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Current Concepts Review

Surgical Management of Irreparable Rotator Cuff Tears

What Works, What Does Not, and What Is Coming

Marion Burnier, MD, Bassem T. Elhassan, MD, and Joaquin Sanchez-Sotelo, MD, PhD

Investigation performed at the Mayo Clinic, Rochester, Minnesota

- The term *functionally irreparable rotator cuff tear* (FIRCT) is intended to capture patients who would experience failure of an attempted primary rotator cuff repair because of the extent of cuff muscle and tendon damage and other patient-related factors.
- Debridement, biceps tenodesis, and/or partial repair of the torn rotator cuff may reduce pain and improve function for selected patients with a FIRCT.
- Static soft-tissue restraints to abnormal glenohumeral head translation, such as implantation of an absorbable balloon in the subacromial space or superior capsular reconstruction (SCR), appear to reduce pain and improve function, although some have reported a relatively high structural failure rate with SCR.
- When improvement of strength is the primary goal of treatment, tendon transfers provide a viable treatment alternative; most tendon transfers for management of a FIRCT are currently performed with arthroscopically assisted techniques.
- Transfer of the lower portion of the trapezius has emerged as a successful alternative to transfer of the latissimus dorsi, whereas transfer of the latissimus dorsi to the lesser tuberosity is being explored as an alternative to transfer of the pectoralis major for functionally irreparable subscapularis tears.

Rotator cuff tears (RCTs) are a very common source of shoulder disability and pain[1-4]. Conservative management and surgical repair lead to successful outcomes in many individuals. However, some rotator cuff tears cannot be reliably repaired[1]. In some individuals with a symptomatic rotator cuff tear that cannot be reliably repaired, conservative treatment directed to retraining of the deltoid and residual rotator cuff can be very effective. When conservative treatment fails, reverse arthroplasty is a successful alternative in older patients, especially in the presence of cuff tear arthropathy[5,6]. However, in younger patients with intact articular cartilage, joint-preserving procedures are preferred. These procedures range from debridement or partial repair to tendon transfers, with many different options in between including balloon spacer or superior capsular reconstruction (SCR). Currently, there is some controversy and confusion about the relative indications of these procedures[7,8]. This review article provides some clarity regarding the features that contribute to the irreparability of a torn rotator cuff, reviews the reported outcomes for available surgical alternatives, and provides an algorithmic approach to aid in the decision-making process for the treatment of young patients with a functionally irreparable rotator cuff tear (FIRCT) who are not candidates for reverse shoulder arthroplasty.

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Defining the Terms: How to Predict That Tendon Repair Will Fail

Before considering treatment alternatives for tears that cannot be reliably repaired primarily, we need to define their characteristics. Most surgeons use the terms *massive* and *irreparable* to define these tears, but these words do not accurately capture the nature of the problem[5]. *Massive* refers to size, but one could argue that an acute tear involving the whole rotator cuff is massive but can often be repaired primarily; thus, massive does not always equal irreparable. By the same token, some chronic tears may have extensive muscle atrophy and fatty infiltration. Even if they are not irreparable, in the sense that the tendon edge can be surgically secured to its footprint, a repair of such a tear with muscle damage may not lead to tendon healing[9-12] or a good clinical outcome[11]. The term *FIRCT* may better capture the clinical problem that we are addressing in this review article.

Risk Factors for Failure

When analyzing the available data on failure of primary cuff repair, a major problem resides in the very definition of failure[13]. Failure can be defined as the need for reoperation, structural failure of the repair, lack of restoration of motion or strength, or poor patient-reported outcomes, including persistent pain. To further complicate things, structural failure may not be equally identified by various imaging modalities (magnetic resonance imaging [MRI], ultrasound, and computed tomography [CT] arthrogram). Many risk factors that may contribute to a higher likelihood of failure have been identified in the literature; Table I summarizes those most commonly encountered.

Extent of Cuff Damage

Several reports have identified various associations between the extent of cuff damage and failure of primary repair[11,14]. Tear size is clearly associated with outcome[10,13,15]. Cofield defined massive tears as those that are >5 cm^1, and Gerber et al., as those involving ≥2 complete tendons[2]; Nobuhara et al. defined the size of the tear by estimating the amount of humeral head exposed[3]. The definition by Gerber et al. may be associated more consistently with function and surgical outcomes[4,13,16]. However, as mentioned above, a massive RCT is not necessarily irreparable[2,13].

Other factors are equally important to characterize a functionally irreparable tear: chronicity, retraction, length and quality of the remaining tendon stump as measured on MRI[17], muscle atrophy and fatty infiltration[18], and fixed abnormal glenohumeral translation (superior humeral head migration for the posterosuperior cuff, often identified as a decreased acromion-tuberosity distance on radiographs, and anterior subluxation for subscapularis tears). In addition, tears at the muscle tendon junction carry a different prognosis than the more common tears off bone[11,14]. Similarly, tear extension to the lower subscapularis or teres minor carries a worse prognosis. Finally, articular cartilage degeneration may lead to persistent pain even if the repair remains structurally intact.

TABLE I Features That May Contribute to a Higher Likelihood of Failure After Primary Rotator Cuff Repair

Extent of cuff damage
Size, retraction, and chronicity of the tear
Tendon length and quality
Muscle atrophy and fatty infiltration
Location (off bone vs. muscle-tendon junction)
Fixed abnormal glenohumeral translation
Tear extension into the lower subscapularis and/or teres minor
Articular cartilage degeneration
Other patient-related factors
Age
Comorbidities (smoking, diabetes, or hypercholesterolemia)
Prior treatments (prior surgery or multiple corticosteroid injections)
Compliance
Expectations
Psychosocial factors (catastrophizing, beliefs, or secondary gains)

Other Patient-Related Factors

Advanced age is an independent risk factor for failure[9,14]. Smoking[19,20], diabetes[21], and hypercholesterolemia adversely affect healing. Prior recent or multiple steroid injections may increase the risk of infection or repair failure[22]. Preoperative range of motion is critically important as well; pseudoparalysis in elevation may be difficult to correct with procedures other than reverse shoulder arthroplasty[23]. Likewise, revision rotator cuff repair and a narrow acromiohumeral distance are associated with a lower success rate[24,25]. Lack of compliance may also lead to structural failure[26]. Finally, psychosocial factors may influence outcome: patients who do not believe in physical therapy do worse without surgery, patients with the potential for secondary gains (Workers' Compensation) also may do worse[27], and patients with preoperative depression or a catastrophizing personality do not seem to improve as much in terms of pain[28].

Implications for Treatment

When a patient with a torn rotator cuff is evaluated, all factors summarized above need to be considered to try to predict whether a primary cuff repair is a reasonable treatment alternative. Active preoperative range of motion is particularly important in the decision-making process. Shimokobe et al. demonstrated that active external rotation of <25° before surgery was a significant risk factor for retear in patients with posterosuperior large or massive tears[29].We favor alternatives to primary repair for patients presenting with a tear involving >2 tendons and any of the following risk factors: advanced fatty infiltration, tendon length of <15 mm measured on MRI, retraction beyond the rim of the glenoid, fixed subluxation, tear at the infraspinatus muscle-tendon junction, or failure of a prior well-done repair. These patients are considered to have a functionally irreparable tear, and as such are considered for the treatment

options that are discussed in the following section. Partial repair and pectoralis minor transfer are included in the tables and figures for completeness but are not discussed in the text.

Joint-Preserving Procedures for FIRCTs

Debridement, Acromioplasty, and Biceps Tenotomy or Tenodesis

The biceps and labrum may contribute to pain in rotator cuff disease[9]. Improvements in pain and function may occur after simply dividing the tendon of the long head of the biceps, with or without adding tenodesis, cuff debridement, and/or acromioplasty[30-32]. Walch et al. reported on 307 arthroscopic tenotomies in patients with a mean age of 64.3 years[33]. At a mean follow-up of 57 months (range, 24 to 168 months), pain was substantially decreased. However, longer follow-up was associated with loss of active external rotation, increasing weakness, and progression of osteoarthritis. Furthermore, fatty infiltration of the teres minor and severe fatty infiltration of the infraspinatus negatively influenced clinical and radiographic outcomes. Pander et al., in a recent report on 39 patients who were followed for a mean of 6.5 years after debridement with or without tenotomy[34], noted that pain scores improved and tenotomy did not influence outcomes. Debate continues over the relative indications of biceps tenotomy versus tenodesis. Tenotomy without tenodesis is associated with a higher rate of cosmetic deformity and cramping, but tenodesis may cause pain at the tenodesis site[35,36]. The benefits and risks of acromioplasty at the time of debridement are also a matter of discussion. Adding an acromioplasty was found to be beneficial by Walch et al. only when the acromiohumeral distance was >6 mm[33]. However, many surgeons have warned regarding the risk of anterosuperior escape and possibly worsening cuff tear arthropathy when the coracoacromial arch is destabilized as a result of acromioplasty[37,38].

Balloon Implantation

A balloon spacer is a preshaped inflatable device made of copolymer poly-DL-lactide and ε-caprolactone material that biodegrades over 12 months. This procedure involves implantation of the balloon spacer between the humeral head and the acromion (Fig. 1). It has not yet been approved by the U.S. Food and Drug Administration. The balloon may be inserted percutaneously or surgically (under arthroscopic visualization). It can be used as a stand-alone treatment or added to a rotator cuff repair to (1) further compress the cuff to the footprint and (2) temporarily prevent proximal humeral head migration while the repair heals. There is limited evidence regarding the outcome of balloon implantation. Senekovic et al.[39] reported outcomes in a series of 24 patients with a mean age of 68.8 years. Functional improvements were maintained at a mean follow-up of 5 years, with a subjective patient satisfaction rate of 86.4%. However, the study group was composed not only of patients with irreparable cuff tears but also those with reparable cuff tears treated with partial repair. Deranlot et al.[40] reported substantial improvements in range of motion

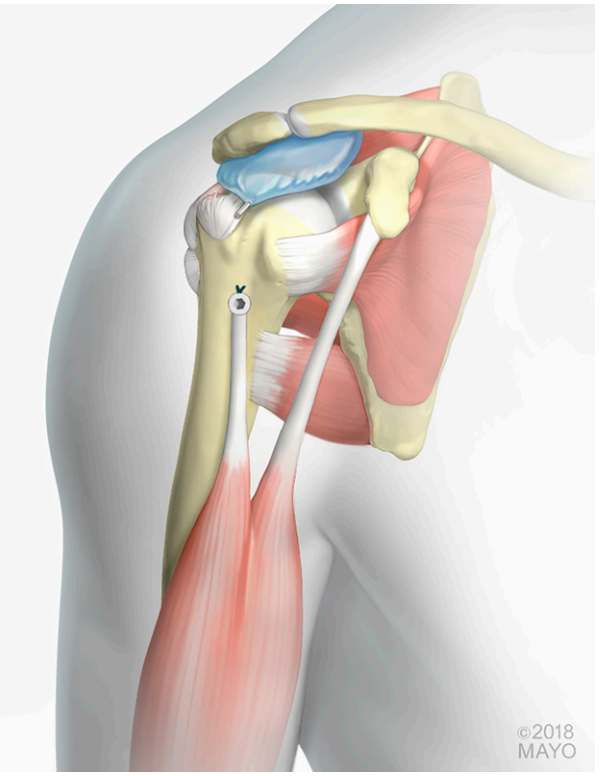

Fig. 1
Subacromial balloon. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

and in the mean Constant score (from 44.8 preoperatively to 76.2 at the latest follow-up) for a series of 39 shoulders with a minimum 1-year follow-up. Another study that included 24 shoulders described less satisfactory outcomes, with a 46% satisfaction rate and a 16.7% complication rate (anterior migration of the balloon, transient deficit of the lateral cutaneous nerve of the forearm, and infection)[41]. Subscapularis insufficiency is considered a contraindication for balloon implantation for fear of anterior migration of the balloon, while a reparable subscapularis tear is not necessarily considered a contraindication.

Graft Interposition

Graft material may be used either to bridge the gap (graft interposition) between the tendon edge and the bone footprint or, more commonly, to augment a direct repair by adding to the mechanical strength, healing potential, or both. Ono et al.[42] reviewed the literature to compare augmentation and bridging for the treatment of large to massive RCTs. With an estimated healing rate of 64% for augmentation and 78% for bridging, they reported no significant difference between the 2 techniques, except for lower pain scores on the visual analog scale in the bridging group. Grafts considered include the biceps tendon[43], fascia lata, human dermal collagen matrix allografts[44], xenografts[45], and synthetic grafts[46]. In a literature review of graft utilization in the bridging reconstruction for FIRCT, Lewington et al.[47] concluded that allograft and xenograft techniques

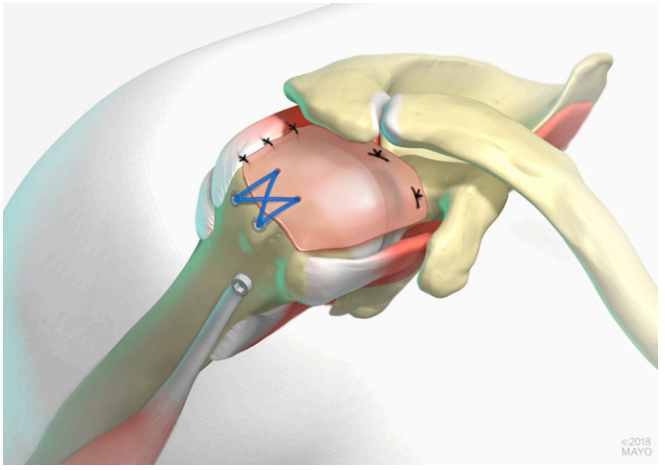

Fig. 2
Superior capsular reconstruction. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

appeared to be favorable, with functional improvement and image-proven graft survival.

SCR

Mihata et al.[48] developed the concept of implanting a thick layer of fascia lata autograft fixed to the superior glenoid rim medially and to the greater tuberosity laterally in order to restore a stable fulcrum and interpose tissue between the humeral head and the coracoacromial arch (Fig. 2). The ability to provide a static restraint against superior humeral head migration and restore a stable fulcrum has been demonstrated in several biomechanical studies[49,50]. SCR resists proximal humeral head migration better than bridging the supraspinatus tendon edge to the greater tuberosity using an interposition graft[48]. Grafts most commonly used include fascia lata autograft[51], acellular dermal allograft[52], and biceps tendon[53]. It is recommended to repair the graft to any remaining posterosuperior cuff. Some surgeons combine SCR with a partial or a complete cuff repair. It is important to understand that different surgeons have described the use of SCR with different graft materials, which likely has a profound influence on the outcomes reported. Using fascia lata in 31 shoulders (23 patients with a mean age of 65.1 years [range, 52 to 77 years]), Mihata et al. reported improvements in active elevation (64°), external rotation (14°), and internal rotation (2 vertebral levels) at a mean follow-up of 34.1 months[51]. However, other authors have reported worse results. Lee and Min, in a study of 36 shoulders managed with either fascia lata autograft or dermal allograft and followed for a mean of 24.8 months, reported a 36.1% retear rate[24].

Using dermal graft for SCR, Denard et al. reported an 18.6% revision rate in a cohort of 59 patients, including 7 patients who underwent revision to reverse shoulder arthroplasty (mean follow-up, 17.7 months)[52]; when thinner (<1-mm) grafts were excluded, the rate of success was 75.5% for shoulders in Hamada stage 1 or 2. Despite a 45% rate of complete healing of the graft, 74.6% of the shoulders were considered a success. According to these preliminary outcomes, arthroscopic SCR of FIRCTs should be reserved for patients with adequate posterior rotator cuff[24].

Tendon Transfers

Muscle-tendon units around the glenohumeral joint may be considered for transfer to the greater or lesser tuberosity. Transfer of tendons has the potential to provide a source of vascularized autograft, a tenodesis effect, and powered tendon fibers. As a general rule, transferred tendons are expected to provide at best 1 less level of strength compared with their native function. Most of these transfers can now be performed with arthroscopically assisted techniques.

Latissimus Dorsi

The latissimus dorsi (LD) tendon can be detached from the humerus through a posteroinferior approach to the axillary region or endoscopically. It can be transferred under the deltoid to the greater tuberosity using open or arthroscopically assisted techniques (Fig. 3). The LD provides sufficient strength and amplitude with a good line of pull, but poor synergism. Buijze et al. reported a 47% increase in length when the LD was

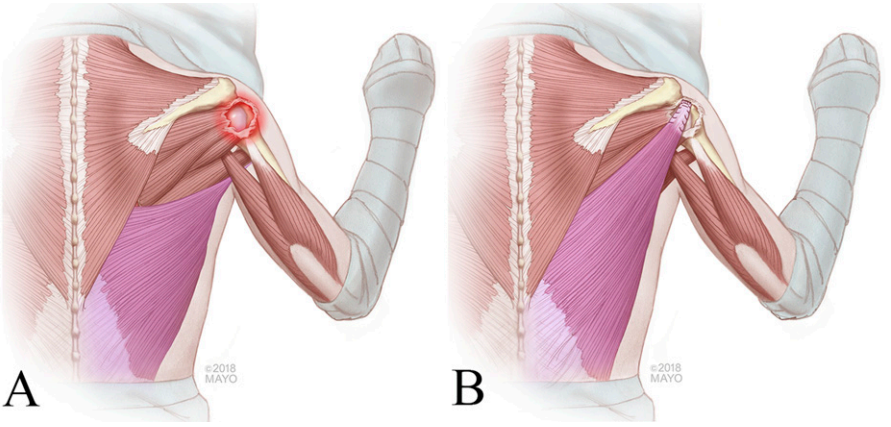

Fig. 3
Illustrations showing the shoulder before (**Fig. 3-A**) and after (**Fig. 3-B**) LD transfer to the greater tuberosity (posterosuperior). (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

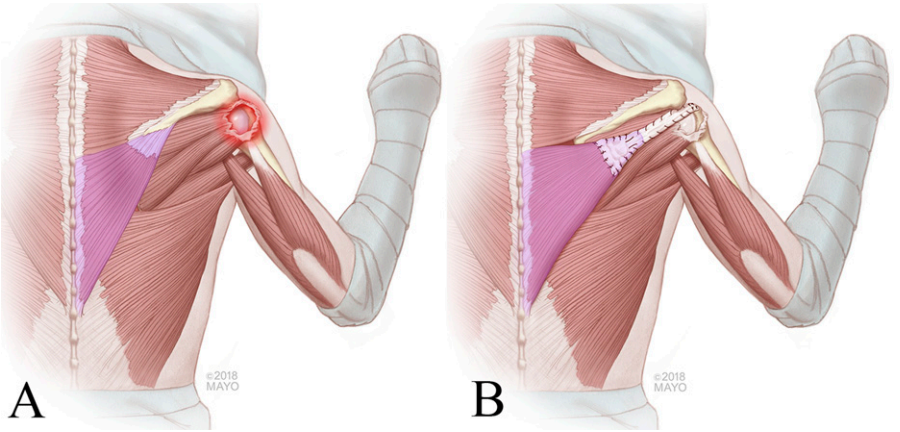

Fig. 4

Illustrations showing the shoulder before (**Fig. 4-A**) and after (**Fig. 4-B**) transfer of the lower trapezius. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

transferred to the greater tuberosity[54]. The ideal site of attachment is debated. A more anterior attachment to the front of the greater tuberosity or the subscapularis maximizes the tenodesis effect and provides more complete humeral head coverage[55-57]. However, better moment arms for external rotation and elevation may be achieved by fixation into the infraspinatus insertion site[58-60].

