur fractures. This spontaneously resolved with only local wound care. It occurred primarily because of the length of the procedure required in performing intramedullary nailing of both fractures at a single setting. Total procedure time for this patient was approximately 300 minutes. One patient with the Schneider nail suffered some buttock pain due to the nailing backing out proximally. This nail ultimately went on to fall, and required revision with a new intramedullary nail which was locked. We feel this was due to the small diameter of the nail used **(picture 3).** The fracture subsequently went on to union. We had one patient with fat embolism syndrome and two patients expired of pulmonary embolus. One which occurred intraoperatively. This patient had the intramedullary nailing performed on his ninth day of hospitalization. The second occurred post-operatively, intramedullary nailing was performed seven days post-injury in that patient.



Pic. 1: Locking bolt misses distal lock hole in Grosse-Kempf Nail

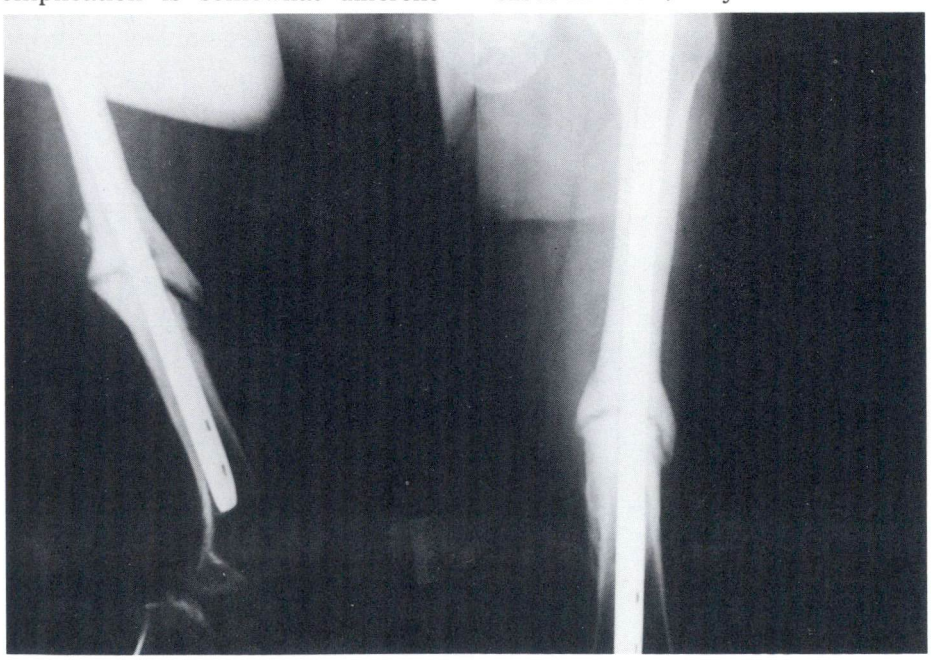
TABLE 1

COMPLICATIONS ASSOCIATED WITH INTRAMEDULLARY NAILING

MECHANICAL	TECHNICAL	BIOLOGIC
Nail migration	Radiation exposure	Fat embolus
Nail breakage	Rotation mal-alignment	Fat emolism syndrome
Nail torque	Angulatory mal-alignment	Buttocks pain
C-Arm failure	Length abnormalities	Non-union
Bolt breakage	Iatrogenic fracture of the femoral neck	Compartment syndrome
Gas injection	Failure to lock	Infection
	Starting hole errors	Delayed union
	Eccentric reaming	Nerve palsies
	Nail selection	Hematoma
	Guide wire penetration	Heterotopic ossification
		Knee stiffness
		Deep venus thrombosis
		Pulmonary embolus
		Arterial laceration
		AV malformation

DISCUSSION

In our review of our first 25 patients with femoral fractures that were treated by intramedullary nailing, we noted a complication rate of 9 of 24 patients for an overall complication rate of approximately 36%. However, I should note that our definition of a complication is somewhat different than what is usually found in the literature. Winquist and Hansen frequently refer to a satisfactory result as any fracture that goes on to heal has less than 1 cm. shortening, less than 10 degrees of angulation of rotation abnormally, and greater than 120 degrees of knee motion.[17] In their report of 520 cases in 1984, they address in their



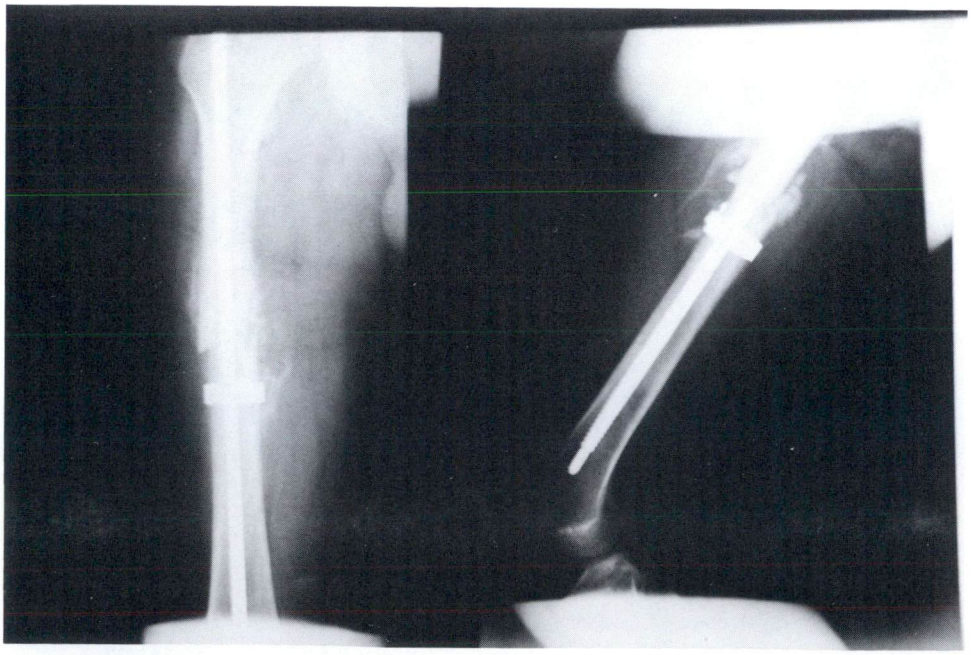
Pic. 2: Severe torsional deformation of Grosse-Kempf nail distal with delayed union of fracture

complication rate only infections and mal-unions. Careful review of their paper however, reveals an overall complication rate of 32%. This included a shortening greater than 1 cm., in 9% on their patients, rotational abnormality of greater than 10 degrees in 8%, angulatory abnormality more than 10 degrees in 8 of 520 patients (1.5%). Peroneal nerve palsy in 10 of 520 patients (1.9%), fat embolism syndrome in 55 of 520 patients (10.5%), and pulmonary embolus in 9 of 520 patients (1.7%).[17]