Two studies have found good outcomes at long-term follow-up[61,62]. Gerber[62] reported 74% good or excellent results at a mean of 10 years. El-Azab et al.[61] reported good pain relief, function, and strength in 93 patients at a mean follow-up of 9 years, with a 10% failure rate and a 4% rate of revision to a reverse arthroplasty. However, progression of arthritic changes in 30% to 40% of shoulders has been reported[62,63]. The outcome of arthroscopically assisted techniques has been described by Castricini et al.[64] in a series of 86 patients with a mean 3-year follow-up. There were substantial improvements in pain and range of motion; strength improved from a mean (and standard deviation) of 1.6 ± 0.7 preoperatively to 4.3 ± 2.3 at the most recent follow-up. Worse outcomes in motion, strength, and Constant scores were observed in patients who had previously undergone cuff repair[64,65].

Balance in the coronal and transverse planes is best when the subscapularis and deltoid are intact[66]. Several studies have described worse outcomes in patients with associated subscapularis tears[63,67,68]. Similarly, worse results have been shown in patients with passive abduction or flexion of <80°, as well as true pseudoparalysis[57,69]. Fatty infiltration of the teres minor is also associated with worse outcomes[70,71]. Most agree that LD transfer is particularly indicated in young and active patients with functional subscapularis and teres minor tendons and active elevation of >80°.

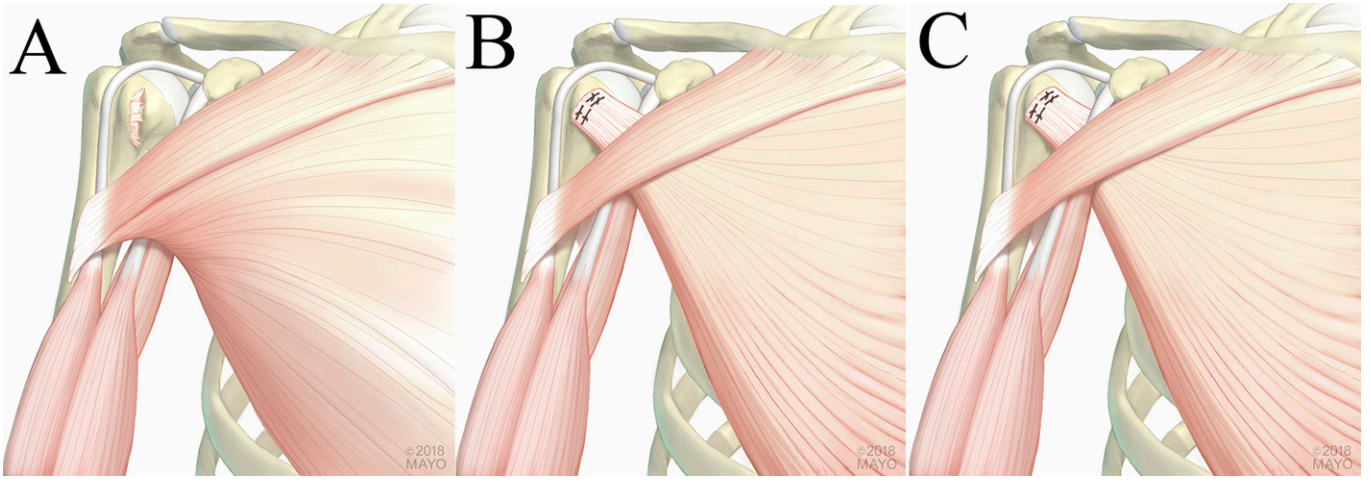

Fig. 5

Illustrations of the PM transfer showing an anterosuperior irreparable cuff tear (**Fig. 5-A**), treated with the original transfer of the PM from the humeral shaft to the lesser tuberosity to repair the lower part of the subscapularis anterior to the conjoined tendon as described by Gerber et al.[77] (**Fig. 5-B**), and with the modified technique of subcoracoid transfer of the clavicular head of the PM described by Resch et al.[78] (**Fig. 5-C**). (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

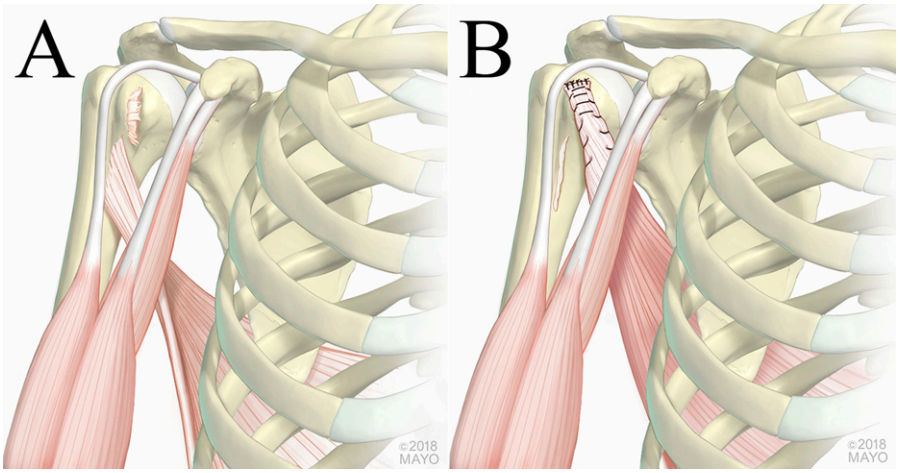

Fig. 6

Illustrations showing the shoulder before (**Fig. 6-A**) and after (**Fig. 6-B**) LD transfer to the lesser tuberosity (anterior). (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

Combined LD and Teres Major Tendon Transfer

In 1934, L'Episcopo described the combined transfer of the LD and teres major muscle to the proximal humeral shaft to regain external rotation in brachial plexus palsy[72]. The original technique was then modified by Habermeyer et al. to treat FIRCT, using 1 incision on the posterior border of the deltoid to avoid deltoid detachment[73]. In their series of 20 patients with a mean age of 55.8 ± 6 years, the mean Constant score increased 34.8 points after 2 years of follow-up. At 5 years, mean flexion and external rotation had increased from 119.4° to 169.3° and from

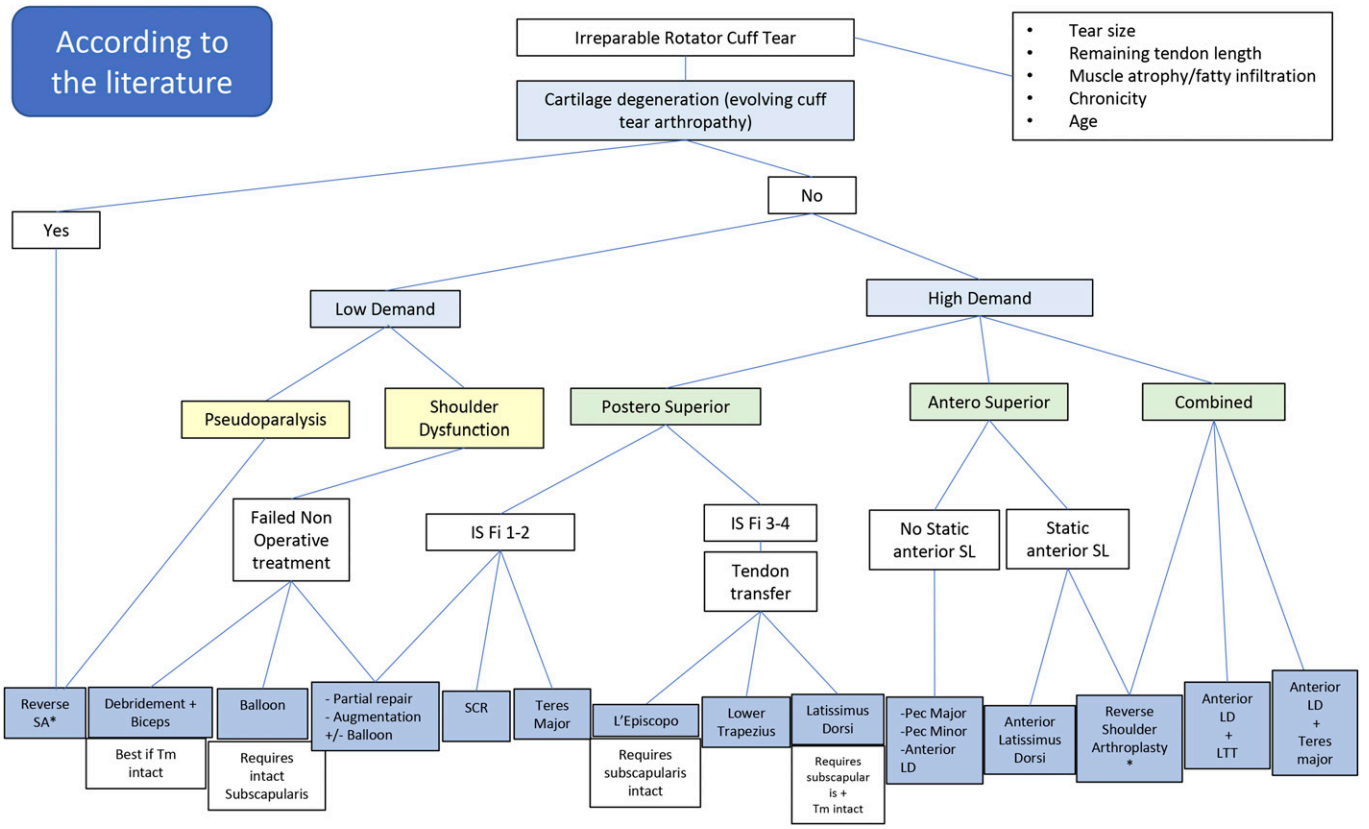

Fig. 7

Evidenced-based algorithm for the management of FIRCTs. *Tendon transfer (TT) added to reverse shoulder arthroplasty (SA) if there is combined loss of elevation and external rotation (CLEER), i.e., pseudoparalysis in both elevation and external rotation. IS Fi = infraspinatus fatty infiltration, SL = shoulder laxity, Tm = teres minor, SCR = superior capsular reconstruction, pec = pectoralis, LD = latissimus dorsi, and LTT = lower trapezius transfer.

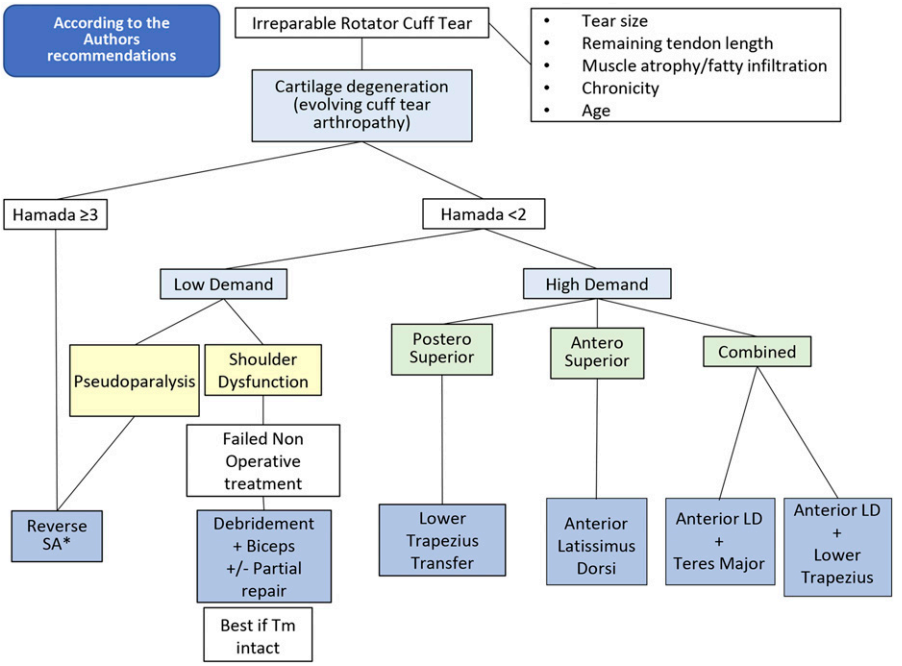

Fig. 8

The preferred procedures of the authors. SA = shoulder arthroplasty, Tm = teres minor, and LD = latissimus dorsi. *Tendon transfer (TT) added to reverse shoulder arthroplasty (SA) if there is combined loss of elevation and external rotation (CLEER), i.e., pseudoparalysis in both elevation and external rotation.

12° to 35°, respectively. Boileau et al.[38] reported the results of this transfer through a deltopectoral approach to the posterolateral aspect of the humerus, close to the teres minor insertion. At mid-term follow-up (mean, 52 months), 84% of the patients treated for posterosuperior FIRCT were satisfied, with a mean gain in active external rotation of 26° with the arm at the side and 18.5° in 90° of abduction. In the study by Habermeyer et al., transfer of only the LD was compared with transfer of the combined LD-teres major muscle in 2 groups of 17 patients who were followed for 6 years[73]. Both techniques achieved good functional results, but isolated LD transfer led to better active abduction and flexion and no progression of cuff tear arthropathy. The L'Episcopo procedure had worse results in patients with a nonfunctional and/or irreparable subscapularis.

Lower Trapezius Transfer (LTT)

The lower portion of the trapezius has a line of pull similar to the infraspinatus. In addition, it has good strength and synergism. However, it lacks enough amplitude to reach the greater tuberosity, requiring an indirect transfer (Fig. 4). Biomechanical studies have shown that the moment arm in external rotation is superior for the lower portion of the trapezius in adduction and superior for the LD in abduction. This technique was initially developed as an open procedure for brachial plexus palsy[74], but it is currently performed with arthroscopic assistance for FIRCTs[75]. Elhassan et al. reported on 33 LTTs for FIRCTs[76]. At a final follow-up of nearly 4 years, range of active motion increased considerably, with mean improvements of 50° in forward flexion, 50° in abduction, and 30° in external rotation. The cohort study included 11 patients with evidence of fatty infiltration of the teres minor muscle; teres minor dysfunction did not seem to influence outcomes. Worse results were obtained in patients with a nonfunctional and/or irreparable subscapularis; however, since the LTT does not impact the balance between external and internal rotator muscles, subscapularis insufficiency is not considered an absolute contraindication. Transfer of the lower

TABLE II Anterosuperior FIRCT Treatment Options*

	Pectoralis Minor Transfer	Pectoralis Major Transfer	Anterior LD Transfer
Tear extent	Upper subscapularis	Whole subscapularis	Whole subscapularis
May correct dynamic anterior instability	No	No	Yes
May correct static anterior instability	No	No	Possible

*FIRCT = functionally irreparable rotator cuff tear, and LD = latissimus dorsi.

TABLE III Posterosuperior FIRCT Treatment Options*

	Partial Repair or Interposition Graft	Debridement	Balloon	SCR	LD Transfer	LTT
Age and activity level	Low to moderate	Older patient and low demand	High demand and reasonable strength	High demand and reasonable strength	Younger patient and severe weakness	Younger patient and severe weakness
Pseudoparalysis in elevation	Questionable	No	Questionable	Questionable	Questionable	Questionable
Pseudoparalysis in external rotation	Questionable	No	No	No	Yes	Yes
Teres minor	Questionable	Best if intact	Best if intact	Best if intact	Best if intact	May be involved
Subscapularis	Questionable	Best if intact	Best if intact	Best if intact	Best if intact	Best if intact

*FIRCT = functionally irreparable rotator cuff tear, SCR = superior capsular reconstruction, LD = latissimus dorsi, and LTT = lower trapezius transfer.

portion of the trapezius has emerged as a successful alternative to transfer of the latissimus dorsi.

Pectoralis Major (PM)

Transfer of a portion of the PM—the clavicular head, the sternal head, or the superior portion of the PM—is the transfer most commonly considered for functionally irreparable subscapularis tears. Gerber et al. originally described transfer of the PM tendon from the humeral shaft to the lesser tuberosity anterior to the conjoined tendon[77] (Figs. 5-A and 5-B). To provide a potentially better line of pull, to our knowledge, Resch et al.[78] were the first to report the modified technique of subcoracoid transfer of the clavicular head of the PM (Fig. 5-C). In a series of 12 patients followed for 28 months, they reported pain relief as well as subjective and objective functional improvements; all 4 shoulders that had been unstable preoperatively were stable at the latest follow-up. The authors did not report any instances of musculocutaneous nerve dysfunction. Moroder et al. recently reported satisfactory long-term outcomes in a cohort of 27 patients treated with a subcoracoid PM transfer[79]. The initial increase in strength eventually returned to the preoperative level, but 77% of the patients were very satisfied at a mean follow-up of 10 years. However, the outcome reported by others has not replicated the experience of Resch et al.[78]. Gavriilidis et al. reported no significant increase in range of motion in 15 patients at a mean follow-up of 37 months[80]. Elhassan et al. reported the outcomes of transfer of the PM sternal head in 11 patients with isolated subscapularis tendon tears and 11 patients with massive rotator cuff tears[81]. Despite improvements in pain and functional outcomes, they reported structural failures in 3 patients with isolated subscapularis tears and 4 patients with massive tears.

Anterior LD

Since the pectoralis major and minor both originate from the anterior aspect of the chest, their lines of pull do not replicate the orientation of the subscapularis. As such, they may worsen anterior humeral head subluxation[81]. Elhassan et al. investigated the feasibility of transferring the LD to the lesser tuberosity as an alternative for anterosuperior FIRCTs[82] (Fig. 6). Amplitude and excursion were found to be appropriate, with low risk of compression of the axillary, radial, and musculocutaneous nerves. The procedure may be performed using open or arthroscopic techniques. To date, the only study, to our knowledge, on the outcome of this technique is by Kany et al.[83].

TABLE IV Grades of Recommendation for the Treatment of Functionally Irreparable Posterosuperior Rotator Cuff Tear

Type of Treatment*	Grade of Recommendation†
Debridement	C
Balloon	C
Graft interposition	C
Partial repair	C
SCR	C
Isolated LD	C
Combined LD and TM	C
TM	C
LTT	C

*SCR = superior capsular reconstruction, LD = latissimus dorsi, TM = teres major, and LTT = lower trapezius transfer. †According to Wright[84], grade A indicates good evidence (Level-I studies with consistent findings) for or against recommending intervention; grade B, fair evidence (Level-II or III studies with consistent findings) for or against recommending intervention; grade C, poor-quality evidence (Level-IV or V studies with consistent findings) for or against recommending intervention; and grade I, insufficient or conflicting evidence not allowing a recommendation for or against intervention.