Although a fracture of the femoral neck iatrogenically created by intramedullary is reported in the literature by Harper in 1986, this is felt to be primarily related to errors on the entrance point. In the two cases reported, the first was due to several large holes made at the entrance point of the piriform recess. The second was caused by a perforation of the medial cortex of the femoral neck with the drill bit.[8]

It is currently encouraged to perform all femoral intramedullary nailings closed whenever technically feasible and in recent reports in the literature from Brumback in December of 1988, their large study reported all nailings performed by closed means. Their implication is that it reduces the incidence of infection.[2] However, the study performed by Leighton published in the Journal of Trauma in 1986 in their review of 65 fractures treated by closed nailing and 65 fractures treated by open nailing technique demonstrated no statistical difference.[11] Our protocol has been that we will attempt a closed nailing, if however after approximately 30 minutes of attempted reduction, we are unable to achieve it by closed means, we will proceed with an open intramedullary nailing. In our small study, this method has not produced any infections. Further support is added by the Grantham study, Orthopedic Review, July 1986, in which he reviewed open intramedullary nailing of femoral shaft fractures performed over a ten year period. In his study of 88 traumatic fractures, the rate of union was 98%, and there were no infections.[5]

In the treatment of comminuted femoral shaft fractures, Johnson in 1987, reviewed their experience with 179 comminuted femoral shaft fractures. His report overall complication rate approached 20%, including only discussion of hardware and technical related complications. No mention was made in his study of any pulmonary



Pic. 3: Schneider nail too small for femur which ultimately went on to fail

complications associated with the procedure.[10] Esser in 1982 reviewed his experience with closed Kuntscher nailing over a 20 year period. In his review of 116 patients, he notes a complication rate of 30% rotational malunion and 30% significant leg length discrepancy. Other complications noted in his review included post-traumatic respiratory insufficiency, chest infection, pin track infection, bone infection, wound infection, DVT, PE, and nail tip pain with 103 out of the 116 patients having some type of complication. If one excludes the patients which suffered from nail tip pain, we still find a complication rate approaching 50%.[5]

Talucci, 1983 reported on incidents of fat embolization associated with early intramedullary nailing. He found no fat embolization with intramedullary nailings in 57 patients performed in the first 24 hours of hospitalization. In 43 patients in which intramedullary nailings were performed 5-24 days post-injury, the incident of fat embolization was 11%.[15]

TABLE 2

CRITERIA FOR FAT EMBOLIZATION SYNDROME

MAJOR	MINOR
Petechiae	Tach > 110
PAO_2 < 60 mm.	Pyrexia > 38.5°C
CNS Depression	Retinal Emboli
Pulmonary Edema	Fat in Urine
	Decreased HCT
	Increased ESR
	Fat in sputum

Diagnosis of fat embolization syndrome is performed by the criteria of Gurd.[7] The major criteria are axillary subconjuctival petechiae, hypoxemia, (PAO_2 less than 60 mm. of mercury), central nervous system depression, out of proportion to hypoxemia, and pulmonary edema. Minor criteria are tachycardia greater than 110 beats per minute, pyrexia, temperature greater than 38.5 degrees centigrade, emboli present in the retina on funduscopic examination, fat present in urine specimen, sudden unexplained drop in the hematocrit value, increased erythrocyte sedimentation rate, and fat globules present in a sputum specimen. The diagnosis of fat embolization syndrome requires at least one sign from the major criteria category and at least three or more signs from the minor criteria category. Adult respiratory distress syndrome occurred in 7% of the immediate nailing group and 5% in the delayed nailing group. Diagnosis of ARDS requires that all the following criteria be met:

TABLE 3

CRITERIA FOR ARDS

(1) Presence of refractory critical hypoxemia.
(2) Evidence of bilateral diffuse infiltrates on chest roentgenogram.
(3) No evidence of hydrostatic or pulmonary edema. (Capillary wedge pressure less than 18 cm. H_2O).
(4) No other explanation for critical hypoxemia. (Such as pneumothorax).

Critical hypoxemia was present in 23% of the immediate nailing group and 14% of the delayed nailing group. The diagnosis of critical hypoxemia was made when the ratio of arterial oxygen tension, PAO_2, to the fraction of expired oxygen, FIO_2, fell below 150. This represents an overall pulmonary complication incidence of 30% in the immediate nailing group and 30% in the delayed nailing group. We should note that the injury severity score was higher in the immediate nailing group but in spite of this, there were no cases of fat embolization syndrome in the early intramedullary nailing group.[7]

Radiation exposure to the surgeon during locked intramedullary nailing was reviewed by Levin in 1987. His study performed during 30 consecutive nailings using the freehand technique for interlocking. The average time of fluoroscopic exposure for interlocking intramedullary nailing of the femur was 12.6 minutes. Film badges were worn at the level of the thyroid gland on a collar outside the lead apron and a ring band was also worn on the dominant hand. The average dose of radiation per procedure of deep ex-

posure was 7 millirems and shallow exposure was 8 millirems. The is well below the governmental guidelines of 18,750 millirems per quarter year (3 months), for hands, forearms, feet, and ankles, and 1250 millirems per quarter year for the whole body. Conclusion of the study was that the freehand technique is a safe method of performing distal interlocking for static intramedullary nailing.[12]

Bucholz in 1987 reported on fatigue fracture on the interlocking nail and treatment of the distal part of the femoral shaft. He reported on 7 patients, all of whom the fracture was 5 cm. or less from the most proximal of the two distal screw holes. Finite element analysis revealed that the stress on a nail exceeded its fatigue endurance limit and that the femur had to regain 50% of its original stiffness through healing to accommodate weight bearing without risk of fatigue fracture of the nail. His recommendations are to use a larger diameter nail, drive the nail down into subchondral area of the knee joint to increase the distance from the site of the fracture to the nail holes, decreasing the leverage at those stress risers. Weight bearing on the injured limb should be delayed until there is clear radiographic evidence of early union of the fracture.[4]

Marks in 1988 reported on heterotopic ossification about the hip with intramedullary nailing of the femur. In his study group of 59 patients with 60 locked intramedullary nails, they were prospectively followed and he found 32% with no heterotopic ossification, minimal in 20%, mild in 28%, moderate in 15%, and severe in 5%. He did find a positive association with an increased injury severity score and head injuries. However, the etiology of the heterotopic ossification remains unknown.[13]

Hunter in 1982 reported on the deformation of femoral intramedullary nails. In a retrospective study of 45 patients treated with Kuntscher nailings, from 1973-1979, he found deformation of the femoral intramedullary nails occurring in 78% of the fractures he treated. This was attributable to elastic or plastic bending of the nail at the time of the introduction of nail. He does note that it is generally not associated with clinical complication, however, mal-union is certainly a possibility. In our experience we noted frequent minor torsional deformations of the Kuntscher and Grosse-Kempf nails. In only one patient, however, was it a significant problem when the Grosse-Kempf nail torqued 90 degrees distally. This made it impossible to lock distally in a fracture that had a grade IV comminution. This patient went on to develop a nonunion, he refused further surgery to address this problem and was treated with electrical bone stimulation. His fracture subsequently progressed to union at 18 months post-injury[9] **(picture 2).**