An Algorithmic Approach to the Surgical Management of FIRCTs

A comprehensive algorithm summarizing the indications of the various surgical procedures according to the literature is provided in Figure 7. Our preferred surgical techniques are summarized in Figure 8. Anterosuperior and posterosuperior irreparable FIRCTs can be separated to better understand different treatment options (Tables II and III).

Overview

Additional research is needed to further agree on definitions of cuff repair failure, prognostic factors predictive for success of primary repair, and long-term outcomes evaluated through prospective randomized studies (Table IV). The most challenging patients continue to be young, high-demand individuals with pseudoparalysis, because they need not only a rebalanced but also a more powerful shoulder compared with low-demand individuals. Although a number of relatively new treatment modalities (implantable balloon, reconstruction of the superior capsule, and new tendon transfers) have emerged over the last few years, only time and adequate follow-up will reveal the true value of these joint-preserving techniques and their precise role in the treatment algorithm, as well as how they fare in comparison with reverse shoulder arthroplasty. ■

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Association Between Femoral Component Sagittal Positioning and Anterior Knee Pain in Total Knee Arthroplasty

A 10-Year Case-Control Follow-up Study of a Cruciate-Retaining Single-Radius Design

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Background: Anterior knee pain is the most common complication of total knee arthroplasty (TKA). The purpose of this study was to assess whether sagittal femoral component position is an independent predictor of anterior knee pain after cruciate-retaining single-radius TKA without routine patellar resurfacing.

Methods: A prospective cohort study of 297 cruciate-retaining single-radius TKAs performed in 2006 and 2007 without routine patellar resurfacing identified 73 patients (25%) with anterior knee pain and 89 (30%) with no pain (controls) at 10 years. Patients were assessed preoperatively and at 1, 5, and 10 years postoperatively using patient-reported outcome measures (PROMs), including the Short Form-12 (SF-12), Oxford Knee Score (OKS), and satisfaction and expectation questionnaires. Variables that were assessed as predictors of anterior knee pain included demographic data, the indication for the TKA, early complications, stiffness requiring manipulation under anesthesia, and radiographic criteria (implant alignment, Insall-Salvati ratio, posterior condylar offset ratio, and anterior femoral offset ratio).

Results: The 73 patients with anterior knee pain (mean age, 67.0 years [range, 38 to 82 years]; 48 [66%] female) had a mean visual analog scale (VAS) score of 34.3 (range, 5 to 100) compared with 0 for the 89 patients with no pain (mean age, 66.5 years [range, 41 to 82 years]; 60 [67%] female). The patients with anterior knee pain had mean femoral component flexion of −0.6° (95% confidence interval [CI] = −1.5° to 0.3°), which differed significantly from the value for the patients with no pain (1.42° [95% CI = 0.9° to 2.0°]; $p < 0.001$). The patients with and those without anterior knee pain also differed significantly with regard to the mean anterior femoral offset ratio (17.2% [95% CI = 15.6% to 18.8%] compared with 13.3% [95% CI = 11.1% to 15.5%]; $p = 0.005$) and the mean medial proximal tibial angle (89.7° [95% CI = 89.2° to 90.1°] compared with 88.9° [95% CI = 88.4° to 89.3°]; $p = 0.009$). All PROMs were worse in the anterior knee pain group at 10 years ($p < 0.05$), and the OKSs were worse at 1, 5, and 10 years ($p < 0.05$). Multivariate analysis confirmed femoral component flexion, the medial proximal tibial angle, and an Insall-Salvati ratio of <0.8 (patella baja) as independent predictors of anterior knee pain ($R^2 = 0.263$). Femoral component extension of ≥0.5° predicted anterior knee pain with 87% sensitivity.

Conclusions: In our study, 25% of patients had anterior knee pain at 10 years following a single-radius cruciate-retaining TKA without routine patellar resurfacing. Sagittal plane positioning and alignment of the femoral component were associated with long-term anterior knee pain, with femoral component extension being a major risk factor.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

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Anterior knee pain is the most common complication of total knee arthroplasty (TKA), with a prevalence of 8% to 36% at 1 year[1]. There are few reports on long-term anterior knee pain, but rates of 45% have been reported at 10 years[1,2]. Determinants of anterior knee pain are multifactorial, and risk factors predicting whether this complication will be present at long-term follow-up remain unclear[1-3].

The single-radius TKA concept is based on the principle of a common flexion-extension axis at the knee with consistent relationships with the patellofemoral joint axis[4] and the tibial longitudinal rotational axis[5]. This principle appears consistent in varus and valgus knees[5]. The single-radius design is thought to be patellofemoral "friendly": a posterior flexion-extension axis lengthens the quadriceps moment arm, reducing patellofemoral joint reaction force. Other modern TKA design concepts, such as left and right-specific femoral components and deeper trochlear grooves, improve patellar glide. These features may reduce the requirement for primary patellar resurfacing, a topic that remains controversial with marked geographic variation[6].

Recent biomechanical studies have suggested that sagittal component alignment is more important than rotation in determining patellofemoral kinematics[7] and that, despite patellofemoral-friendly features, deep-flexion patellofemoral pressures are often excessive as a result of artificially maintained patellar offset[8]. The primary aim of this study was to investigate sagittal femoral component position as a predictor of anterior knee pain at long-term follow-up after cruciate-retaining single-radius TKA without routine patellofemoral resurfacing. The null hypothesis was that sagittal femoral component positioning did not determine anterior knee pain.

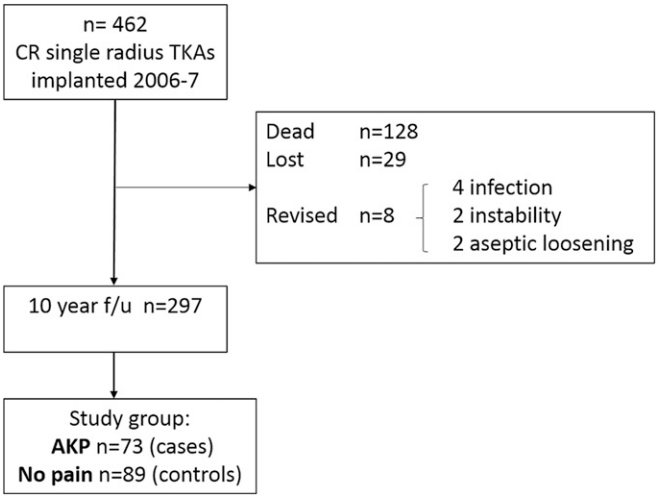

Fig. 1

Study group details. CR = cruciate-retaining, f/u = follow-up, and AKP = anterior knee pain.

Materials and Methods

Ethical approval was obtained for this prospective study (Scotland [A] Research Ethics Committee 16/SS/0026). From 2006 to 2007, data were recorded for 462 patients undergoing Triathlon single-radius TKA (Stryker Orthopaedics) (Fig. 1). The TKAs were performed by 7 surgeons at a large orthopaedic teaching hospital[9]. At 10 years, 326 patients were alive with an intact TKA. Cemented, cruciate-retaining TKAs were performed via a medial parapatellar approach and with use of a measured resection technique. Patellar resurfacing was performed, rarely, at the surgeon's discretion to address

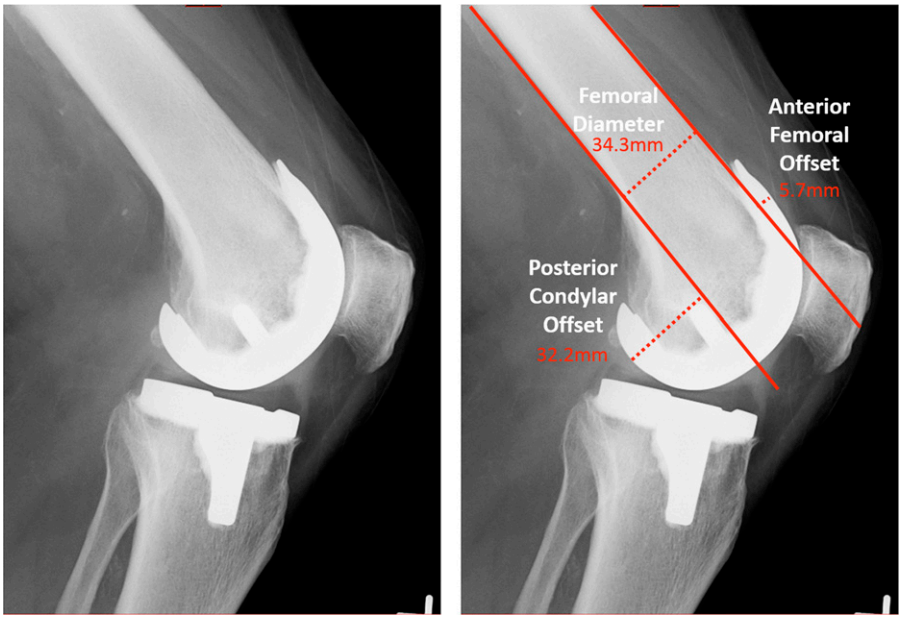

Fig. 2

Anterior femoral offset ratio (anterior femoral offset/femoral diameter) and posterior condylar offset ratio (posterior condylar offset/femoral diameter) measured on an adequate lateral radiograph.

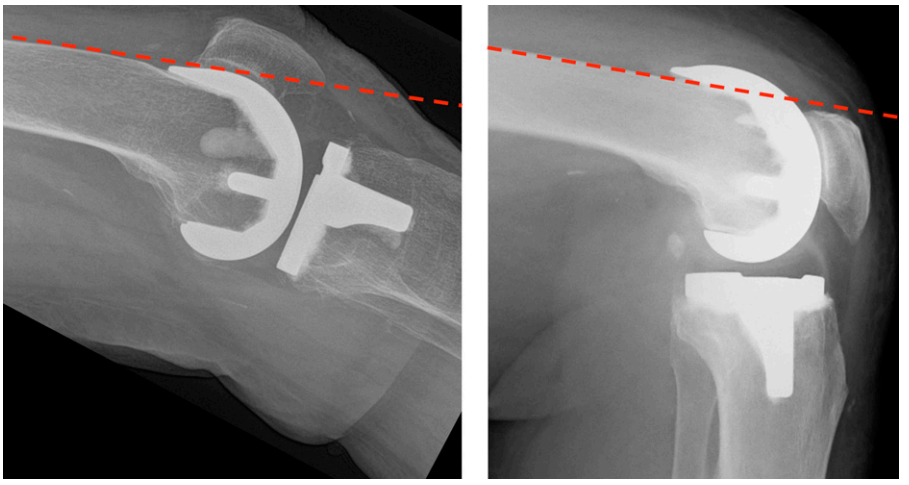

Fig. 3
Examples of a flush femoral component (left) and a femoral component that is not flush (right).

inflammatory arthropathy or patellofemoral osteoarthritis. All patients followed a standardized postoperative rehabilitation protocol.

General health (Short Form [SF]-12[10]) and knee-specific (Oxford Knee Score [OKS][11]) patient-reported outcome measures (PROMs) were collected prior to surgery and at 1, 5, and 10 years following surgery via postal questionnaire. Satisfaction was measured at 1, 5, and 10 years[12]. Expectation fulfilment was measured at 5 years using the Hospital for Special Surgery (HSS) Knee Surgery Expectations survey[13]. The SF-12 is a validated questionnaire with physical and mental component summary (PCS and MCS) scores. The OKS is a validated knee score containing 12 questions (each with 5 possible answers); the total score ranges from 0 to 48, with higher scores indicating better function. The HSS Expectations score is validated[13] to measure expectation fulfilment for 17 activities following knee surgery[14]. Collection of data was independent of routine clinical care. Patients who did not respond by mail were telephoned. Full details and analysis of the entire cohort (n = 462) have been published previously[9].

At 10 years after the TKA, the patients were asked to record pain scores on a visual analog scale (VAS) ranging from 0 to 100. When pain was present, they were asked to identify its location within the knee as at the "front," "back," "inside edge," "outside edge," "all over," or "other." Those reporting anterior knee pain at 10 years (n = 73) formed our case group and those reporting no pain in any area (n = 89) were the control group. Those indicating diffuse pain all over the knee were not included in either group.

Patient demographics, comorbidities, the indication for the TKA, surgeon, side, complications, and reoperations were recorded. Radiographic analysis was performed on short-leg weight-bearing radiographs using a picture archiving and communication system (PACS) measurement tool (Kodak Carestream) on the earliest acceptable postoperative lateral image. All follow-up radiographs were examined to assess loosening or other causes of pain, details of which have been published previously[9]. Those with radiographic evidence of loosening as a potential source of pain were excluded. Radiographs were examined by 2 independent reviewers (C.E.H.S. and L.Z.Y.) who had no clinical contact with the patients. Implant alignment[15], posterior condylar offset[16], and anterior femoral offset[17] were measured using published methods (Fig. 2). This analysis required adequate lateral radiographs with aligned and superimposed femoral component pegs facilitating femoral flexion measurement against the femoral anatomical axis (Figs. 2 and 3). Posterior condylar offset and anterior femoral offset were converted into ratios (the posterior condylar offset ratio and the anterior femoral offset ratio) relative to the femoral diameter. The Insall-Salvati ratio was calculated, and patella baja was defined as an Insall-Salvati ratio of <0.8. Femoral component oversizing was defined as an anterior femoral offset ratio of >15% and a posterior condylar offset ratio of >95%.

TABLE I Location and Severity of Pain 10 Years Following Cruciate-Retaining Single-Radius TKA without Routine Patellar Resurfacing (N = 297*)

Location of Pain	No. (%) of Patients	Mean VAS Pain Score (95% CI)
Anterior	73 (25)	34.3 (28.5 to 40.6)
Posterior	16 (5)	44.1 (29.7 to 59.8)
Medial	35 (12)	29.2 (20.7 to 38.2)
Lateral	32 (11)	35.7 (26.8 to 45.4)
Diffuse	80 (27)	51.4 (46.2 to 57.0)
Other	6 (2)	30.5 (11.3 to 50.6)
No pain	89 (30)	0

*Some patients reported pain in >1 location.

TABLE II Preoperative Characteristics of Patients with Anterior Knee Pain Compared with Those with No Pain at 10 Years

Variable	Anterior Knee Pain (N = 73)	No Pain (N = 89)	P Value	95% CI for Difference in Group Means
Female sex*	48 (66)	60 (67)	0.539†	
Age† *(yr)*	67.0 (64.9 to 69.0) (38-82)	66.5 (64.6 to 68.4) (41-82)	0.79§	−2.31 to 3.21
BMI† *(kg/m²)*	31.6 (29.8 to 33.3)	30.6 (29.1 to 32.1)	0.401§	−1.29 to 3.20
Right-sided TKA*	40 (55)	38 (43)	0.125†	
Comorbidities*				
Depression	6 (8)	3 (3)	0.297#	
Pain in other joints	28 (38)	25 (28)	0.132†	
Back pain	21 (29)	20 (22)	0.332†	
Indication*				
Osteoarthritis	62 (85)	77 (87)	0.0845†	
Inflammatory arthropathy	5 (7)	5 (6)		
Other	6 (8)	7 (8)		
PROMs†				
SF-12 PCS	32.2 (29.8 to 34.5)	29.3 (27.5 to 31.4)	0.495§	−2.83 to 5.82
SF-12 MCS	50.3 (46.7 to 54.0)	51.5 (48.3 to 54.6)	0.423§	−7.21 to 3.05
OKS	18.9 (17.2 to 20.6)	18.3 (16.0 to 20.6)	0.688§	−2.34 to 3.54

*The values for the pain and no-pain groups are given as the number of patients with the percentage in parentheses. †Chi-square test. ‡The values for the pain and no-pain groups are given as the mean with the 95% CI in parentheses, with the second parentheses for "Age" showing the range. BMI = body mass index. §Student t test. #Fisher exact test.

Statistical Analysis

Data were analyzed using SPSS version 21.0 (IBM). A single-measure (2-way mixed) intraclass correlation coefficient was used to quantify interobserver reliability (values of >0.75 indicate satisfactory reliability). Categorical variable correlation was calculated using the kappa statistic. Univariate analysis

TABLE III Radiographic Measurements in Patients with Anterior Knee Pain Compared with Those with No Pain at 10 Years

Variable	Anterior Knee Pain (N = 62)	No Pain (N = 71)	P Value	95% CI for Difference in Group Means
Femorotibial angle* *(°)*	175.1 (171 to 179)	177.9 (177 to 178)	0.993†	−0.8 to 0.8
Coronal plane*				
Medial proximal tibial angle *(°)*	89.7 (89.2 to 90.1)	88.9 (88.4 to 89.3)	0.009†	0.2 to 1.4
Lateral distal femoral angle *(°)*	85.7 (85.3 to 86.1)	85.7 (85.3 to 86.1)	0.969†	−0.6 to 0.6
Sagittal plane*				
Posterior tibial slope *(°)*	4.5 (3.8 to 5.2)	5.3 (4.6 to 5.9)	0.107†	−1.7 to 0.16
Femoral component flexion *(°)*	−0.6 (−1.5 to 0.3)	1.4 (0.9 to 2.0)	<0.001†	−3.0 to −1.0
Posterior condylar offset ratio *(%)*	94.0 (90.6 to 97.4)	97.3 (93.8 to 100)	0.192†	−0.08 to 0.02
Anterior femoral offset ratio *(%)*	17.2 (15.6 to 18.8)	13.3 (11.1 to 15.5)	0.005†	0.01 to 0.07
Insall-Salvati ratio*	1.01 (0.95 to 1.07)	1.01 (0.98 to 1.05)	0.938†	−0.07 to 0.6
Patella baja (Insall-Salvati ratio <0.8)‡	10 (16)	5 (7)	0.100§	
Femoral component flush anteriorly‡	13 (21)	28 (39)	0.016§	
Femoral component oversizing‡	19 (31)	16 (23)	0.228§	
Tibial underhang* *(mm)*	0.15 (−0.22 to 0.52)	0.21 (−0.15 to 0.57)	0.817†	−0.6 to 0.5

*The values for the pain and no-pain groups are given as the mean with the 95% CI in parentheses. †Student t test. ‡The values for the pain and no-pain groups are given as the number of patients with the percentage in parentheses. §Chi-square test.