Reinders in his 1984 paper reviews technical faults and complication in interlocking nailing of femoral fractures using the AO system. His recommendations include that with locked nails, the femoral nail not be wedged in the canal, as interference fit is not necessary to fracture stability since the nail will be locked. He also recommends using a supline position placing the locking screws is easier, rotational alignment of the femur is easier to maintain, and operation of the C-arm appears to be easier also. Although he does recommend using the tip of the greater trochanter as a starting point in contrast to the pyriformis fossa, which other authors recommend. He does note that a too far lateral starting point will result in a fracture of the medial wall, and too medially starting point may result in fracture of the femoral neck or damage to the vascular supply to the femoral head. He recommends to avoid eccentric reaming to progress in an easy controlled manner and not to ream through comminuted pieces. At the time of insertion of the nail, slight resistance should be met only, in order to help prevent torsional deformation of the nail or displacement of unrecognized fracture fragments.[14]

Other logistic problems which we have encountered include patient positioning. It is our method now to use the supine position as this eliminates the difficulty with the fracture angulating

into the valgus position when the patient is lying in the lateral decubitus position. The supine position eliminates this problem allows easy visualization of rotational and angulatory deformities. It also allows for easier interlocking of the femoral nail. The principal disadvantage is a compromise of access to the proximal femur by the patient's flank and this difficulty can be overcome usually by flexing and adducting the hip on the injured side.

Difficulties in managing the femoral fracture with a closed reduction for closed nailing technique have been addressed in several ways. Assistance by a knowledgeable un-scrubbed surgeon may dramatically improve the efforts for a closed nailing. Also, closed reduction is easier when nailing is performed on the day of injury. The strong preoperative traction to sufficiently overdistract the fracture slightly should be used, thereby avoiding excessive interoperative traction which may result in sciatic nerve palsy. Closed reduction can also be facilitated by the use of a smaller IM nail in the proximal fragment which has been placed over a guide wire to help manipulate the proximal fragment. The Russell-Taylor instrumentation set has provided for this with a special instrument which has been designed specifically for this purpose.

Interlocking nailing of femoral fractures is performed followed reaming. Reaming of the intramedullary canal has produced of it's own, a set of numerous complications and pitfalls for one to deal with. Cannulated flexible reamers must be passed over a guide wire which is ball-tipped. Progressive reamings can be performed in 1 mm. increments until cortical bone is reached, at which time .5 mm. increments should be used to avoid jamming the reamer. If the reaming system is a coiled spring shaft, it is essential that the power drive not be reversed as this can lead to unwinding of the reamer shaft. Should the reamer become jammed using this type of system, the ball-tipped guide can be used to back-out the reamer by hammering against a vise grip clamp to the ball tip guide. While reaming it is also important to stabilize the guide wire both in insertion of the reamer to avoid pushing the guide wire distally across the knee, or retrograde across the reduced fracture. Since looking eliminates the need for a tight interface fit in the intramedullary canal, over-reaming is appropriate and the nail should not meet with a great deal of resistance when inserting. In particular, with the Russell-Taylor nail, it seems to be somewhat oversized and according to personal communication with Dr.'s Russell and Taylor, it is usually .3 mm. larger than its stated size. For this reason, reaming 1.5 mm. to 2.0 mm. larger than the nail which is planned to be placed in the intramedullary canal is appropriate.

In order to establish correct limb length, appropriate measurement should be made pre-operatively of the uninjured extremity. From this measurement, the appropriate nail can be selected. As a check to this method, it has been our habit to use a second ball-tipped guide wire which we measure against the first ball-tipped guide wire which is in place in the intramedullary canal to determine the appropriate length of the nail to be used.

The insertion of the distal transfixing screws in the use of the interlocking nail has, in our experience, been one of the more challenging aspects of this procedure. We have attempted to use the manufacturer's distal targeting devices on both the Grosse-Kempf and the Russell-Taylor nailing systems. It has been our experience that the distal targeting device, especially the Russell-Taylor distal targeting device, works very nicely on saw bones, however in the operative suite it proves to be rather cumbersome and unreliable. For this reason, we have gone to the exclusive use of the free-hand technique. It may well be that the distal targeting device would function properly, but often there is some torsional deformation of the nail which the distal targeting device is unable to compensate for. Our technique involves using a long pointed awl and with the C-arm fluoroscopic unit the distal transfixing hole visualized as a perfect circle with the pointed awl centered in the hole. Utilizing this technique, we have found

that we have been able to achieve distal interlocking in a rapid fashion with minimal radiation exposure to the surgeon.

Post-operatively, weight bearing has been delayed until roentgenographic evidence of healing is evident with the formation and bridging of callus. A conservative approach has proven to be effective in the treatment of our patients with only one patient having a delayed union which occurred in the patient with the Grosse-Kempf nail which torqued 90 degrees and was unable to be locked distally despite the comminution which would have indicated the locking mode to be appropriate. Bucholz in 1987 reviewed fatigue fracture of the interlocking nail and the treatment of fractures of the distal part of the femoral shaft, and his findings demonstrated that stress on the nail exceeded it's fatigue endurance limit unless 50% of the original stiffness of the femur had been regained through healing. Weight bearing prior to that would risk fatigue of fracture of the nail.[4]

CONCLUSIONS

Intramedullary nailing of femoral fractures is a technically demanding procedure, requiring careful pre-operative planning, and precise technique. It is a procedure which has decreased hospital stay, decreased mortality and morbidity associated with femoral fractures, and improves the patient's chances of returning to being a productive member of society.

We feel it can safely be performed in a community hospital setting but requires a team approach.

We recommend that an attempt be made to perform the procedure on the day of injury, if unable to do so, one should place the patient in skeletal traction and wait approximately seven days prior to proceeding with the procedure.

Closed nailing should be performed if possible, however if after 30 minutes one is unable to adequately reduce the fracture, we would recommend proceeding with an open technique.

Radiation exposure to the surgeon will continue to be a source of worry. Our most recent experience with the IM nailing has shown that the total C-arm fluoroscopic time for the procedure including distal interlocking can be under five minutes on a consistent basis. Certainly, this is one portion of the technique which is extremely dependent on the learning curve. Over-reaming of the femoral canal is an essential part of the procedure to help prevent torsional deformation of the nail on insertion.

Delayed weight bearing should be a part of the post-operative protocol until roentgenographic evidence of callus formation is present. Our overall complication rate of 36% is consistent with what is reported in the literature by other authors. Certainly, this is higher than we would all like to see, however, considering the severity of the injury, the technically demanding nature of the procedure, and the multitude of equipment required to perform the technique successfully, it is not surprising that problems are encountered. As with all difficult endeavors, time and experience will improve the results reported.

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Transitional Fractures of the Adolescent Ankle: Further Classification

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ABSTRACT: This paper will present both the Juvenile Tillaux and the Triplane epiphyseal fractures as they have been presented historically. Their relationships to the adolescent ankle, in injury, have been to identify these fractures as two separate entities. As tomographic evaluation and subsequently computerized tomography have entered into the diagnostic capabilities in evaluating these two separate fractures multiple similarities have occurred. The fact that these two fractures both occur at almost identical times during a period of adolescence in which the distal tibial epiphysis is fusing asymmetrically has now been appreicated. Multiple classifications have been submitted and revised but have, with the exception of one author, continue to separate these two fractures. von Laer was the first to suggest an all encompassing classification for both the Juvenile Tillaux and the Triplane fracture and he subsequently termed this the transitional fracture of adolescence. This paper takes von Laer's classification and further subdivides it, presenting a usable classification in which identifies a progression from the most immature to the most mature type of fracture. The paper also discusses treatment of the fracture and presents six new additional cases that were treated by the author. **Key Words:** Adolescence, Classification, Epiphysis, Tibial Fracture, Transitional.

INTRODUCTION

Injuries to the distal tibial epiphysis of the adolescent ankle have been well documented. The Juvenile Tillaux and the Triplane Epiphyseal fractures have historically been referred to separately, although in recent literature, it has been recognized that these fractures should be classified together. The term Transitional Fracture was first used in 1962, but went unnoticed because it was in the German literature. Transitional fractures derive their name because they occurred during a transitional period of asymmetric fusion of the distal tibial epiphysis. Multiple authors have suggested various grading systems which deal primarily with the Triplane fracture. A grading system, however, is necessary since neither the Juvenile Tillaux fracture of the Triplane fracture can be classified within the Salter-Harris or the Lauge-Hansen classifications. These fractures are now recognized to occur by the same mechanism of injury, that is, external rotation on a plantar flexed foot. The fracture is age dependent and a differentiating presentation are dependent on skeletal maturity of the distal tibial epiphysis. Thus, the Juvenile Tillaux fracture is actually a more skeletally mature version of the Triplane fracture. A classification with an appropriate grading system, encompassing all of these concepts will be proposed. This paper will also review the literature and present six additional cases of this fracture.

***Independence Orthopedics and Sports Medicine**

HISTORICAL REVIEW

The Tillaux fracture was first described by Sir Astley Cooper, although it derives its name from a drawing on a scrap of paper by Paul Jules Tillaux. The drawing was discovered after his death by Chaput. The fracture, as described, originally applied to adults and involves the anterolateral tibia, extending from the distal articu-

lar surface of the tibia upward to the lateteral cortex. The fracture is the result of an external rotation force. The displacement fracture may be small, including only the anterior tubercle or large, including the anterior and posterior tubercles and a part of the tibial articular surface. The fragment is roughly triangular in the adult.[1]

The corresponding epiphyseal fracture, the Juvenile Tillaux or Kleiger fracture, was first discussed by Kleiger and Mankin in 1964.[2] The fracture occurs by the same mechanism as in the adult, as well as the Triplane fracture. The fracture appears on x-ray as a Salter-Harris type III fracture, in which the fracture line extends through the growth plate and then vertically through the distal tibial epiphysis. The resultant anterolateral fragment fractures and externally rotates with the fibular fragment and the intact anterior tibiofibular ligament.[3,4,5] The fracture fragment is usually quadrilateral in shape. It represents approximately 2.5% of the fracture of the ankle in children.

Although Kleiger's series was small, involving only eight cases, it did present several key points. First, in a review of sixty patients' ankle x-rays ranging in age from twelve to twenty, it was found that fusion of the distal tibial ephiphyseal plate proceeded asymmetrically, beginning centrally first, then medially and finally laterally. The entire process occurred over an average of eighteen months.

Secondly, using stress external x-rays, Kleiger demonstrated that rotary instability was a feature of this fracture and for this reason recommended that the reduction be maintained in a long leg cast with the foot in full medial rotation. He concluded that most of these fractures could be handled by closed means and recommended open reduction for displaced fractures.

Dingeman reviewed five cases exhibiting an average of two millimeters of displacement. He recommended open reduction, stating that the periosteal flaps frequently prevented a successful closed reduction.[6]

Molster, in follow-up reports of six cases, recommended open reduction be performed for most cases, using small K-wires across the epiphysis into the metaphysis or small cancellous screws into the epiphysis. He justified surgery because his patients had minimal residual arthrosis, whereas in a series of Rang's involving thirty cases, eight patients exhibited residual pain at their two year follow-up examination.[7] Spiegal reviewed an additional six fractures, all treated with closed means, with only one patient exhibiting articular incongruity at the three year follow-up examination.

Interestingly, three of the eight fractures in Kleiger's study and posterior metaphyseal fragments and in retrospect they were actually Triplane fractures.

In 1970, Marmor described what he called an "unusual" fracture of the lower tibial epiphyseal plate, occurring in a twelve-year-old female. Post-reduction films of what appeared to be a Salter-Harris type II fracture revealed a widened ankle mortice. An open reduction was performed and Marmor noted that there were three fracture fragments occurring in different planes. He described the fracture components as follows: 1) a rectangular fragment representing the anterolateral quadrant of the distal tibial epiphysis; 2) a medial and posterior portion of the epiphysis, in addition to a posterior metaphyseal spike and; 3) the tibial metaphysis.

Lynn, in 1972, reported two more cases similar to Marmor's previous description. He termed these as Triplane fractures, stating that they represented complex injuries not applicable to the Salter-Harris classification. He noted that the fracture appeared to represent a Salter type II fracture on the lateral view and a type III fracture on the A-P view. He recommended open reduction for these fractures.[8]

Cooperman, in 1978, reviewed fifteen Triplane fractures. Of these, tomograms were available on five patients and computerized tomography in one patient. It was concluded that the Triplane fracture consisted of two fragments, not three: one fragment consisting of the major part of the tibi-