TABLE IV Intraclass Correlation Coefficients for Radiographic Measures and Ratios

Measure/Ratio	Intraclass Correlation	95% CI	P Value
Coronal			
Lateral distal femoral angle	0.856	0.80 to 0.89	<0.001
Medial proximal tibial angle	0.914	0.88 to 0.94	<0.001
Sagittal			
Posterior tibial slope	0.810	0.75 to 0.90	<0.001
Femoral diameter	0.986	0.98 to 0.99	<0.001
Femoral flexion	0.913	0.88 to 0.94	<0.001
Ratios			
Posterior condylar offset ratio	0.956	0.94 to 0.97	<0.001
Anterior femoral offset ratio	0.524	0.39 to 0.64	<0.001
Insall-Salvati ratio	0.900	0.86 to 0.93	<0.001

was performed using parametric (Student t test: paired and unpaired) and nonparametric (Mann-Whitney U) tests to assess differences in continuous variables between groups. Nominal categorical variables were assessed using the chi-square or Fisher exact test. The Pearson correlation was used to assess correlation between linear variables. Variables significantly associated with anterior knee pain at the <10% level were entered stepwise into a multivariate binary logistic regression analysis using an enter methodology to identify independent predictors of anterior knee pain. A p value of <0.05 was considered significant.

Receiver operating characteristic (ROC) curve analysis was used to identify the threshold femoral component flexion and medial proximal tibial angle that identified anterior knee pain. The area under the curve (AUC) ranges from 0.5 (a test with no accuracy) to 1.0 (perfect accuracy). The threshold value is the point of maximal sensitivity and specificity in predicting anterior knee pain.

Post hoc power analysis was performed for the risk of anterior knee pain in association with an extended femoral component. Using the defined rate of anterior knee pain of 32% in patients with a flexed component (n = 84) and 71% in those with an extended component (n = 42), with an alpha of 0.05, a 2-way analysis defined the power as 99.1%.

Results

At 10 years, 297 (91%) of the 326 patients were alive, had an intact TKA, and recorded VAS scores and pain location. The 29 non-responders (8 who could not be contacted, 11 with dementia, and 10 who declined to participate) were significantly older at TKA than the 297 responders (mean age [and standard deviation], 69.9 ± 9.8 versus 66.1 ± 8.6 years; p = 0.008, unpaired t test), but there were no other significant differences in baseline demographics or PROMs. Patients reporting pain in regions not involving the anterior aspect of the knee were excluded (n = 135) (Table I), resulting in a study cohort of 162 patients: 73 with anterior knee pain and 89 with no pain at 10 years. The patients with anterior knee pain had a mean VAS pain score of 34.3 ± 25.1 (range, 5 to 100): 8 reported some additional lateral pain; 9, some medial pain; 5, some posterior pain; and 6, pain in multiple areas. The VAS score was 0 for the patients with no pain. Nine patients—4 with anterior knee pain and 5 with no pain at 10 years—had undergone primary patellar resurfacing. One patient underwent

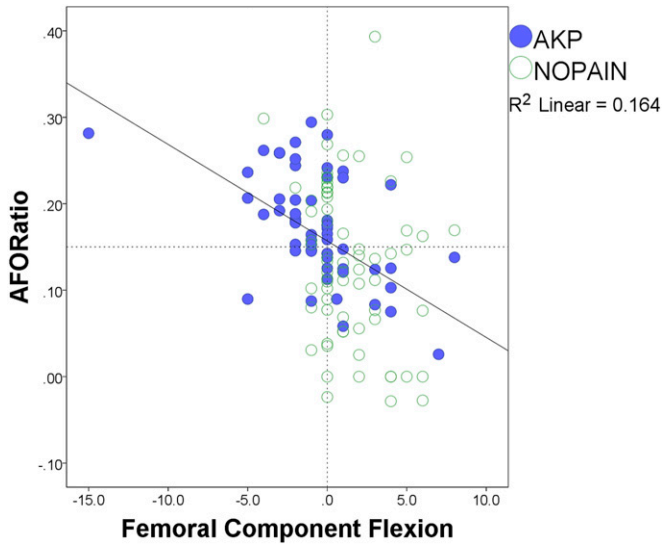

Fig. 4

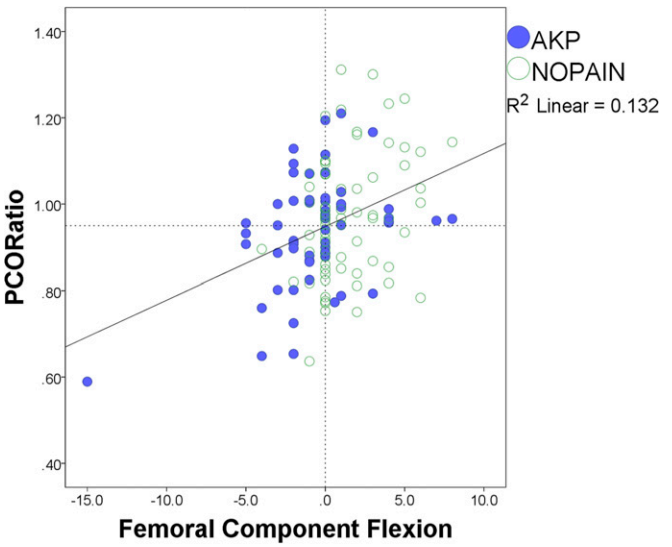

Fig. 5

Fig. 4 Graph showing the correlation between femoral component flexion and the anterior femoral offset (AFO) ratio (R = −0.405; p < 0.01, Pearson correlation). AKP = anterior knee pain. **Fig. 5** Graph showing the correlation between femoral component flexion and the posterior condylar offset (PCO) ratio (R = 0.364; p < 0.01, Pearson correlation). AKP = anterior knee pain.

TABLE V Multivariate Analysis of Predictors of Anterior Knee Pain at 10 Years

Predictors in Model (R^2 = 0.263)	Odds Ratio (95% CI)	P Value
Femoral component extension	1.39 (1.14 to 1.70)	0.001
Medial proximal tibial angle	0.74 (0.56 to 0.97)	0.027
Patella baja (Insall-Salvati ratio <0.8)	0.20 (0.05 to 0.85)	0.029
Anterior femoral offset ratio	0.04 (0 to 139)	0.444
Femoral component flush anteriorly	1.73 (0.37 to 5.42)	0.619

TABLE VI Effect of Radiographic Features on Probability of Developing Anterior Knee Pain

Radiographic Measure	Odds Ratio	95% CI	P Value
Single variable			
Anterior femoral offset ratio >15%	1.49	1.04 to 2.12	0.026
Valgus tibia	2.15	1.09 to 4.25	0.022
Extended femoral component	3.03	1.71 to 5.35	<0.001
Combination of variables			
Anterior femoral offset ratio >15% and extended femoral component	3.98	1.84 to 8.59	<0.001
Oversized and extended femoral component	4.04	1.17 to 14.0	0.015
Valgus tibia and anterior femoral offset ratio >15%	4.16	0.9 to 19.3	0.045
Valgus tibia and extended femoral component	10.9	1.42 to 83.4	0.003

secondary resurfacing and had persistent anterior knee pain thereafter.

There were no significant differences in preoperative characteristics between the patients with and those without anterior knee pain (Table II). Early complications (wound leakage/dehiscence, cellulitis, deep infection, venous thromboembolism, and myocardial infarction) were not associated with 10-year anterior knee pain (p = 0.580, chi-square test). Early stiffness requiring manipulation under anesthesia was not associated with late anterior knee pain, with 3 of the 73 with pain and 1 of the 89 without pain having such stiffness (p = 0.253).

Radiographic Analysis

Lateral radiographs were inadequate to determine the posterior condylar offset ratio and anterior femoral offset ratio measurement in 11 of the 73 patients with anterior knee pain and 18 of the 89 with no pain, and these patients were excluded from radiographic analysis. The results of the radiographic analysis of the remaining 133 patients are given in Table III. Intraclass correlations are shown in Table IV. The femoral component flexion, anterior femoral offset ratio, and medial proximal tibial angle differed between the patients with and those without anterior knee pain (Table III). When the femoral component was flush with the distal part of the femur (Fig. 3),

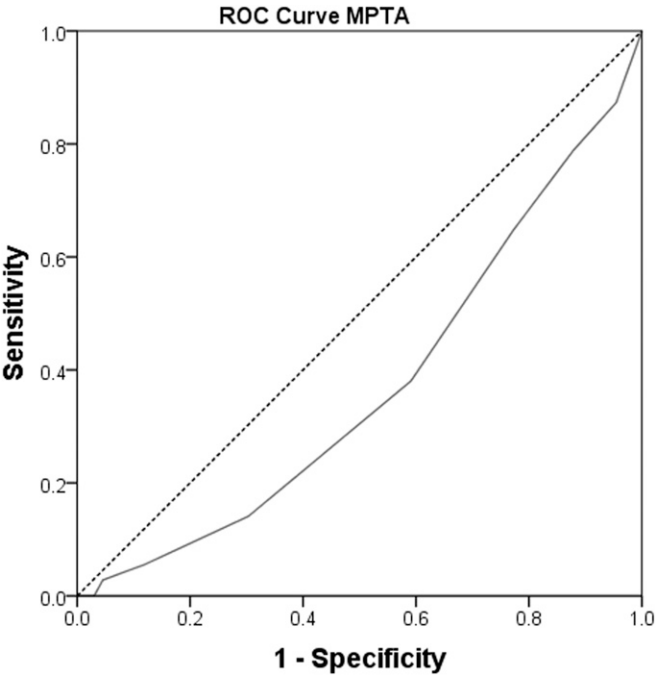

Fig. 6

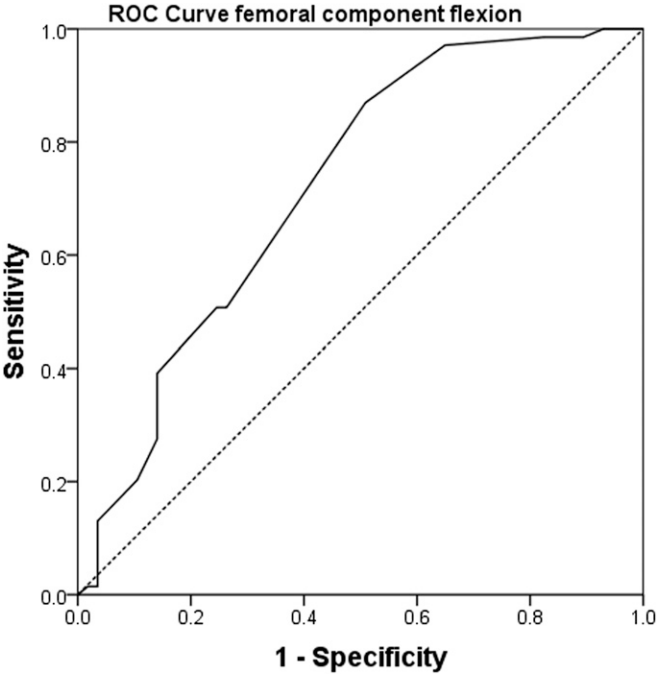

Fig. 7

Fig. 6 ROC curve for anterior knee pain and the medial proximal tibial angle (MPTA) (AUC = 0.372). **Fig. 7** ROC curve for anterior knee pain with a threshold value of −0.5° of femoral component flexion (AUC = 0.721).

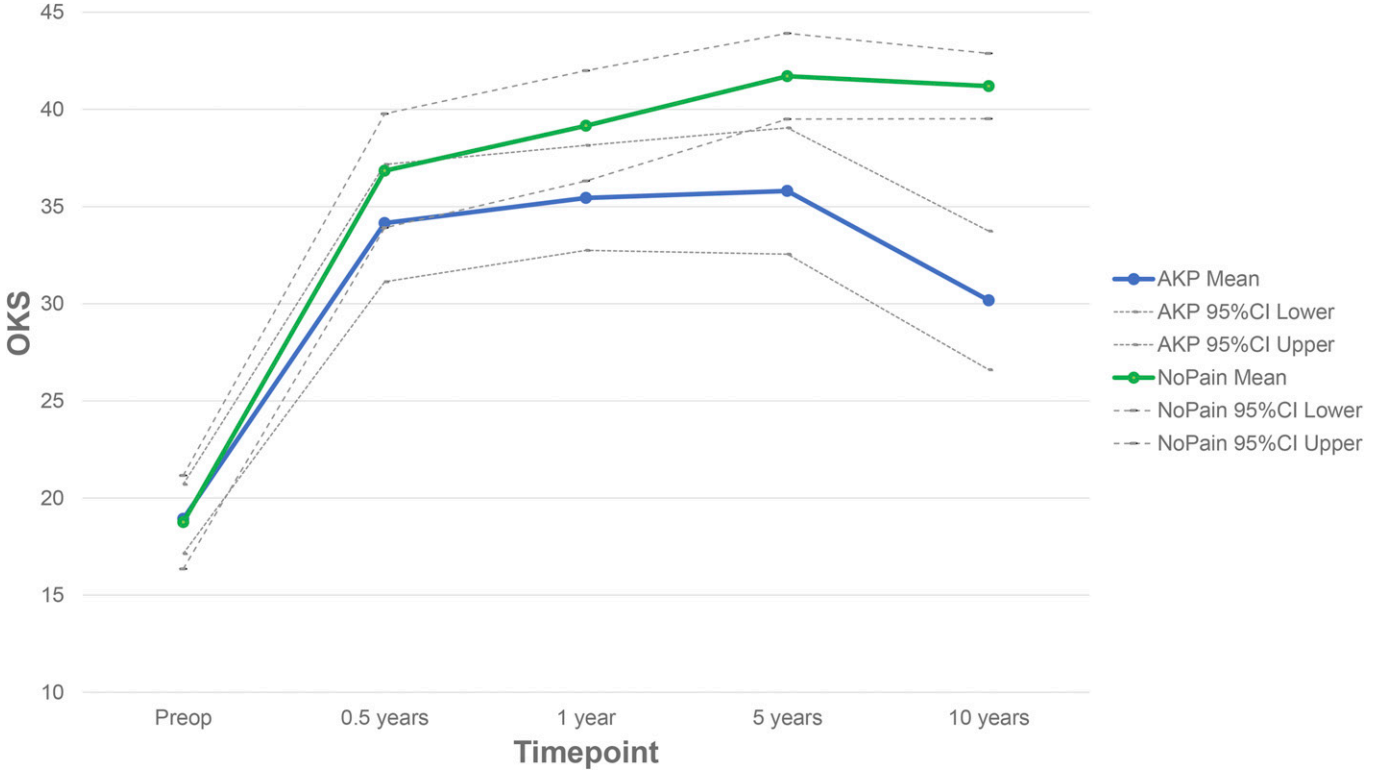

Fig. 8

Longitudinal OKSs in patients with anterior knee pain (AKP) and those with no pain at 10 years.

the patient was less likely to have anterior knee pain than when the component was not flush; 13 (21%) of the 62 patients with anterior knee pain and 48 (68%) of the 71 with no pain had a flush component ($p = 0.016$). There was excellent interobserver agreement in defining whether the femoral component was flush (Cohen kappa = 0.915; $p < 0.001$). Femoral component

TABLE VII PROMs of Patients with Anterior Knee Pain Compared with Those with No Pain at 10 Years by Follow-up Time Point

Follow-up Time/Score	Anterior Knee Pain (N = 73)	No Pain (N = 89)	P Value
1 yr			
PCS*	41.9 (10.0) (19 to 61)	44.6 (11.0) (14 to 58)	0.219†
MCS*	51.4 (9.8) (29 to 65)	53.2 (11.1) (24 to 66)	0.178†
OKS*	35.5 (8.5) (16 to 48)	37.2 (9.1) (11 to 48)	0.035†
Dissatisfied‡	3 (4)	1 (1)	0.565§
5 yr			
PCS*	40.9 (11.1) (19 to 57)	43.1 (11.4) (19 to 61)	0.287†
MCS*	51.1 (9.7) (27 to 71)	52.7 (10.7) (26 to 67)	0.186†
OKS*	35.7 (10.2) (5 to 48)	39.6 (9.2) (14 to 48)	0.010†
Dissatisfied‡	5 (7)	3 (3)	0.045§
10 yr			
PCS*	35.5 (11.6) (15 to 57)	43.4 (10.6) (21 to 57)	<0.001†
MCS*	48.5 (9.4) (26 to 67)	51.5 (9.7) (28 to 65)	0.037†
OKS*	29.6 (10.9) (7 to 48)	40.1 (7.1) (17 to 48)	<0.001†
Dissatisfied‡	14 (19)	4 (4)	<0.001§

*The values given as the mean with the standard deviation in the first parentheses and the 95% CI in the second. †Mann-Whitney U test. ‡The values are given as the number of patients with the percentage in parentheses. §Chi-square test.

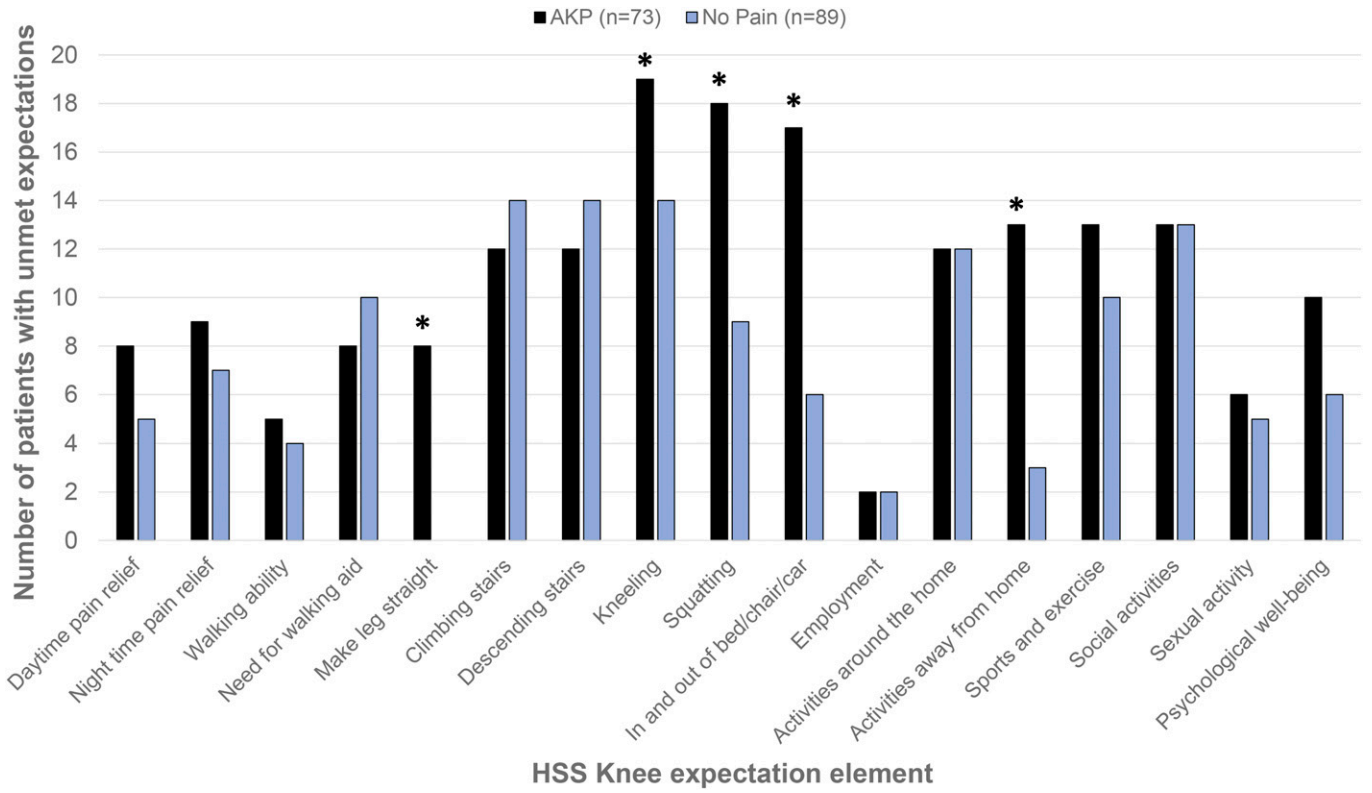

Fig. 9

Unmet expectations as measured using the HSS Knee Surgery Expectations score in patients with anterior knee pain (AKP) and those no pain at 10 years.