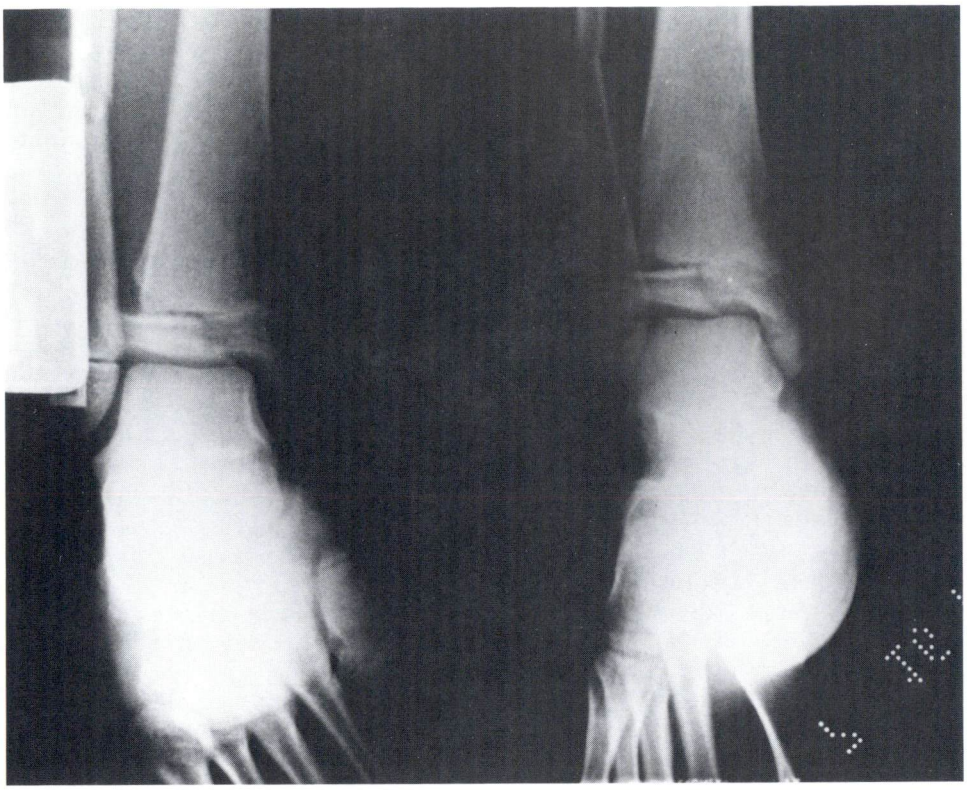

Fig. 1, Case II, A-P View, Transitional Type II Fracture

al shaft with the attached medial malleolus and the anteromedial part of the epiphysis; and the other fragment composed of the remainder of the epiphysis and the posterior metaphyseal fragment with an attached fibula. He concluded closed reduction could be accomplished in most cases.[9]

Since then, multiple authors, in separate studies of Triplane fractures, including the evaluation computerized tomography examination, noted that there could be two to four fragments as well as an associated oblique fracture of the distal fibula, occurring four to six centimeters proximal to the tip of the lateral malleolus.[10] Dias proposed that the Triplane fracture be graded according to the amount of force and the associated fibular fracture.[11]

Most recent authors have found the combined incidence of Triplane and Juvenile Tillaux fractures to be as much as 10% of all of children's ankle fractures, higher than originally thought.

Multiple authors have also suggested that Juvenile Tillaux fractures are more mature versions of the Triplane fracture, occurring when the distal tibial epiphysis has fused to a further extent. Recent studies reveal that the Juvenile Tillaux fracture occurred in older patients, further support this hypothesis. Triplane fractures, involving the medial tibial malleolus, have been found in the most immature patients.

von Laer,[11] in 1985, was the first in the English literature to use the term Transitional fracture. Transitional fractures were actually first suggested by Titze and Ehart in 1962, in the German literature. This was actually two years before Kleiger recognized the Juvenile Tillaux fracture, as mentioned previously.

von Laer, in his study of thirty-two fractures, stressed that age dependency or skeletal immaturity of the distal tibial epiphysis, was responsible for the different fracture patterns that can be seen. These fractures occur by the same mechanisms of injury, that is, external rotation on a plantar flexed foot. The position of the fracture line is exclusively dependent of maturity of the distal tibial epiphysis. He separated

these fractures into Biplane, Triplane I and Triplane II. In Triplane I the metaphyseal portion of the fracture ends in the physis. In Triplane II, the metaphyseal fragment extends through the physis, the epiphysis and into the joint.

TREATMENT

Recommended treatment for nondisplaced fractures is a long leg cast with the ankle in internal rotation for eight weeks. When displacement of greater than two millimeters persists on either the A-P or lateral view, closed reduction under general anesthesia is recommended, using an internal reduction force. If unsuccessful, open reduction should be performed. Tomograms preoperatively should be utilized in these fractures having displacement in order to determine the location and size of the fragment. Associated fibular fractures may complicate the reduction, in that the fibular fracture may need to be reduced before the reduction of the Triplane fracture can be completed.

The overall prognosis for treating these fractures, if properly recognized, is good. Premature closure of the affected epiphyseal plate has been documented, but since the epiphyseal plate is near skeletal maturity, leg length discrepancies are rare.

CONCLUSION

In summary, the Triplane and Juvenile Tillaux fractures are well recognized, usually as separate entities. This is despite the fact that both fractures occur by the same mechanism and within the same age range, an eighteen month period during adolescence when the distal tibial epiphysis fuses, in asymmetric manner. Although it has been alluded to by several authors that the Juvenile fracture is a more mature form of the Triplane fracture, no classification has incorporated these fractures together until recently by von Laer. However, he did not include concommittant fibular fractures in his classifications. A classification system should be present that recognizes the degree of skeletal maturity of the fracture, as well as the amount of force that has occurred during the injury. The term Transitional fracture of the Adolescent Ankle is thus appropriate. A classification now suggested incorporates a sequence by which the classification would progress from the most immature to the most mature fractures, that is:

Type I: Three and four part Triplane fractures, including displacement of the medial malleolus. These would represent fractures occurring in the most immature distal tibial epiphysis.

Type II: The classic two part Triplane fracture, indicating a more mature distal tibial epiphysis.

Type III: The classic Juvenile Tillaux fracture.

Each classification could further be subdivided into those fractures occurring with a concommittant fibular fracture. This would recognize a greater external rotational force that had occurred at the time of the fracture.

The presence of such a classification would allow easier recognizability of these fractures, which are often missed. It would serve as a prognostic indicator to not only fractures which may be immature and have a higher possibility for arthrosis, but also serve to help identify which fractures may need to be treated surgically. In addition, the current eponyms that tend to separate theses fractures could be incorporated into a more manageable classification.

CASE PRESENTATIONS

Case I

D.B., a ten-year-old black female, was seen in the emergency room complaining of left ankle pain. She stated that she had been pushed down steps at school and described the mechanism of external rotation of her ankle. X-rays revealed a Triplane fracture or Transitional type II fracture. There was a two millimeter gap that was present and was accepted and no closed reduction was performed. The patient was placed in a long leg cast with the ankle in neutral for seven weeks. At one year follow-up examination, the patient complained of intermittent pain in the affected

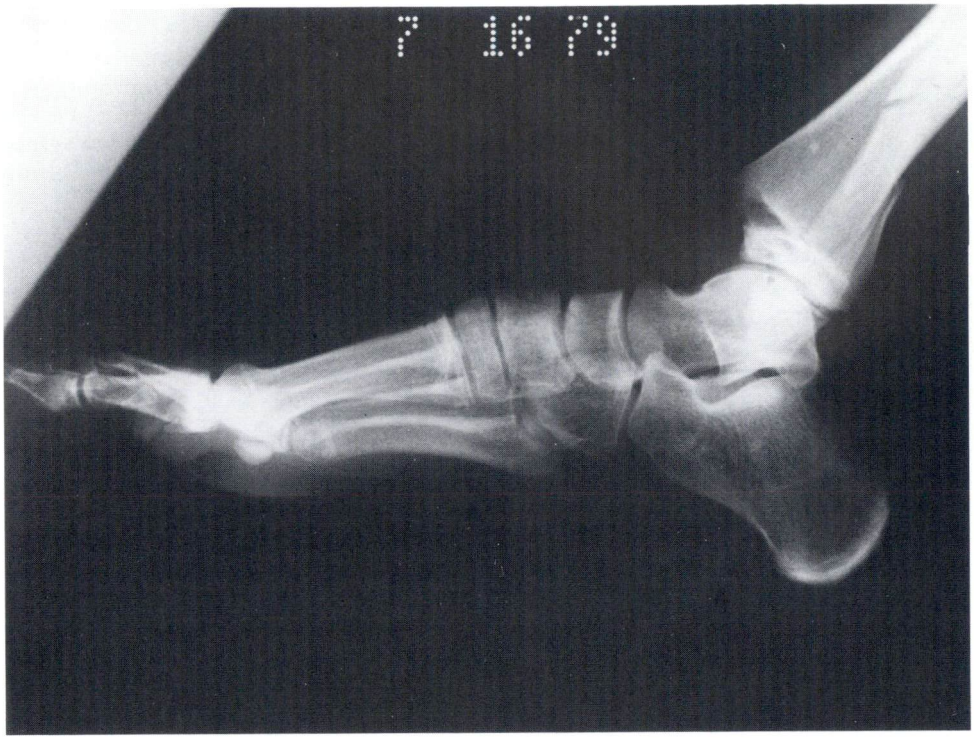

Fig. 2, Case II, Lateral View, Transitional Type II Fracture

ankle when running. Physical examination revealed range of ankle motion to be similar bilaterally. No leg length discrepancy was present. No rotation or angular deformity was present. Comparison x-rays showed that the epiphyseal plate in the affected leg had fused while the non-affected one was open.

Case II

B.A., a twelve-year-old white female, was admitted complaining of right ankle pain, after she felt off her skateboard. X-rays revealed a Triplane fracture or Transitional type II fracture, involving the medial malleolar fracture and a fracture of the distal one-third of the fibula. Closed reduction under general anesthesia was performed and the patient was placed in a long leg cast with internal rotation of the ankle. Cast immobilization was discontinued at six weeks and graduated ambulation was instituted. At the eleven month follow-up examination, the patient denied complaints and ambulated without a limp. Dorsi and plantar flexion were equal. Leg length was also equal. X-rays revealed the distal tibial epiphyseal plate to be fused and the medial malleolus and fibula healed, without displacement or angular deformity.

Case III

C.L., a fifteen-year-old black male,

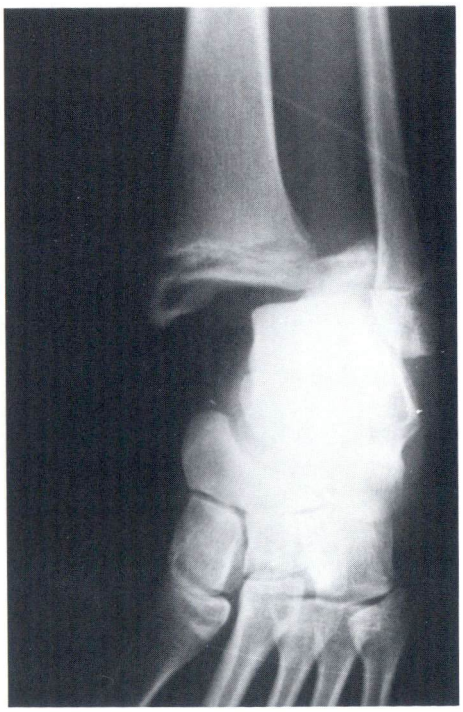

Fig. 3, Case V, A-P View Left Ankle, Transitional Type III Fracture

sustained an external rotation injury to the left ankle when he was tackled during a football game. X-ray revealed a minimally displaced Triplane fracture or Transitional type II fracture. The patient was placed in a long leg cast with the ankle in internal rotation. Weight bearing was allowed at three weeks. A short leg walking cast was applied at six weeks. The cast was removed at nine weeks. The patient sustained a inversion adduction injury to the same ankle at three month post-fracture; however, x-rays were negative for a fracture and the patient had only intermittent pain with full weight bearing. The patient was lost to follow-up examination.

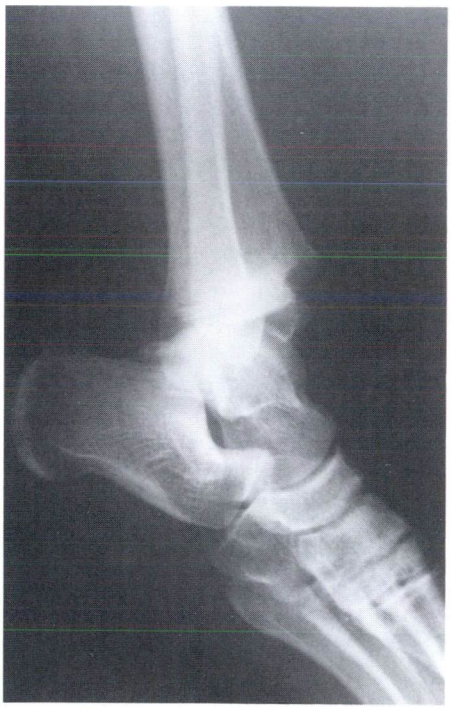

Fig. 4, Case V, Lateral View Left Ankle, Transitional Type III Fracture

Case IV

M.G., a fourteen-year-old white male, sustained an external rotation injury after falling at home. X-rays revealed a Transitional type II fracture or minimally displaced Triplane fracture of the ankle. After closed reduction, a long leg cast was applied with the ankle in internal rotation. A short leg walking cast was applied at four weeks. Immobilization was discontinued at seven weeks. At nine weeks the patient walked with a mild painless limp. Dorsi-flexion was 20 degrees on the right, 15 degrees on the left. Plantar flexion was 30 degrees bilaterally. The fracture was healed with minimal articular incongruity and no angulation at his last examination at one year.

Case V

A.M., a twelve-year-old black female, weight in excess of 200 pounds, sustained a external rotation injury to the left ankle when she lost her balance while on roller skates. She presented to the emergency room with an apparent posterolateral dislocation of the ankle without palpable pulses. X-rays showed a displaced Transitional type III or Juvenile Tillaux fracture with a displaced fragment line between the tibia and fibula. Attempted closed reduction in the emergency room and again under general anesthesia were unsuccessful. At surgery, the large anterolateral fragment was between the tibia and fibula with a tear of the interosseous membrane. Open reduction was successfully performed and the fracture was held with two Kirschner wires. Articular congruity of the ankle mortice was restored. A long leg cast with the ankle in full internal rotation was applied for six weeks, at which time the pins were removed and a short leg cast was applied. Immobilization was discontinued at ten weeks and graduated weight bearing was begun. At one year follow-up examination, x-rays demonstrated completion of fusion of the distal tibial epiphysis. Articular congruity was present. The patient complained of intermittent mild aches associated with inclement weather. Physical examination revealed ambulation without a limp. Dorsi-flexion was 50 degrees on the right and 45 degrees on the left. Plantar flexion was equal bilaterally. A leg length discrepancy of less than one-eighth of an inch was noted.