*Indicates questions with significant differences between the anterior knee pain and no-pain groups ($p < 0.05$).

oversizing was not associated with anterior knee pain ($p = 0.228$, chi-square test). Those with an anterior femoral offset ratio of >15% of the femoral diameter (the median anterior femoral offset ratio) were more likely to have anterior knee pain (35 [56%] of 63) than were those with an anterior femoral offset ratio of <15% (23 [36%] of 64; $p = 0.026$).

Femoral component flexion correlated with a reduced anterior femoral offset ratio ($R = -0.405$; $p < 0.01$, Pearson correlation) (Fig. 4) and an increased posterior condylar offset ratio ($R = 0.364$; $p < 0.01$, Pearson correlation) (Fig. 5). Flush femoral components were more flexed (mean and standard deviation, 1.77° ± 2.4°; 95% confidence interval [CI] for differences in means −5° to 7°) than those that were not flush (mean, −0.8° ± 3.0°; −15° to 8°; $p = 0.001$; 95% CI = 0.77° to 2.9°).

Multivariate analysis (Table V) showed femoral component flexion, the medial proximal tibial angle, and patella baja (Insall-Salvati ratio of <0.8) to independently predict anterior knee pain at 10 years ($R^2 = 0.263$). Odds ratios are reported in Table VI.

ROC curve analysis demonstrated that the medial proximal tibial angle could not be used to identify patients with anterior knee pain (AUC = 0.372, Fig. 6). ROC analysis using femoral component flexion to predict anterior knee pain gave an AUC of 0.721 (95% CI = 0.63 to 0.81; $p < 0.001$) (Fig. 7): a threshold of −0.5° of femoral flexion had an 87% sensitivity and a 51% specificity.

PROMs

OKSs were worse starting from 1 year in the anterior knee pain group ($p < 0.05$, Fig. 8). All other PROMs were worse at 10 years (Table VII). A higher percentage of patients with anterior knee pain were dissatisfied at 10 years (19% compared with 4% of the patients with no pain; $p < 0.001$, chi-square test) because of unmet expectations regarding the TKA making the leg straight, kneeling ability, squatting ability, getting in and out of a bed/chair/car/bus, ability to perform activities outside the home, and ability to take part in recreational activities (Fig. 9). Dividing the OKS into constituent questions showed that patients with anterior knee pain had worse scores for getting in and out of a car/public transport, pain at night, shopping, and descending stairs ($p < 0.05$) compared with those with no anterior knee pain. Ten-year OKSs correlated with femoral flexion (Pearson correlation = 0.224; $p = 0.013$), the anterior femoral offset ratio (Pearson correlation = −0.183; $p = 0.04$), and the posterior condylar offset ratio (Pearson correlation = 0.187; $p = 0.038$) but not with the medial proximal tibial angle (Pearson correlation = −0.42; $p = 0.631$).

Discussion

A quarter of patients alive with an intact single-radius cruciate-retaining TKA who had not undergone routine patellar resurfacing reported anterior knee pain at 10 years. Patients with anterior knee pain at 10 years reported worse

PROMs (OKS) beginning at 1 year. Radiographic measures including femoral component flexion, anterior femoral offset ratio (absolute and >15% of the femoral diameter), whether the femoral component was flush with the distal part of the native femur, and the medial proximal tibial angle, all with strong interobserver agreement, were significantly associated with anterior knee pain. Multivariate analysis indicated that, in this TKA design, femoral component flexion, tibial component coronal alignment (medial proximal tibial angle), and patella baja independently predicted long-term anterior knee pain. When the analysis was corrected for those variables, the anterior femoral offset ratio and a flush femoral component were no longer significant predictors, possibly reflecting the relationship between femoral flexion and the anterior femoral offset ratio. ROC curve analysis confirmed that femoral component extension of ≥0.5° correctly identified patients with anterior knee pain 87% of the time.

Postoperative anterior knee pain is the most common complication following TKA, and its association with PROMs confirms its importance. Post-TKA anterior knee pain has been reported in 80% to 85% of patients during chair rising and in 90% on stair climbing[18]. There have been few reports on anterior knee pain in 10-year cohorts[1], but the rates reported in association with multi-radius designs (26% after cruciate-retaining TKA[3] and 30% after posterior-stabilized TKA with resurfacing[2]) are comparable with our results. A number of variables have been considered as potential causes of anterior knee pain, including patellar resurfacing, "overstuffing," denervation, fat-pad excision or retention, component rotation, joint-line alteration, sagittal alignment, and medial/lateral translation[1]. The roles of these variables have not been consistently reported, and the multitude of different TKA designs and resurfacing combinations makes comparisons difficult[1]. When present, anterior knee pain is difficult to manage, with 60% of cases persisting after secondary patellar resurfacing[19].

Routine patellar resurfacing was not performed for our patient cohort. Meta-analysis of numerous randomized controlled trials demonstrated no difference in anterior knee pain between resurfaced and non-resurfaced patellae[20], although reoperation rates were higher after TKAs that did not include patellar resurfacing, a fact confounded by the bias inherent in secondary resurfacing being possible[20]. Primary resurfacing rates vary internationally, with rates of 4% in Norway and 82% in the United States[6]. Across multiple national joint registries, the rate of primary resurfacing in TKAs was 35% in 2010[6]; thus, the results of TKAs without resurfacing are applicable to the majority of TKA cases worldwide.

The influence of patellofemoral overstuffing and anterior femoral offset on anterior knee pain has been investigated previously[17,21,22]. Pierson et al.[21] examined changes in anterior femoral offset in 838 patients (86% with a cruciate-retaining TKA, all with patellar resurfacing), concluding that overstuffing (arbitrarily defined as any anterior femoral offset increase or anterior patellar displacement of >15%) had no effect on range of motion or Knee Society Scores in comparative groups with different sample sizes (ranging from 19 to 41 in the "stuffed" group versus 723 to 769 in the "unstuffed" group). Sagittal femoral alignment was not considered. Matz et al.[22] evaluated 970 patients who underwent posterior-stabilized TKA with resurfacing and divided them into 3 groups: increased, decreased, and unchanged anterior femoral offset. They found no difference in Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores among the groups, concluding that there were no consequences of patellofemoral overstuffing. Beldman et al.[17] investigated overstuffing (any increase in anterior femoral offset or posterior condylar offset) in 193 patients treated with posterior-stabilized TKA with resurfacing and found anterior overstuffing in 43%, posterior overstuffing in 87%, and total overstuffing in 80%. They reported no effects of overstuffing on anterior knee pain or WOMAC scores at 1 year. In all 3 studies, the authors used arbitrary definitions of overstuffing, considered only absolute values, and identified associations with overstuffing rather than anterior knee pain. Defining any increase in offset as overstuffing may mask effects of truly significant overstuffing by dilution.

Despite the patellofemoral-friendly features of the TKA design used in our study, anterior knee pain was reported in 25% of our patients at 10 years. Although modern femoral component trochleae are designed to reproduce anatomical patellar tracking, cadaveric studies suggest that physiological kinematics are not restored[8]. Artificially maintained patellar offset throughout motion increases patellofemoral pressures and may cause anterior knee pain[8]. Limiting the anterior femoral offset ratio by femoral component flexion may reduce this effect. Tibial component rotation was found to affect peak retropatellar pressures in cadavers[23]. However, a recent study of 46 TKAs performed with computer navigation showed sagittal alignment to have a greater effect on patellofemoral kinematics (patellar tilt and medialization) than did rotational alignment[7]. Although we did not measure component rotation, an important study weakness, this study supports the importance of femoral sagittal alignment on patellofemoral biomechanics. We are unable to comment on the effect of patellar resurfacing as we did not include a comparison group with that procedure; however, a beneficial effect of resurfacing has not been proven[20].

The cohort in this study consisted of the first single-radius TKAs performed at our institution, so it includes our learning curve. Initially, the 7° anterior femoral flange was often implanted more parallel to the anterior aspect of the femur than we would now advocate, resulting in component extension and an increased anterior femoral offset ratio. Femoral component flexion is now achieved by utilizing a posterior femoral entry point. The results of this study appear to support this strategy. The importance of sagittal component alignment in predicting long-term anterior knee pain, and thus PROMs, in patients with this TKA is a novel finding and is relevant in an age of precision implantation and robotic technology. Although these data identify sagittal component positioning as important in the long-term success of single-radius

TKA, it cannot be ascertained whether this variable alone causes anterior knee pain. Further research is required to investigate additional variables such as joint-line restoration, coronal alignment, and component rotation, which were not assessed here.

Limitations of this study include no comparison with preoperative radiographs and no measurement of implant rotation or joint-line restoration. Hip-knee-ankle radiographs were not used for measurement of coronal alignment, making interpreting medial proximal tibial angle results difficult. Lateral radiographs were adequate to define anterior and posterior femoral cortex alignment and thus the distal femoral axis (Fig. 2), but full femoral bowing was not measured. Fat-pad resection was not documented, although its effect on anterior knee pain has not been proven in the longer term[24]. The patella was rarely resurfaced, so conclusions cannot be drawn regarding TKA with resurfacing. Postoperative skyline radiographs were unavailable, and patellar offset and tilt were not assessed. There was no formal recording of intraoperative patellar tracking. Anterior knee pain rates were measured at 10 years only. Previous studies have shown variation in anterior knee pain over time[1]. However, as implant survival is routinely reported at 10 years this was considered an acceptable time point. Nine percent of patients were lost to follow-up.

Conclusions

Despite a patellofemoral-friendly design, anterior knee pain was reported by 25% of patients alive with an intact prosthesis at 10 years after receiving a single-radius cruciate-retaining TKA without routine patellar resurfacing. When anterior knee pain was present it was associated with inferior PROMs, including an OKS that was worse starting at 1 year. Multivariate analysis showed femoral component flexion, tibial component coronal alignment (medial proximal tibial angle), and patella baja to independently predict long-term anterior knee pain in patients treated with this TKA design. ROC curve analysis demonstrated that femoral component extension predicted anterior knee pain with 87% sensitivity. ■

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"Is There a Doctor on Board?" The Plight of the In-Flight Orthopaedic Surgeon

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Abstract

» The most common in-flight medical emergencies are syncope, gastrointestinal distress, and cardiac conditions that include arrhythmias and cardiac arrests. Treatment algorithms for these emergencies are important to review and are included in this article.

» If confronted with a challenging in-flight medical emergency in which an orthopaedic surgeon believes that he or she is unable to offer sufficient help, consulting with ground-based physicians hired by the airlines is always an appropriate and readily available option.

» While providing care to the patient, the doctor is absolved from liability unless the care offered is grossly negligent and/or deliberately harmful.

» If the aircraft is registered in or is departing from countries within the European Union block or Australia, or if the patient is a citizen of one of those international bodies, the doctor is legally required to assist.

"*Is there a doctor on board?*" It is a phrase that we, as orthopaedic surgeons, have often taken with uncertainty tens of thousands of meters or feet in the air, away from our colleagues in the emergency room, medical wards, and behind the anesthesia curtain. Although we were trained to adapt, think, or muscle our way through challenges and hardships, this phrase remains among those that inspire feelings of doubt for many orthopaedists. Leadership in the operating room often comes innately, yet taking charge in an in-flight medical emergency may seem unnatural for an orthopaedic surgeon. The goal of this article is to assist the practicing orthopaedic surgeon with a review of the most commonly encountered in-flight medical emergencies. We also have included an update on the various rules and regulations of most domestic and international flights as well as a discussion of the complex ethical concerns and specific legal considerations related to in-flight medical emergencies.

Common In-Flight Medical Emergencies and Treatment Plans

Because of the lack of a standardized reporting system for in-flight medical emergencies, it has been estimated that only 17% are appropriately documented[1,2]. Of the 10,189 cases reported by Sand et al.[2] in 2009, the most common events included syncope (53.5%), gastrointestinal distress (8.9%), and cardiac conditions (5.3%) (Table I). Other common in-flight medical emergencies, which may be underreported because of rapid reversal, are allergic reactions, asthma attacks, and hypoglycemia[2,3]. Flight diversion occurs in only 2.8% of in-flight medical emergencies, most commonly because of myocardial infarction (22.7%), stroke (11.3%), and seizure (9.4%)[2]. All-cause in-flight deaths have been reported to occur at a rate of 0.31 in-flight deaths per 1 million passengers[4].

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TABLE I Rates of In-Flight Medical Emergencies

Medical Events	Percentage*
Syncope	53.5%
Gastrointestinal distress	8.9%
Cardiac conditions	5.3%
Suspected myocardial infarction	0.3%
Psychiatric episodes	3.5%
Acute anxiety	3.2%
Dyspnea	2.1%
Asthma	1.8%
Seizure	2.1%
Births	0.01%

*Because of wide variation in the types and reporting of in-flight medical emergencies, only the most common in-flight medical emergencies related to the content of this article are depicted here. As such, this list represents approximately 75% of the in-flight medical emergencies reported.

Death occurs in <0.5% of in-flight medical emergencies, 86% of which are due to myocardial infarction[2,5]. As with any patient encounter, approaching in-flight medical emergencies requires taking an accurate history and performing a relevant physical examination[6]. A basic understanding of treatment strategies for the most common conditions is crucial to providing effective medical care.

To facilitate care provision, the U.S. Federal Aviation Administration (FAA) provided airlines with a required list of the basic minimum amount of medical equipment, materials, and medications, which the crew is instructed to provide to physicians upon request[7,8]. In addition to including medications that orthopaedic surgeons are accustomed to using, including the injectable local anesthetic lidocaine, emergency kits contain several life-saving medications that are not routinely utilized by orthopaedic surgeons. Medical advocacy organizations have more recently come out with their own recommendations for first-aid kits for airlines, representing a collaborative effort by the Aerospace Medical Association, the International Air Transport Association (IATA), the International Academy of Aviation and Space Medicine (IAASM), the American Osteopathic Association (AOA), the American College of Emergency Physicians (ACEP), and the American Medical Association (AMA), that was published as a report in 2016. These equipment recommendations are outlined in Table II[8,9].

Syncope

Syncope may occur during travel because of a number of etiologies, most commonly secondary to dehydration and hypoglycemia[5,10,11]. The effective steps following an appropriate history review and physical examination include measuring blood pressure and pulse with the available sphygmomanometer and stethoscope in flight (Fig. 1). If low blood pressure and volume are evident, consider placing the patient in the Trendelenburg position with the administration of oral fluids, as tolerated, and/or an intravenous fluid bolus, if needed[6,12]. If hypovolemia is not evident and the patient has a confirmed diabetic history, the blood glucose level should be measured. However, as blood glucose monitors are not carried by all airlines, the use of the patient's monitor or another traveler's monitor may be attempted. If disposable strips or lancets are not available, the transmission risk is generally negligible if cleaned with alcohol[6,13]. If blood glucose is low or there is a high index of suspicion for hypoglycemia, the administration of oral carbohydrates, intravenous dextrose, or intramuscular glucagon, depending on availability, is the recommended next step[6,13]. Specific etiologies of syncope that would not be reversed by the above interventions include stroke, myocardial infarction, and symptomatic bradycardia. As both hypovolemia and hypoglycemia can result in tachycardia (>100 beats per minute), bradycardia (<60 beats per minute) in the setting of syncope raises the suspicion of symptomatic bradycardia as a possible root cause[14]. If symptomatic bradycardia is suspected, based on patient history and/or slow pulse on examination, administering a 0.5-mg intravenous push of atropine may be attempted[15].

Acute Coronary Syndromes and Cardiac Arrest

Patients reporting chest pain, dyspnea, and nausea with risk factors, including age >50 years, smoking history, and previous acute coronary syndrome episodes, should be presumed to be having a repeated acute coronary syndrome episode[16]. The appropriate treatment options available include aspirin (barring patient allergy or substantial hemorrhage), supplemental oxygen, and sublingual nitroglycerine tablets[7,16]. For certain subtypes of myocardial infarction, which would not be diagnosable without an electrocardiogram, nitroglycerine may exacerbate hypotension. If this occurs, an intravenous fluid bolus should be promptly administered[6,16]. If these measures fail to relieve the patient's symptoms, the care provider should urgently recommend the pilot to divert course and to land as soon as possible[12].

If the patient's condition deteriorates into cardiac arrest (e.g., loss of pulses), compression-only cardiopulmonary resuscitation (CPR) and use of the plane's automated external defibrillator (AED) with assistance from the crew are recommended and should take place in a clear, open area to avoid passenger traffic and potential falling objects while the flight is in motion[7,17-19]. Figure 2 outlines a modified Advanced Cardiovascular Life Support (ACLS) protocol for cardiac arrest with

TABLE II Required Emergency Medical Equipment for a First-Aid Kit Onboard an Airline[8,9] *

Content	Quantity
First-aid kit equipment manual	NS
Basic instructions for use of the drugs in the kit	1
Adhesive tape: surgical (1.2 cm × 4.6 m) and 2.5-cm standard roll	1
AED	1
Airways, oropharyngeal (3 sizes): 1 pediatric, 1 small adult, 1 large adult or equivalent	3
Alcohol sponges	2
Analgesic, non-narcotic, tablets, 325 mg	4
Antihistamine tablets, 25 mg	4
Antihistamine injectable, 50 mg (single-dose ampule or equivalent)	2
Antiseptic swabs (10 per pack)	NS
Atropine, 0.5 mg, 5 mL (single-dose ampule or equivalent)	2
Aspirin, 325 mg	4
Bandages: adhesive strips, gauze (7.5 × 4.5 cm) and triangular folded (100 cm)	NS
Bronchodilator, inhaled (metered-dose inhaler or equivalent)	1
CPR mask with 1-way valve (adult, small adult, and pediatric sizes)	3
Dextrose, 50%, 50 mL injectable (single-dose ampule or equivalent)	1
Disposable gloves	1
Dressings: burn (10 × 10 cm), sterile compress (7.5 × 12 cm), and sterile gauze (10.4 × 10.4 cm)	NS
Epinephrine, 1:1,000, 1 mL, injectable (single-dose ampule or equivalent)	2
Epinephrine, 1:10,000, 2 mL, injectable (single-dose ampule or equivalent)	2
Incident record form	NS
Intravenous administration set	1
Lidocaine, 5 mL, 20 mg/mL, injectable (single-dose ampule or equivalent)	2
Needles (2 18G, 2 20G, 2 22G, or sizes necessary to administer required medications)	6
Nitroglycerine tablets, 0.4 mg	10
Pad with shield or tape for eye	NS
Self-inflating manual resuscitation device with adult, small adult, and pediatric masks	3
Sphygmomanometer	1
Stethoscope	1
Syringes (1 5 mL, 2 10 mL, or sizes necessary to administer required medications)	4
Scissors (10 cm), if permitted by applicable regulations	1
Skin closure strips	NS
Thermometer (non-mercury)	NS
Tourniquet	1
Tweezers, splinter	NS
0.9% saline solution, 500 mL	1

*NS = not specified and G = gauge.

instruction on when to defibrillate and administer epinephrine[7,16]. If the patient is revived, then the diversion of the flight course and landing are essential. If the patient does not recover following 20 minutes of compressions, it may be appropriate for the care provider to consider cessation of intervention and pronunciation of a time of death[6,20,21].

Acute Neurologic Deterioration

Stroke may present initially with dysarthria, muscle weakness, and headache with eventual loss of consciousness and should be suspected in patients with histories of hypertension, smoking, or previous stroke[22]. Treatment is limited within the aircraft and should consist only of supplemental oxygen and a recommendation to land urgently for a complete workup[6,22]. Although aspirin is useful in

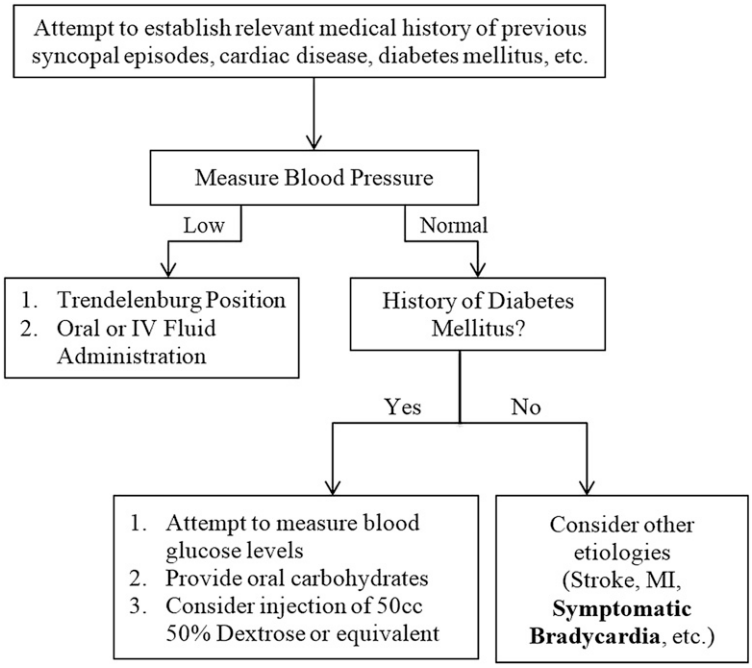

Fig. 1

Initial evaluation and treatment of in-flight syncope. IV = intravenous and MI = myocardial infarction.

the treatment of ischemic stroke, it may worsen the prognosis of a hemorrhagic stroke and is therefore contraindicated in this setting in which discerning a subtype is not currently possible[22].

Similarly, seizures may present with a postictal state resembling a stroke[22]. Seizures may be induced by low cabin oxygen pressure and should be treated primarily with supplemental oxygen, as most aircrafts do not carry anti-epileptic medications[6,7]. If the patient has a diabetic history, attempts should be made to diagnose and reverse possible hypoglycemia[6,23]. A lack of improvement with these limited measures justifies urgent diversion and landing.

Drug Overdose

In patients presenting with acute mental status change with no risk factors for seizure disorders or strokes, the consideration of a drug overdose is appropriate. These situations may occur during flight from willful use or body packing, the attempted concealment of illicit drugs within the body for smuggling purposes[24]. Body packing should be ruled out for an individual with no history of recreational drug use or with signs of drug toxicity shortly after arrival on an international flight[24]. Patients who are having an opioid overdose may present with constricted pupils, sedation, and respiratory depression. Patients with cocaine or amphetamine overdoses often present with anxious affect, dilated pupils, tachycardia, and hypertension[24]. Although opioid overdoses in flight are being reported increasingly, naloxone is currently not included in the FAA's recommendations of a standard medical kit[7,25]. Similarly, benzodiazepines, the first-line treatment for cocaine and amphetamine overdoses, are not often available onboard[7]. Diagnosis may be difficult, given the limited resources available in flight to complement a suggestive history, clinical signs, and physical examination findings. Signs of gastrointestinal obstruction or perforation, such as abdominal distension or diffuse tenderness, may be present. Imaging modalities used to confirm the diagnosis in suspected body packers are not available in flight[24]. Cengel et al.[26] suggested that ultrasonography may be a useful initial imaging method, after demonstrating 91% sensitivity in detecting the presence or absence of abdominal drug packets in a cohort of 45 patients. Although ultrasound equipment can reasonably be stored and utilized on an aircraft, feasibility, efficacy, and cost studies are lacking to support the recommendation of carrying ultrasound capability in flight. Care for suspected body packers should include attempts to identify and remove the source, if the body pack is evident on examination (abdominal and rectal)[24]. If unable to identify the source in flight, the provider for the patient with a suspected opioid overdose should focus on airway protection from aspiration; thus, the surgeon should attempt to intubate the patient and provide oxygen. If hypotension occurs, boluses of intravenous normal saline solution should first be administered, followed by epinephrine if hypotension persists[27]. For patients who may be having amphetamine or cocaine overdoses, the orthopaedist is capable of relieving acute chest pain and preventing hyperthermia. Nitroglycerin, which is available in flight, has been shown to alleviate cocaine-associated chest pain from suspected myocardial ischemia[28]. To prevent hyperthermia from the overdose, use ice water to douse the patient[29]. In any of these situations, discuss flight diversion with the pilot and the ground-based medical support team.

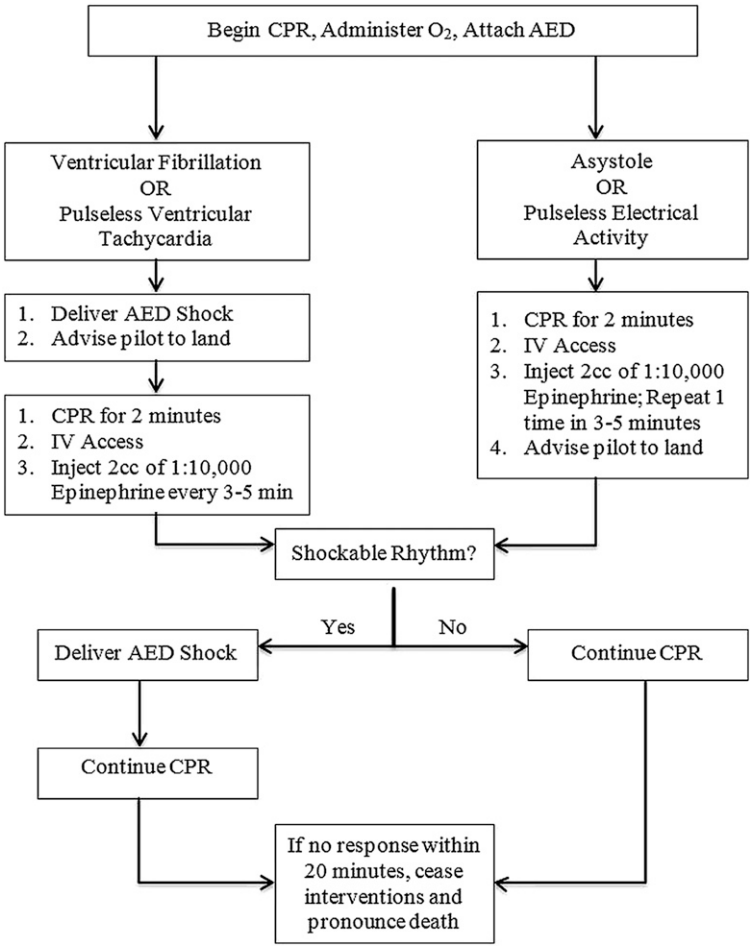

Fig. 2

Suggested treatment approach for in-flight cardiac arrest. O_2 = oxygen, AED = automated external defibrillator, and IV = intravenous.

Dyspnea

Two common causes of dyspnea during airline travel include asthma attacks and allergic reactions, especially in children. During the flight, a failure to bring albuterol inhalers in carry-on baggage risks exacerbation, and a failure to bring epinephrine pens in carry-on baggage risks anaphylaxis[3,7,13]. In managing an asthmatic episode, administration of the airline's albuterol rescue inhaler with supplemental oxygen is appropriate[7,13]. For persistent asthmatic symptoms, an antihistamine may be administered. The World Allergy Organization (WAO) recommends an oral, intramuscular, or intravenous corticosteroid if available for patients who were refractory to the above treatments. For either a persistent severe asthma attack or an anaphylactic reaction, an intramuscular 1:1,000 epinephrine injection at 0.01 to 0.5 mg/kg into the vastus lateralis should be administered[3].

Older patients with dyspnea may be having an acute exacerbation of chronic obstructive pulmonary disorder. Following taking a medical history and performing a physical examination, management should at least consist of supplemental oxygen, bronchodilator therapy, and recommendation to the pilot to descend to a lower altitude where oxygen levels are higher[6]. Continued dyspnea with an absence of breath sounds unilaterally may represent spontaneous pneumothorax because of cabin pressure changes[6,30]. These cases require urgent decompression with a large-bore catheter (ideally 14 gauge or higher) in the fifth intercostal mid-axillary space of the affected side[31]. Recommendations to divert and land urgently are appropriate in any case of a persistently unstable patient despite appropriate medical management.

Gastrointestinal Distress

Severe diarrhea and vomiting are the second most commonly reported in-flight medical emergencies and are especially likely in passengers returning from countries in the developing world[13,32]. As the FAA does not require airlines to carry antiemetic or intestinal anticholinergic therapies, few airlines routinely carry these agents[33]. Management of these symptoms should be conservative[7,13]. Intravenous isotonic fluid may be administered if the patient becomes clinically dehydrated.

Psychiatric Emergencies

Psychiatric emergencies comprise nearly 3.5% of all in-flight medical emergencies, with 90% of these due to acute anxiety[34]. Patients may present with

hyperventilation, sweating, and palpitations[34]. A careful history and physical examination should investigate for a history of panic attacks or phobias and for possible substance use or abuse mimicking a panic attack. Treatment should consist primarily of reassurance and support for panic attacks, as benzodiazepines are often not available in flight[7,13,34]. Fewer than 0.01% of psychiatric emergencies have required the diversion of the flight course and landing for urgent treatment[34].

Obstetric Emergencies

In-flight births are exceedingly rare, accounting for <0.01% of in-flight medical emergencies[2]. In these situations, it is recommended that non-obstetric physicians provide no more than reassurance and supportive care for the patient, as most women will deliver vaginally even if labor is prolonged[13,35]. In cases of spontaneous vaginal bleeding from potential spontaneous abortions or miscarriages, supportive care should be provided with recommendations to receive medical care upon landing at the expected destination[13].

Ethical and Legal Responsibilities of Physicians

When asked by an airline crewmember to provide care for a fellow traveler, orthopaedic surgeons may believe that they have a duty to assist. Stemming from medical school, all orthopaedic surgeons have taken oaths to practice with beneficence and nonmaleficence, and to place the interests of patients above their own[36]. The American Academy of Orthopaedic Surgeons (AAOS) Code of Medical Ethics and Professionalism for Orthopaedic Surgeons stressed that[37]: "the orthopaedic profession exists for the primary purpose of caring for the patient." On the ground with other colleagues available, it may be in the best interests of patients to be treated by acute care specialists. The AAOS Code further emphasized that "an orthopaedist has an obligation to render care only for those conditions that he or she is competent to treat"[37]; however, at nearly 35,000 feet (nearly 11,000 m), does a lack of alternatives compel an orthopaedist to treat? Does the orthopaedist believe that the patient would do better without his or her attempted help? These questions must be grappled with in real time. In many scenarios, we believe that the orthopaedist will determine that his or her care is better for the patient with the in-flight medical emergency than no professional intervention. As such, many orthopaedists may offer assistance. Although ethical obligations must be weighed, legal ramifications must also be considered. As in any situation, the initiation of patient treatment creates a doctor-patient relationship, and the unusual circumstances of in-flight medical emergencies do not necessarily absolve the provider of liability risk[6]. Furthermore, the legal requirements of physicians in the countries in which the aircraft is registered, wherein the incident occurs, and from which the patient derives citizenship all may ultimately impact the physician's course of action[12,38-40]. For instance, although the United States, the United Kingdom, and Canada do not compel medical professionals to offer assistance, the European Union (EU) and Australia legally require physicians to treat the patient[12,38-40]. As such, if the aircraft is registered in an EU country or Australia, if the aircraft is currently within those countries' boundaries, or if the patient in question is a citizen of one of the EU member states or Australia, then the physician may be legally required to offer assistance, regardless of the physician's country of citizenship. For events within the U.S. jurisdiction, doctors who choose either to treat or not treat the patient are protected from liability unless the voluntary treatment offered is found to be grossly negligent and deliberately harmful[41].

Determining how this framework affects the doctor on board may be understandably difficult to deal with during in-flight medical emergencies, which often require immediate action. Although accustomed to processing and managing acute patients in the trauma setting, orthopaedic surgeons are also trained to act within a team; we often rely on our colleagues for assistance when confronted with scenarios that fall outside our scope of practice. However, the lack of other medical professionals on board should not prevent consultation for additional perspective. For situations in which the orthopaedic surgeon seeks additional medical, ethical, and/or legal advice or information with regard to an in-flight medical emergency, consultation with a ground-based team of consultant physicians contracted by the airline is an available option and is recommended. Trained specifically for in-flight medical emergencies, these physicians can serve as valuable teammates for the in-flight orthopaedic surgeon and can both facilitate the treatment of in-flight medical emergencies and clarify the orthopaedic surgeon's in-flight responsibilities. Moreover, many consultant firms keep track of the medical facilities available at specific airports and can recommend where to land, if diversion is deemed necessary[42].

Following evaluation, treatment, and discussion with an airline-associated physician on call, the treating orthopaedic surgeon may recommend that the pilot divert course and land. If this occurs, the pilot is not legally obligated to follow the onboard doctor's recommendation, and if the pilot chooses not to land, the physician is not legally responsible for any resulting potential patient harm; however, shared decision-making between the physician and pilot and crew is always encouraged, and consultation of ground-based medical teams may provide useful additional insight[6,41]. When the plane does land, either following diversion or at the final destination, the flight team is responsible for notifying emergency medical services to be stationed and prepared to offer care. Although no strict recommendations exist for volunteer physicians upon landing, the U.S. Centers for Disease Control and Prevention (CDC) recommendations for patient handoffs

from air to ambulance agencies include communicating with the ground ambulance team the clinical status of the patient and which, if any, interventions have been taken[43]. Following the transfer of care, medical doctors are prohibited from receiving monetary compensation for their efforts, unlike they do through insurance for ground-based care that they deliver; however, they may accept gifts from the airline including travel vouchers, food and drink, and complimentary seat upgrade(s)[12,41]. The complexities of the ethical and legal framework with regard to in-flight medical emergencies present challenges for any orthopaedist offering care. The summary of basic requirements provided above offers the orthopaedic surgeon a template to ethically and legally manage a patient during an in-flight medical emergency.

Conclusions

During in-flight medical emergencies, orthopaedic surgeons may believe that they are morally compelled to provide treatment to patients, or they may be legally mandated by the laws of the EU and Australia to provide treatment for patients. Because of the minimal overlap of common orthopaedic injuries with those that most commonly occur during flights[2], orthopaedic surgeons may be hesitant to provide care for emergencies for which they have little recent experience with treating. This can be complicated by unfamiliarity with the legal framework surrounding in-flight medical emergencies and the associated potential for legal liability. This article provides orthopaedic surgeons with treatment algorithms for the most common in-flight medical emergencies, including syncope and cardiac arrhythmia or arrest. We summarize the legal requirements to offer treatment depending on both on the country of origin and destination of the aircraft and on the citizenship of the patient. We hope this review will assist the orthopaedic surgeon to answer the overhead call and effectively diagnose and treat patients under these increasingly common situations.

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Anterolateral Complex Reconstruction Augmentation of Anterior Cruciate Ligament Reconstruction

Biomechanics, Indications, Techniques, and Clinical Outcomes

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Abstract

» Injury to the anterolateral complex may be identified on advanced imaging and may manifest with a higher level of instability, in particular with pivot-shift testing.

» The anterolateral ligament reconstruction or modified Lemaire procedure may be used to reconstruct the anterolateral complex of the knee to augment anterior cruciate ligament (ACL) reconstruction.

» Indications for anterolateral ligament reconstruction are evolving, but relative indications include revision ACL reconstruction, grade-III pivot shift, generalized ligamentous laxity, young age (<20 years), or high-level or high-demand athlete.

» Early outcomes have suggested that anterolateral ligament augmentation of ACL reconstruction may decrease the risk of re-tear of the ACL reconstruction.

Historically, surgeons performed anterior cruciate ligament (ACL) reconstruction with an extra-articular ligament reconstruction because of concerns with rotational stability. Outcomes from isolated extra-articular ligament reconstructions were poor, and, with the advent of arthroscopy, the focus turned to intra-articular reconstruction of the ACL and later anatomic reconstruction[1-4]. However, recent data have shown that there remains unacceptably high revision rates in ACL reconstruction, up to 18%, particularly in the younger population[5-10]. The results of these failures are multifactorial, but one of the concerns is lingering lateral rotatory instability, which may not be completely restored with current ACL reconstruction techniques. As a result, there has been a renewed interest in restoring the anterolateral complex during ACL reconstruction.