Case VI

L.H., a twelve-year-old female, sustained an external rotation injury to her right ankle after falling down three steps at home. The patient only complained of minimal pain and was not brought to the emergency room until

swelling began approximately twelve hours later. X-rays, including comparison studies, revealed a nondisplaced, Transitional type III or Juvenile Tillaux fracture; however, initially the diagnosis was missed by the emergency room physician. Two days later, when the patient was referred to Orthopedics, a correct diagnosis was made. The patient was placed in a short leg cast without reduction. Weight bearing was begun at two weeks. Cast immobilization was discontinued at one month. At two months follow-up, the patient denied pain and ambulated without a limp. The patient was lost to subsequent follow-up examination.

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Results of AML Femoral Prosthesis: Minimum One Year Follow-Up Study

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INTRODUCTION

The long term results of cemented total hip arthroplasty using the older cementing techniques have been considered unacceptable to most orthopaedic surgeons. Loosening rates of 19.5% to 50% have variously been reported in 2 to 10 year follow-up studies.[1,18,19] To improve on these results newer cementing techniques have been developed as well as the concept of biologic ingrowth, for fixation of total joint arthoplasty.

Biologic ingrowth is a concept whose goal is to establish a natural, and hopefully enduring interface between the implant and host tissue. More specifically the goals of the biologic ingrowth type of hip replacement are: (1) in the short-term to match the immediate and predictable excellent results of total hip arthoplasty obtained with newer cement techniques, and (2) in the long term to maintain these results with a lower long term failure rate, (hopefully in a healthy femur, free of cement disease). Porous coated implants have been used for over a decade in several U.S. centers. Engh has used a Moore type stem with a sintered type of metallic porous surface since 1977, with good short term results reported.[6,7,8] Results from other authors have also shown good result, with noncemented femoral prostheses.[2,4,17]

The purpose of this paper is to retrospectively report the clinical results of the AML femoral prosthesis at our institution. We have used the AML femoral prosthesis since 1985. The scope of this paper is limited to those patients in whom a primary noncemented AML femoral prosthesis was implanted at least one year prior to this study.

MATERIAL AND METHODS

During the period from July 1985 to March 1988 there were 36 primary, noncemented AML femoral prostheses implanted at our institution. All patients were mailed questionnaires prior to their final follow up examination concerning their preoperative and postoperative status. The questionnaires were based on the Harris hip score system.[13] The total point allocated for pain (44), function (47), deformity (4), and range of motion (5), were unaltered from the Harris hip score system. Of the 36 patients enrolled in this study four were deceased at time of follow up, three were unable to be contacted, and four refused to participate in follow up examination. Hence, there are 25 patients available for follow up examination.

The noncemented femoral prosthesis was combined with various types of acetabular components, based on the appearance of the acetabulum at the time of surgery, and the surgeon's preference. There were eleven self centering components (bipolar), ten porous coated components, and four threaded acetabular components utilized.

The mean patient age at time of surgery was 55.5 years with a range of 32 to 76 years. There were 14 females and 11 males. The average time to follow up examination was 1.8 years with a range of 1.1 years to 3.1 years. There were 14 patients with a preoperative diagnosis of osteoarthritis, I with rheumatoid arthritis, 5 with avascular necrosis of the femoral head, 2 with femoral neck fracture, 1 with post-traumatic arthritis, and 2 with congenital hip dysplasia. The mean preoperative Harris hip score in these 25 patients was 43.7.

The patients in this study routinely received prophylactic perioperative antibiotics, usually a first generation cephalosporin, with the first dose given one half hour prior to beginning of surgery and continued for 48 hours after surgery. Deep venous thrombus prophylaxis was also routinely utilized in some form at the discretion of the operating surgeon. A posterolateral ap-

proach was routinely utilized. The surgical goals are different from those using cement, and one wants to retain as much cancellous bone as possible in all areas that may come in contact with the porous coating of the prosthesis.[10] Postoperatively the patients were managed with an abduction pillow for several days while in bed. Physical therapy was usually instituted on the first postoperative day by dangling the legs at the bedside and ankle pumps. Ambulation with a walker was usually started on the second postoperative day either non-weightbearing or toe-touch weightbearing on the affected extremity. Most patients were discharged on the seventh to tenth postoperative day. Ambulation after discharge was routinely walker or crutches, toe touch weightbearing for approximately six weeks and then progressive weightbearing on the affected extremity at the discretion of the operating surgeon.

CLINICAL RESULTS

The clinical results as represented by the Harris hip scores revealed an average postoperative score of 87.6 **(Table 1).** All patients scores increased after surgery. Seventy six percent of patients had Harris hip score of 80 or greater. Almost all patients commented that they were satisfied with their surgery. There were, however, three exceptions. Patient #3 developed severe heterotopic ossificaiton, which required excision of the heterotopic ossification, treatment with radiation, and revision of the acetabular component twenty-one months after his original surgery. Patient #4 developed progressive pain and underwent revision surgery twenty-two months after his index operation. At the time of revision numerous debris particles were found.[5] Patient #21 is a workmen's compensation case and has been dissatisfied with his surgery secondary to persistent thigh pain even at rest. At this time we have no good explanation for this poor result.

RADIOGRAPHIC RESULTS

A summary of the radiographic data obtained in this study is given in Tables 2 and 3. These tables record the quality of fit of the femoral component and the adaptive bony changes that occurred as outlined by Engh.[6] Engh has classified femoral component fit with the AML femoral prosthesis as either interference fit with uniform contact (type 1), good fit with several areas of contact (type 2), or poor fit with minimal contact area in the femoral diaphysis (type 3). Furthermore, the adaptive bony changes seen in the latest follow up radiographs are outlined.

The adaptive bony change most frequently seen in this study was calcar resorption, noted in 60% of hips **(Table 2).** Calcar resorption seemed to stabilize by one year without any significant change noted in those hips observed beyond one year. Endosteal new bone formation was the second most frequently observed adaptive bony change **(Table 3).** It was most frequently seen near the smooth tip of the stem, or near that area of the prosthesis where the porous coating ended. The bone in these areas gave the appearance of a supporting wedge between the prosthesis and the endosteum. Radiopaque or "white" lines were noted occasionally, most commonly near the smooth tip of the stem **(Table 3).** These lines were usually less than 1 millimeter from the implant surface. No prostheses were noted to have circumferential radiopaque lines.

COMPLICATIONS

There were three cases of heterotopic ossification, only one of which required treatment. There was one urinary tract infection. Metallic debris was found at one revision. There were no fractures or dislocations. There were no superficial or deep infections. No nerve palsies occurred. Two revisions were undertaken, however, no other revisions are under consideration at this time.