There are 2 common techniques utilized to restore the anterolateral complex: anterolateral ligament reconstruction, and a modified Lemaire procedure[2]. The publication by Claes et al. on the anterolateral ligament led to the reintroduction of extra-articular ligament augmentation of ACL reconstructions with modern techniques[11]. Most commonly, an anterolateral ligament reconstruction involves a soft-tissue graft fixed at the origin and insertion point of the anterolateral ligament. Others have focused on the anterolateral soft tissues including the superficial iliotibial band and the deep iliotibial band with its Kaplan fibers, which

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comprise the anterolateral complex of the lateral knee: the modified Lemaire procedure[2].

This article will review the biomechanics and indications for an extra-articular ligament augmentation, typical patient workup, surgical technique, rehabilitation protocol, and clinical outcomes of the anterolateral ligament reconstruction and the modified Lemaire procedure.

Anatomy and Biomechanics

The ACL originates in the femoral condyle in the intercondylar notch and inserts anteriorly on the central tibial plateau. It functions principally to prevent anterior tibial translation, as well as the rotation of the tibia[12,13].

The ACL itself is composed of 2 bundles with separate biomechanical functions and insertion points. The anteromedial bundle has an oval-shaped femoral insertion that inserts posteriorly to the posterolateral bundle. The anteromedial bundle inserts on the tibia near the lateral horn of the lateral meniscus, and the posterolateral bundle inserts posterolaterally to the anteromedial bundle[12,13]. During flexion, the anteromedial bundles are longer and more taut. In contrast, the posterolateral bundles are tighter and longer during extension[13,14]. The combined tensile effect of these 2 bundles is responsible for preventing excessive anterior tibial translation. When the ACL is torn, anterior tibial translation can increase up to 15 mm at 30° flexion about the knee[12,15,16]. Similarly, tearing the mediolateral fibers of the ACL removes substantial resistance to internal tibial rotational forces, resulting in a complete shift of the rotary axis to a more medial position, as can be identified in pivot-shift testing[12,17].

If torn or ruptured, the ACL has little potential for healing[12,18]. This can lead to dynamic instability of the knee joint with episodes of tibial translation or giving-way episodes commonly associated with pivoting of the joint[18]. Additionally, secondary stabilizers have been identified that contribute to stability of the knee. The more superficial anterolateral complex has been implicated in restraining internal tibial rotation, and its integrity during an ACL tear has functional implications in the overall stability of the knee[19-21].

The anterolateral complex has been difficult to characterize anatomically, although it has been broken down into several different layers (Fig. 1). The top portion consists of the superficial, middle, and deep layers of the iliotibial band[21-23]. The deeper capsule-osseous layer is the most medial portion of the iliotibial band[24]. Moreover, there is a lateral capsule joint that merges anteriorly to the lateral collateral ligament (LCL) and encompasses the superficial layer of the anterolateral complex[21]. The lateral capsular ligaments of the knees consist of the anterior capsular ligament, the mid-third capsular ligament, and posterolateral arcuate complex. The anterolateral ligament could refer to either a portion of the mid-third

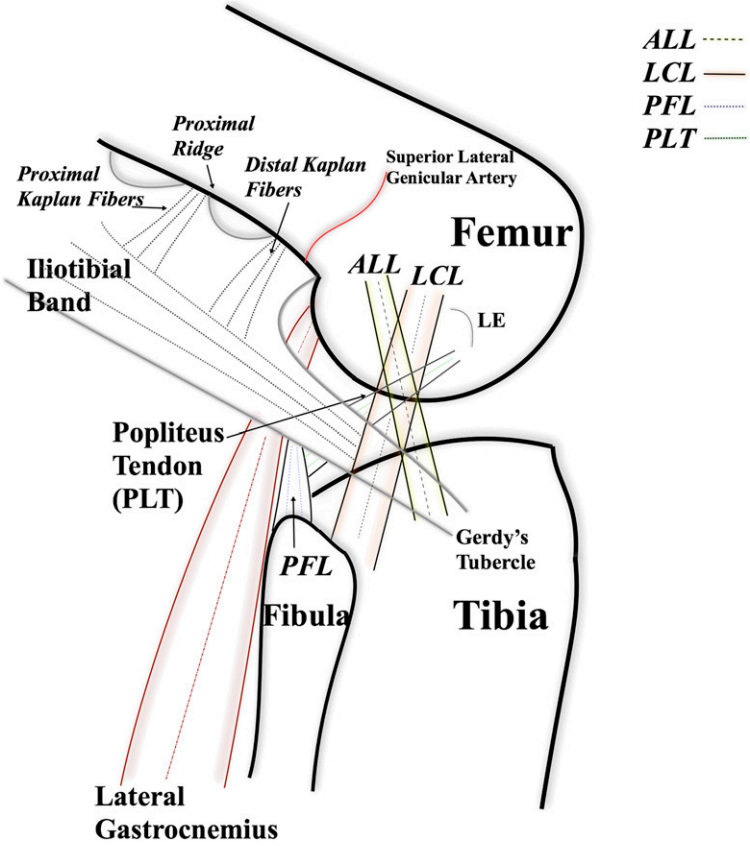

Fig. 1

Diagram showing the anterolateral complex anatomy. ALL = anterolateral ligament, PFL = popliteofibular ligament, LE = lateral epicondyle, and PLT = popliteus tendon.

capsular ligament, the capsule-osseous layer, or both depending on the author's specifications[11,21,23]. Determining the functional role of the anterolateral complex in patients with ACL tears has proven to be difficult because of the inconsistencies characterizing anatomical structures. Sectioning the Kaplan fibers and the capsule-osseous layer of the iliotibial band markedly increases internal tibial rotation through a typical range-of-motion test[25]. Moreover, sectioning the anterolateral ligament has been demonstrated to increase internal tibial rotation by upwards of 3.3° at 45° of knee flexion, but has less of an effect at physiological ranges of tibial translation[26]. In addition, a recent study indicated that patients with injuries that involved both the ACL and the anterolateral capsule had higher pivot-shift values, demonstrating the role of the anterolateral complex in maintaining the rotational stability of the tibia[27].

Indications and Contraindications

Anterolateral ligament complex reconstruction or extra-articular augmentation was historically common; however, long-term outcome studies using modern techniques are not yet available, to our knowledge. The majority of data are from in vitro, cadaver studies, and clinical data are short-term. The lack of in vivo medium-term or long-term outcome studies makes it difficult to understand which patients do well following anterolateral complex reconstructions, and, thus, it remains unclear as to which patients are best indicated for this procedure.

To date, the best available evidence would suggest that anterolateral complex reconstruction is a viable surgical option for patients undergoing ACL reconstruction who are young (<20 years of age), demonstrate hyperlaxity, or engage in high-risk activities or sports or for patients undergoing revision ACL reconstruction. Some authors have also included a grade-III pivot shift as an indication for an anterolateral complex reconstruction[28-30].

Although a patient may have a grade-III pivot shift preoperatively or during intraoperative examination, often an isolated anatomic ACL reconstruction can successfully restore a stable knee. Moreover, Peeler et al. determined that the grading of pivot shift is highly variable among expert surgeons and even among the same surgeon[31]. As such, caution is advised when using the pivot-shift grade as an isolated indication for anterolateral complex reconstruction.

Some authors have reported that patients with hyperlaxity should be considered for an anterolateral complex reconstruction[28-30]. Hyperlaxity may be measured by the Beighton score[32]. The Beighton score requires patients to perform 5 tasks in which both limbs are evaluated: (1) passive dorsiflexion and hyperextension of the fifth metacarpal joint beyond 90°, (2) passive apposition of the thumb to the flexor aspect of the forearm, (3) passive hyperextension of the elbow beyond 10°, (4) passive hyperextension of the knee beyond 10°, and (5) active forward flexion of the trunk with the knees fully extended so that the palms of the hands rest flat on the floor. If a task is present on the unilateral side, then the task score equals 1, and if a task is present bilaterally, then the task score equals 2. For activity 5, the maximum score is 1. A score of 0 to 3 is normal, a score of 4 to 6 is laxity, and a score of 7 to 9 is hyperlaxity[32].

High-risk activities include sports or activities that require sharp changes in direction such as cutting or pivoting. Common sports with higher risks are soccer, football, or basketball.

Patients with ACL tears with associated multiligament reconstruction (e.g., posterior cruciate ligament, posterolateral corner) are a unique group who typically experience these tears following major trauma. The most common complication following multiligament reconstruction is stiffness, and the addition of an anterolateral complex reconstruction, although theoretically beneficial for a grossly unstable knee, may be counterproductive in this patient population.

Patient Workup

History

The workup for patients who may be candidates for anterolateral complex reconstruction is identical to the workup for patients who are candidates for any ACL reconstruction. A thorough history should be obtained for all patients, with particular attention given to age, prior injury, surgical history, sporting activities, and history of hyperlaxity. An assessment of prior failed operations including potential etiologies of failure is necessary for all patients. ACL femoral tunnel malposition remains the main culprit for failure of a primary ACL reconstruction in up to 80% of cases[33]. However, in the revision setting, patients should be asked whether they ever felt back to normal or stable or whether there was another traumatic event following the primary surgical procedure. Prior operative notes and intraoperative photographs should also be obtained and reviewed.

Symptoms that may indicate associated pathology should be evaluated. Mechanical symptoms such as catching or locking may indicate meniscal pathology. Pain or crepitus may be a sign of chondral injury or mild arthritis. Research from the Multicenter ACL Revision Study (MARS) group found that only 10% of patients will have normal articular cartilage or menisci when they undergo a revision surgical procedure[33].

A comprehensive understanding of the patient's functional goals with regard to profession and recreation is critical, as contact sports or activities requiring cutting may benefit more from additional stability. Patients who do not wish to engage in high-risk activities may not benefit from anterolateral complex reconstruction.

Physical Examination

For all patients, a physical examination of both knees should be performed. Overall leg alignment should be observed in the

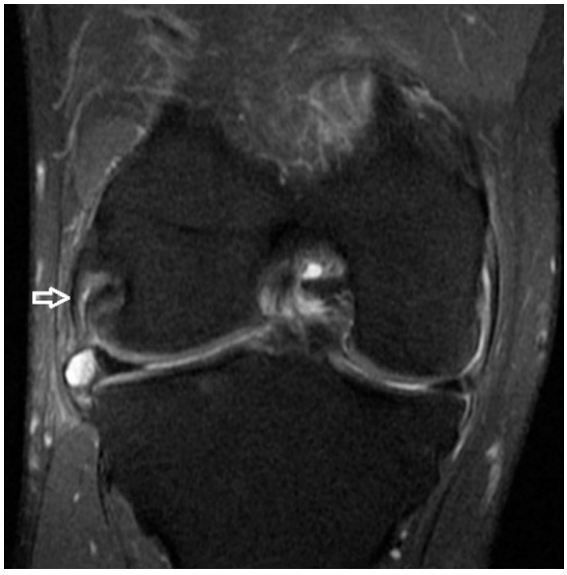

Fig. 2-A

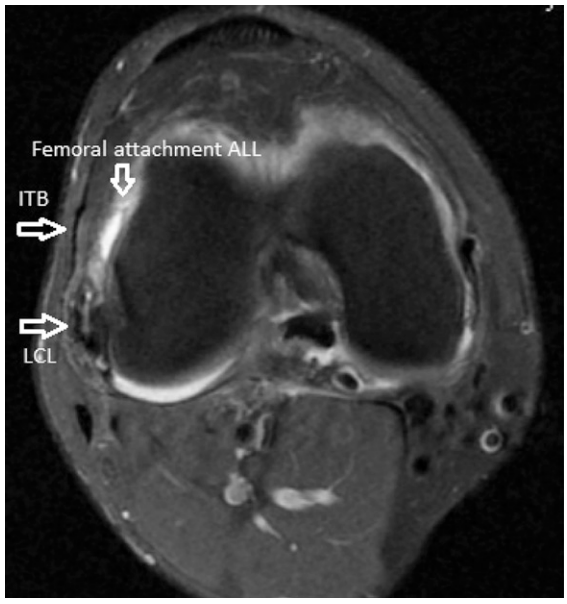

Fig. 2-B

Figs. 2-A and 2-B T2-weighted MRI scans of the femoral avulsion of the anterolateral ligament (ALL). The open arrow demonstrates the course of the ALL. **Fig. 2-A** Coronal view. **Fig. 2-B** Axial view. ITB = iliotibial band.

standing position. The patient is asked to walk at a normal pace and then at a fast pace. At a normal pace, some patients are able to compensate, and the fast pace may highlight gait abnormalities. An abnormal foot progression angle to maintain stability may indicate a component of rotation and varus or valgus thrust gaits may indicate a degree of coronal imbalance.

In the seated or lying position, the uninjured knee should be examined first for comparison. If the injured knee is examined first, patients may experience pain during maneuvers, which can lead to guarding and an inability to examine the uninjured knee. An inspection of the knee should be made for prior incisions and any muscle atrophy, particularly quadriceps or hamstring. Active and passive range of motion for extension and flexion and any block to motion should be recorded. Careful attention to the degree of laxity in the uninjured knee, but also in other joints, should be noted. With the patient sitting, knees flexed to 90° and feet firmly planted on the floor, the patient can often demonstrate an anterolateral drawer by actively contracting the quadriceps, indicating the anterolateral laxity.

Lachman testing and pivot-shift testing should be performed. Clinicians should be careful in acute injuries, as it may be too painful for patient to undergo any special test maneuvers. The assessment of associated injuries should be evaluated and documented as it may be necessary to address these at the same time. Other potential injuries are to the medial collateral ligament, LCL, posterior cruciate ligaments, posterolateral corner, and meniscus. These can be examined with varus and valgus stress tests, and additional meniscal tests (joint-line tenderness, Thessaly, Apley tests), dial tests, and posterior drawer tests.

Imaging Studies

Imaging studies including radiographs and magnetic resonance imaging (MRI) are helpful in the evaluation of potential candidates for anterolateral complex augmentation with ACL reconstruction. A standard radiographic series of the knee, including anteroposterior, Merchant or sunrise, or posteroanterior weight-bearing (Rosenberg view)[34], should be obtained. A Segond fracture is commonly associated with an anterolateral ligament injury[35].

An evaluation for degenerative joint disease should be made. Patients with moderate to advanced arthritic changes may be suited for osteotomy or arthroplasty depending on age, activity level, and patient preference. In the revision setting, previous femoral and tibial tunnel position, as well as the location and type of fixation, should be noted. The amount of tunnel lysis should also be measured.

If there is suspicion for abnormal limb alignment on physical examination or standard radiographs, then a standing full-length alignment radiograph may be warranted. Varus and valgus alignment and tibial slope should be measured.

Advanced imaging should be obtained. In the revision setting, a computed tomography (CT) scan may be beneficial to measure tunnel lysis and bone loss but is beyond the scope of this review. An MRI scan should be obtained to evaluate the anterolateral complex and for associated injuries. In their systematic review on imaging diagnosis of anterolateral ligament reconstruction, Puzzitiello et al. found that the full length of the ligament could be visualized in 20.6% to 96.7% of knees[35]. The anterolateral ligament is best evaluated on the coronal and axial images (Figs. 2-A and 2-B). Disruption of the anterolateral ligament may occur at the

femoral, tibial, or meniscal attachments. Several definitions and classifications have been described, but it remains unclear as to which ones are helpful for predicting the need or success of anterolateral complex reconstruction[35].

Additional Surgical Considerations

If the decision is made to add an anterolateral complex reconstruction, then several surgical considerations must be made. In the revision setting, the position of prior tunnels should be evaluated and determined if it will interfere with tunnels for an anterolateral ligament reconstruction. Similarly, in the multiligament reconstruction, all planned tunnels should be assessed with possible interference with anterolateral ligament tunnels. If the position may interfere with anterolateral ligament tunnels, then one may consider a modified Lemaire procedure. However, we would caution the use of anterolateral complex reconstruction in the multiligament scenario, as many of these patients experience stiffness, which may be exacerbated by additional constraint.

In the scenario of other associated injuries, including meniscal repair and osteotomy, we would also recommend careful consideration to the sequence of procedures. We recommend making all other osseous procedures and meniscal repairs and then reevaluating the degree of laxity. An anterolateral complex reconstruction may not be needed after these procedures.

Surgical Technique: Anterolateral Ligament Reconstruction

There are several techniques of anterolateral ligament reconstruction described. Our preference is to use a single-strand semitendinosus allograft for the anterolateral ligament augmentation with interference screws and an autograft bone-patellar tendon-bone or quadrupled semitendinosus for ACL reconstruction when available. We performed the procedure with the patient in the supine position under a regional block with an indwelling catheter and we monitored anesthesia care to avoid the need for endotracheal intubation. This decreases the risk of anesthetic complications and recovery time from anesthesia and facilitates pain relief in the early postoperative period. We have also started using long-acting bupivacaine liposome suspension, which obviates the need for an indwelling catheter while still providing 2 to 3 days of postoperative pain relief.

The first step is to harvest the autograft for the ACL reconstruction. For the semitendinosus, a 4-cm vertical incision is made along the anteromedial aspect of the tibia just distal and 3 cm medial to the tibial tubercle. The sartorius fascia is sharply split obliquely along the line of the pes tendons and is carefully reflected to facilitate later repair. The semitendinosus is identified, and its reflections and attachments are split. With the distal attachment intact, an open tendon stripper is used to harvest the graft. The muscle is removed from the graft and the tendon is quadrupled and prepared. It is measured on proper sizing determined for its femoral and tibial sides. It is placed in tension on the back table until insertion.

A standard diagnostic arthroscopy is performed to identify intra-articular injuries using standard anteromedial and anterolateral portals. Any meniscal or chondral injuries are addressed at this time. Next, the femoral and tibial footprints of the residual ACL are prepared.

The key to a successful anterolateral ligament augmentation is a proper sequence of events to ensure that neither graft is injured during drilling or positioning of the other. The femoral tunnel for the ACL graft should be performed first. Our preference is to use an outside-in technique with an appropriately sized retrocutter. The camera is placed in the anteromedial portal and then a femoral guide is placed in the anterolateral portal and the drill is placed. The cutting drill is then flipped, and the femoral socket is made retrograde to a depth of 20 to 25 mm with at least a 7-mm lateral cortex left intact. After drilling the femoral tunnel for the ACL reconstruction, the tunnel for the femoral insertion of the anterolateral ligament should be drilled to prevent guide pins from puncturing grafts.

The lateral epicondyle, the Gerdy tubercle, and the fibular head are marked. A 3 to 5-cm incision is made at the level of the lateral epicondyle and proximally (Fig. 3-A). Dissection is made down to the bone. The lateral epicondyle is identified, and a guide pin is placed 8 mm proximal and 4 mm posterior to it. The pin is placed in a slightly proximal and anterior trajectory. This is confirmed with fluoroscopy.