DISCUSSION

The concept of biologic ingrowth for fixation of femoral prosthetic implants is based on the idea that osseous tissue will develop within the porous surface of the implant and result in a solid bone-implant interface. As discussed previously the goal of biologic ingrowth is twofold: the short-term goal is to

TABLE 1

CLINICAL DATA

PATIENT	AGE	ACETABULUM	YRS F/U	DIAGNOSIS	PRE-OP	POST-OP
#1	58	bipolar	3.1	AVN	68	95
#2	58	bipolar	2.8	AVN	33	95
#3	56	bipolar	2.7	OA	43	66
#4	50	porous	2.5	OA	49	68
#5	49	threaded	2.4	RA	45	66
#6	47	porous	2.3	OA	43	96
#7	48	porous	2.3	OA	41	97
#8	40	bipolar	2.3	AVN	49	81
#9	32	bipolar	2.1	AVN	55	100
#10	50	threaded	2.0	AVN	27	100
#11	59	bipolar	2.0	OA	39	97
#12	38	threaded	1.8	CHD	30	95
#13	76	bipolar	1.8	FNF	N/A	97
#14	70	porous	1.8	OA	56	80
#15	45	porous	1.4	PTA	45	100
#16	56	porous	1.4	OA	16	77
#17	56	porous	1.3	OA	27	75
#18	57	threaded	1.3	OA	49	91
#19	65	porous	1.2	OA	58	98
#20	48	bipolar	1.2	OA	58	98
#21	35	bipolar	1.1	OA	38	44
#22	66	porous	1.1	OA	63	100
#23	72	bipolar	1.1	FNF	N/A	98
#24	61	porous	1.1	OA	40	88
#25	39	bipolar	1.1	CHD	34	89
average	**55.5**		**1.8**		**43.7**	**87.6**

Legend: bipolar = self-centering type acetabulum; porous = AML Porocoat acetabulum; threaded = one of several different porous coated/screw in type acetabular components. AVN = avascular necrosis of the femoral head; RA = rheumatoid arthritis; OA = osteoarthritis; FNF = femoral neck fracture; PTA = post-traumatic arthritis; CHD = congenital hip dysplasia.

N.B. Pre-operative Harris hip scores were not included in the femoral neck fracture patients because they were not felt to be representative. For example, patient #23 would have given herself 91 out of 91 possible points for pre-operative pain and function scores even though she had an acute displaced femoral neck fracture.

achieve the immediate and predictable excellent results of cemented hip arthroplasty, and the long-term goal is to maintain these results with lower long-term failure rates, in healthy femurs free of cement disease.[8] The overall quality of the patient's bone is theoretically a crucial factor insofar as giving the implant the proper support to allow for biologic fixation to occur. The ideal candidates for porous coated prostheses seem to be those patients who are younger, healthier, and more active. These patients seem to be the best candidates because they have better quality bone and they are at higher risk for failure with conventional cemented hip arthroplasty.

In attempting to meet the first goal of biologic fixation it seems that initial fit of the implant of primary importance. Engh in describing his surgical technique for the AML femoral prosthesis felt it was desirable to attempt to take advantage of the superior mechanical properties of cortical bone compared with cancellous bone by establishing extensive cortical bone-implant contact.[6] As much cancellous bone as possible is retained in the intertrochanteric area to be in contact with the porous coating of the prosthesis. The implant is larger in cross-section than the intramedullary rasps and trial prostheses to take advantage of tight initial fit. This concept is probably most important in the older patient with osteoporosis whose cancellous bone strength is decreased.

This study presents the results of 25 patients with 25 primary hip arthroplasties utilizing an uncemented

TABLE 2

RADIOGRAPHIC DATA (INTERTROCHANTERIC ZONE AND TYPE OF FIT)

PATIENT	CALCAR	SETTLE	CANCELLOUS CHANGE	WHITE LINES	TYPE FIT
#1	+	–	–	–	1
#2	+	–	–	–	1
#3	–	–	–	–	1
#4	–	–	–	+	1
#5	+	–	–	–	1
#6	+	–	–	–	2
#7	+	–	–	–	3
#8	+	–	–	–	2
#9	+	–	+	–	2
#10	+	–	–	+	1
#11	–	–	–	+	1
#12	+	–	–	+	1
#13	–	–	–	–	2
#14	–	–	–	–	1
#15	+	–	–	–	3
#16	–	–	–	–	1
#17	–	–	–	–	1
#18	+	–	–	–	1
#19	+	+	–	+	2
#20	–	–	–	–	2
#21	–	–	–	–	1
#22	–	–	–	–	1
#23	+	+	+	+	3
#24	+	–	–	–	1
#25	+	–	–	–	1

Legend: CALCAR = calcar resorption; SETTLE = setting; CANCELLOUS CHANGE = cancellous bone changes; WHITE LINES = radiopaque lines around the implant; TYPE FIT = type of fit as described by Engh.

AML porous coated femoral prosthesis and various acetabular components. The results compare favorably with the report of Engh presenting the 2 to 5 year follow up results of 26 patients with primary hip replacement using the AML femoral component and cemented acetabular components. The Harris hip scores in that study rose from average preoperative score of 58.8 to an average postoperative score of 89.0 at one year, and 91.4 at two years.[6] The mean preoperative Harris hip score in this study was 43.7 and the mean postoperative score was 87.6. Other studies have reported similar results.[9,17]

The authors are encouraged by the stable radiographic appearance of the implants. The adaptive bony changes noted in the femur have been discussed in detail by Engh.[8] Currently none of the femurs in this study have radiographic changes that are of pathologic concern. Generalized stress shielding and diffuse disuse osteopenia with this component was not noted in any of our patients. None of the femoral components has shifted noticeably from the initial postoperative radiographs.

CONCLUSION

Total hip arthroplasty utilizing the porous coated AML noncemented femoral prosthesis provides a consistently reliable hip replacement with few complications, and a high patient satisfaction rate. The Harris hip scores and radiographic appearance of the femoral components are both more than satisfactory in the opinion of the authors. Although still early in the learning curve with this prosthesis, the reproducibility of satisfactory results is very gratifying. These short term results appear promising, and this prosthesis seems to have met the first of its two goals, (i.e. immediate and predictable results of cemented total hip arthroplasty) in this small study group. Overall, the porous coated AML noncemented femoral prosthesis has provided us with consistently reliable implant for our younger more active patients in need of total hip arthroplasty.

TABLE 3

RADIOGRAPHIC DATA (INTRAMEDULLARY ZONE)

PATIENT	CORT HYPERTROPHY	STEM SHIFT	WHITE LINES	ENDO BONE
#1	–	–	–	–
#2	–	–	–	–
#3	–	–	+	–
#4	–	–	–	–
#5	–	–	–	–
#6	–	–	–	–
#7	+	–	–	–
#8	–	–	–	–
#9	–	–	–	+
#10	–	–	–	–
#11	+	–	–	+
#12	–	–	+	–
#13	–	–	–	–
#14	+	–	+	+
#15	+	–	+	+
#16	–	–	–	–
#17	–	–	–	–
#18	–	–	–	+
#19	–	–	–	–
#20	+	–	–	–
#21	–	–	–	–
#22	–	–	–	–
#23	–	–	+	+
#24	–	–	–	+
#25	–	–	–	–

Legend: CORT HYPERTROPHY = cortical hypertrophy; WHITE LINES = radiopaque lines around the implant; ENDO BONE = endosteal new bone formation.

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