The tunnel is then overdrilled with a 5-mm drill to a depth of 25 mm. At this point, the femoral tunnel is visualized through the anteromedial portal to determine if the anterolateral ligament guide pin or tunnel has violated the ACL femoral tunnel. Additionally, if fluid extravasates from the anterolateral ligament tunnel, this can also indicate ACL tunnel violation. If this occurs, the anterolateral ligament tunnel position should be reevaluated and confirmed to be in proper position and adjusted if necessary. Drilling the anterolateral ligament tunnel prior to the ACL graft passage prevents piercing the ACL graft or suspensory fixation when making the anterolateral ligament tunnel.

Next, the ACL reconstruction is completed. Our preferred technique is to perform this with an ACL aiming guide placed through the anterolateral portal. An appropriately sized flip cutter is placed through the guide and a socket is made with retrograde drilling to allow a socket size of at least 20 to 25 mm with at least 7 mm of cortical bone. Next, the ACL graft is positioned. The tibial anterolateral ligament tunnel trajectory is far enough away from the tibial tunnel of the ACL that this tunnel may be drilled after fixation of the ACL graft.

Passing sutures are placed through the femoral and tibial sockets and retrieved together through the anteromedial portal to prevent skin bridges during graft passage. The femoral side of the graft is passed through the anteromedial portal first and tightened down using an adjustable

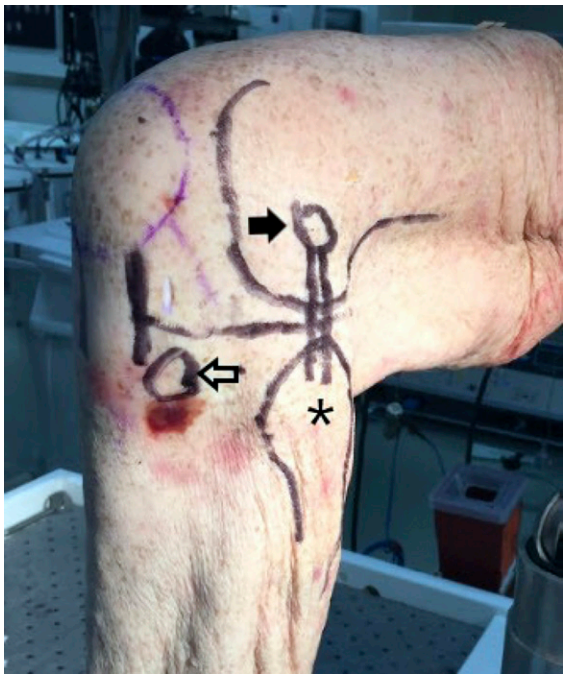

Fig. 3-A

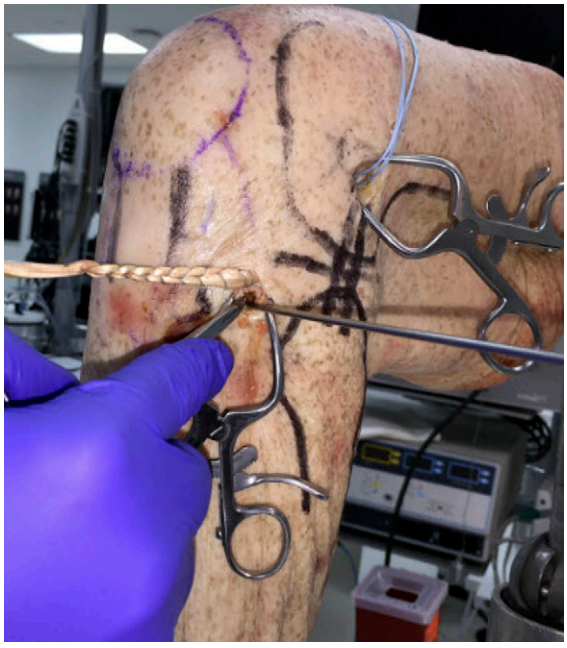

Fig. 3-B

Figs. 3-A and 3-B Approach anterolateral ligament reconstruction. **Fig. 3-A** An incision was made proximal to the lateral epicondyle, and a longitudinal incision was made 1 cm distal to the joint line and 2 cm posterior to the Gerdy tubercle. The open arrow indicates the Gerdy tubercle, the closed arrow indicates the lateral epicondyle, and the asterisk indicates the fibular head. **Fig. 3-B** The graft was passed from proximal to distal using a clamp and a passing suture for the shuttling technique. The previously placed pin at 1 cm distal from the joint line and 2 cm posterior to the Gerdy tubercle that is in place through the distal incision is used to wrap the graft around to check for isometry through the knee range of motion.

suspensory fixation device. Next, the tibial side of the graft is passed through the anteromedial portal and tightened on the tibial side with a cortical button.

The tibial tunnel for the anterolateral ligament is then determined. A longitudinal incision 1 cm distal to joint line and 2 cm posterior to the Gerdy tubercle is made (Fig. 3-B). A Kelly clamp is placed from the femoral incision of the anterolateral ligament down to the midpoint between the Gerdy tubercle and the fibular head. The Kelly clamp should be beneath the retinaculum but remain extracapsular. This facilitates a path for graft passage. A passing suture is also placed at this point. At 1 cm distal to the joint line and 2 cm posterior to the Gerdy tubercle, a Beath pin is placed distal from the joint line to avoid a breach of the articular cartilage (Fig. 3-B). The free end of the graft can be wrapped around the pin to check for isometry through range of motion of the knee. Once an appropriate length of graft is determined, the allograft is marked at this point and is then whipstitched and sutures are passed through a tenodesis interference screw and are inserted into the femoral anterolateral ligament socket after a tap is used to prepare the tunnel. The previously placed passing suture is used to pull the allograft through the previously made path to its tibial insertion. The graft is looped around the distal pin and the knee is taken through the range of motion to check for isometry. The position is adjusted as necessary. Next, to facilitate the appropriate length of graft, the knee is placed at 90° and the graft is pulled taut. A point 18 mm distal to the pin is marked. The graft is whipstitched from the pin to this point distally. The excess graft is cut. A 5-mm drill is drilled over the Beath pin to a depth of 25 mm. A tap is used. The knee is then placed in full extension and the graft is tensioned through the biotenodesis screw. Excess sutures are cut. The wounds are closed in layers. The knee is placed in full extension.

Surgical Technique: Modified Lemaire Procedure

In comparison with the standard anterolateral ligament reconstruction, Lemaire developed an operation that uses a strip of the iliotibial band fed through a bone hole to attach a ligament posteriorly to the LCL on the femur to the Gerdy tubercle[2,36].

Similar to our standard ACL reconstruction, we perform the procedure with the patient in a supine position under regional block with indwelling catheter and monitored anesthesia care to avoid the need for endotracheal intubation. The ACL reconstruction is performed as described previously.

After ACL reconstruction, laxity is tested and, if there remains rotational laxity, then a modified Lemaire procedure may be added. A longitudinal incision from the Gerdy tubercle to 10 cm proximally is made. The iliotibial band is visualized. A 1-cm-wide strip of the middle third of the iliotibial band is harvested with a 6 to 8-cm length. The

strip should be 1 cm anterior to the posterior border of the iliotibial band. Care should be taken to preserve the most posterior aspect of the iliotibial band. The distal attachment to the Gerdy tubercle is left intact. Next, the LCL is identified and a vertical slit in the tissue anterior and proximal to the LCL is made. A Kelly clamp is placed through these slits to create a tunnel for the iliotibial-band strip to pass. The strip of the iliotibial band is taken deep to the LCL (Fig. 4).

The femoral attachment site is identified. It is positioned proximal to the LCL on the metaphyseal flare of the lateral femoral condyle at the center of the distal Kaplan fibers. This area is cleared of soft tissue with a periosteal elevator. A low-profile ligament staple is used for cortical fixation to secure the iliotibial band with the knee at 30° of flexion under tension.

The defect in the iliotibial band is closed with interrupted absorbable sutures. The skin is closed in layers. The knee is placed in full extension.

Rehabilitation

Patients with anterolateral complex augmentation followed standard ACL reconstruction rehabilitation. The patient is kept in a brace while at rest until able to perform an unassisted straight leg raise. This typically occurs around 4 to 7 days. Early range of motion is initiated. Crutches are used as necessary for comfort, but the patient is typically weaned from the crutches by 10 to 14 days. A typical return to sport is between 6 and 8 months after the patient demonstrates the ability to participate in a battery of functional testing.

Clinical Outcomes

Historically, lateral extra-articular reconstruction has had mixed clinical long-term outcomes, with certain studies indicating potential abnormal joint kinematics and even arthrosis[37-39]. Anatomic anterolateral ligament reconstruction can cause overconstraint of internal rotation beyond 30° of knee flexion during pivot-shift testing[40]. However, in instances in which preoperative high-grade pivot shifts have been identified, the combined reconstructions of the ACL and the anterolateral ligament reconstruction have resulted in overall improved stability in the pivot-shift test, indicating improved rotational stability[41,42].

Combining ACL and anterolateral ligament reconstruction also significantly reduced rupture rates in both bone-patellar tendon-bone and quadrupled hamstring tendon grafts. In a prospective cohort study of 502 patients who were 16 to 30 years of age and participated in pivoting sports, the addition of anterolateral ligament reconstruction with a quadrupled hamstring tendon graft resulted in a 3.1 times fewer graft failure compared with quadrupled hamstring tendon graft alone and 2.5 times fewer graft failure when compared with bone-patellar tendon-bone alone. The quadrupled hamstring tendon graft and anterolateral ligament were also associated with an increased 1.9 odds of

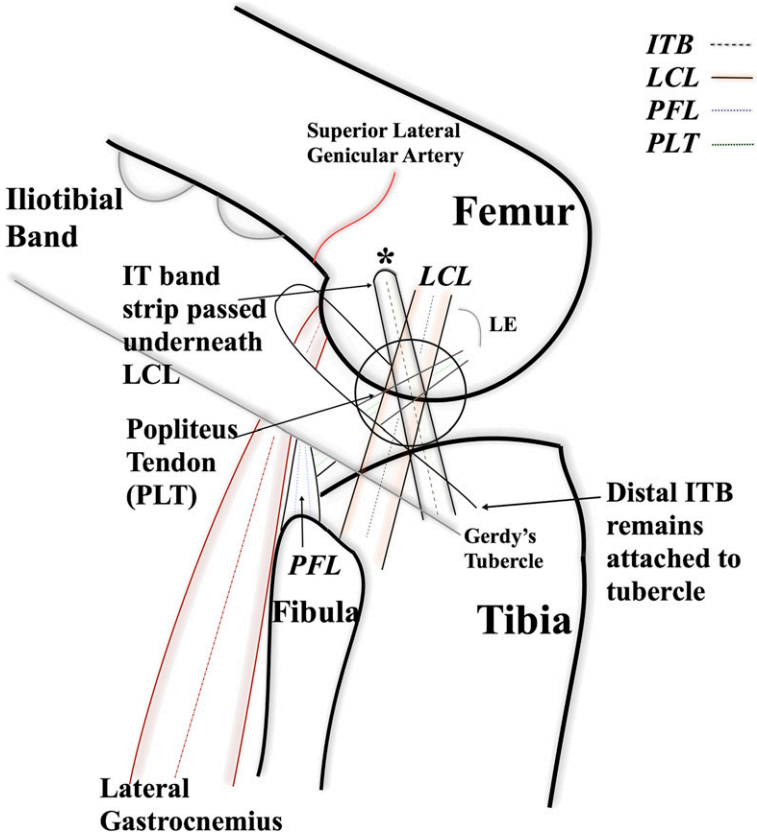

Fig. 4

Modified Lemaire procedure. The asterisk indicates the strip of the iliotibial band (ITB) placed underneath the LCL and attached deep and proximal to the LCL on the metaphyseal flare of the lateral femoral condyle; this strip of ITB is secured with a low-profile ligament staple. PFL = popliteofibular ligament, LE = lateral epicondyle, PLT = popliteus tendon, and IT = iliotibial.

returning to pre-injury level. Of note, there was no difference in return to pre-injury levels of quadrupled hamstring tendon graft and anterolateral ligament and bone-patellar tendon-bone graft alone. The study did not include patients with bone-patellar tendon-bone and anterolateral ligament reconstruction[43,44]. In this study, there were also no significant differences in pain between patient populations[43,44]. These combined reconstructive operations were also associated with low complication rates[44], suggesting that they could provide more postoperative stability for patients for high risk of re-rupture with limited complications.

Similar to the anterolateral ligament reconstruction, early-stage postoperative studies indicate that ACL reconstruction with a modified Lemaire procedure is able to reduce the residual rotational stability associated with ACL reconstructive surgical procedure alone while avoiding the overconstraint of the knee measured by pivot-shift laxity[45,46]. A 2-year study followed the progress of patients with patellar autograft (bone-patellar tendon-bone) reconstructions, double-bundle hamstring reconstructions, and bone-patellar tendon-bone reconstructions with Lemaire reconstructions. Although patients across the study had improved anterior tibial translation values, patients with the addition of Lemaire reconstruction had the highest lateral compartment anterior tibial translation correction as measured on stress radiographs[47]. Clinically, all patients returned to sport, but only 64% of patients who underwent bone-patellar tendon-bone with a modified Lemaire procedure returned to the same level of sport compared with 75% of patients in the other 2 groups[47]. However, these differences were not significant and may represent a selection bias as patients selected for the modified Lemaire procedure were not randomized but were chosen if they demonstrated higher degrees of laxity. Interestingly, the levels of postoperative knee pain and International Knee Documentation Committee (IKDC) subjective assessment scores were similar across all groups despite differences in return to the same level of sport.

Although there have been a few studies that perform a direct head-to-head comparison of clinical outcomes between anterolateral ligament and modified Lemaire extra-articular augmentations of ACL reconstruction, a recent robotic study using cadavers compared the postoperative biomechanics of both procedures. The study found that there was residual laxity after isolated ACL reconstruction in the setting of anterolateral ligament and Kaplan fiber injuries[48]. Both the modified Lemaire and anterolateral ligament augmentation procedures with ACL reconstruction restored anterior tibial translation similar to the native knee[48]. However, both also led to overconstraint in tibial internal rotation[48]. There was greater constraint to tibial internal rotation with the modified Lemaire procedure compared with the anterolateral ligament augmentation[48]. Biomechanical modeling can be conflicting and cannot be substituted for more dynamic clinical analysis[45,49]. Also, early clinical studies mentioned previously have demonstrated that ACL reconstruction combined with a modified Lemaire procedure could concurrently reduce rotational instability of the knee without any loss of motion[45], suggesting that a longer follow-up of the clinical outcome is needed to resolve the conflicting finding.

Additional Considerations for Anterolateral Ligament Reconstruction Compared with the Modified Lemaire Procedure

Aside from potential differences in biomechanics and clinical outcomes, one must consider the cost differences. An anterolateral ligament reconstruction can be performed with autograft or allograft. An autograft may result in additional surgical morbidity, particularly in revision cases, and an allograft will add a financial cost. A modified Lemaire procedure utilizes native tissue. However, there may be surgical morbidity of resecting a portion of the iliotibial band including fascia herniation from the defect. A modified Lemaire procedure may also be more attenable to a salvage situation when a patient unexpectedly demonstrates unsatisfactory rotary instability following technically sound anatomic ACL reconstruction, because it does not require a graft or specialized equipment.

Summary

The long-term clinical effects of augmentation of ACL reconstruction with anterolateral complex reconstruction remain to be determined. Biomechanical and early clinical data support that it can help to increase the rotational stability of an ACL reconstruction. Indications are evolving, and further studies are increasingly published with encouraging results. Additional studies are necessary to determine the long-term outcomes of these procedures, particularly with respect to restoration of function and reduction of failures following ACL reconstruction. In addition, the cost-effectiveness in relation of numbers needed to treat to prevent a failure between standard isolated ACL reconstruction, anterolateral ligament augmentation, and modified Lemaire augmentation must be evaluated.

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Isolated Treatment of a Comminuted Capitate Fracture

A Case Report

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Abstract

Case: Comminuted fractures of the capitate, in the absence of associated carpal injuries, are exceedingly rare. Treatment of this complex injury is not well-documented in the literature. We describe the case of a comminuted capitate fracture that was successfully managed with Kirschner wire fixation.

Conclusion: Based on this case and a review of the literature, management of a comminuted capitate fracture with Kirschner wire fixation can lead to successful treatment and positive patient outcomes.

The capitate is the largest and most central carpal bone; it is well-protected by surrounding osseous structures[1,2]. Fractures of the capitate are rare, accounting for only 1.3% of all carpal fractures[3-5]. Most commonly, capitate fractures occur in conjunction with other carpal injuries, including scaphoid fractures or perilunate dislocations, or scaphocapitate fracture syndrome[3,6,7]. An isolated capitate fracture, defined as a fracture through the capitate without evidence of perilunate dislocation or surrounding carpal fractures, is exceedingly rare[3,6]. When reported in isolation, capitate fractures are often nondisplaced simple fractures through the capitate body or avulsion-type injuries[1,8]. Comminuted capitate fractures and their treatment are not well-documented in the literature.

Commonly, capitate fractures occur due to direct trauma to the dorsal aspect of the wrist or via a fall on a fully flexed or extended wrist[1]. Given the typical nondisplaced nature of isolated capitate fractures, treatment is usually nonsurgical with cast immobilization[8]. In the setting of an unstable carpus, fractures typically occur through the capitate body, and open reduction and internal fixation (ORIF) with Kirschner wires or headless compression screws is performed. More importantly, concomitant ligamentous injuries and fractures of the scaphoid are addressed[1,5-9].

Management of displaced capitate fractures without associated carpal injuries is not often reported in the literature. We present the unique case of a 22-year-old woman with a comminuted capitate fracture without perilunate dislocation. To our knowledge, this is the first reported case of a comminuted capitate fracture without associated carpal injuries that required operative stabilization with Kirschner wires.

The patient was informed that data concerning the case would be submitted for publication, and she provided consent.

Case Report

A 22-year-old right-hand-dominant woman presented as a transfer patient to a level-I trauma center following a high-speed motor-vehicle collision. She was an unrestrained passenger in a vehicle that was "T-boned" while traveling at 60 mph (97 km/hr). Initial radiographs revealed a comminuted capitate fracture in the right hand (Fig. 1). A small radial styloid fracture, measuring approximately 2.5 mm, also was noted. Subsequently, computed tomography (CT) was performed to better delineate the injury and to rule out associated carpal injuries. CT confirmed a comminuted capitate fracture with dorsal displacement of the proximal pole (Fig. 2). Volarly, the third metacarpal, the capitate, the lunate, and the distal aspect of the radius were contiguous, and congruency of the distal carpal row was maintained. There was no evidence of a scaphoid fracture, scapholunate ligament disruption, or other associated carpal injuries.

Consultation by a fellowship-trained orthopaedic hand surgeon was obtained in the emergency department. Given the substantial displacement, the unstable appearance of the fracture, and its involvement of the lunocapitate and third carpometacarpal joints, ORIF was recommended. The following day, the patient underwent ORIF with use of a 4-cm

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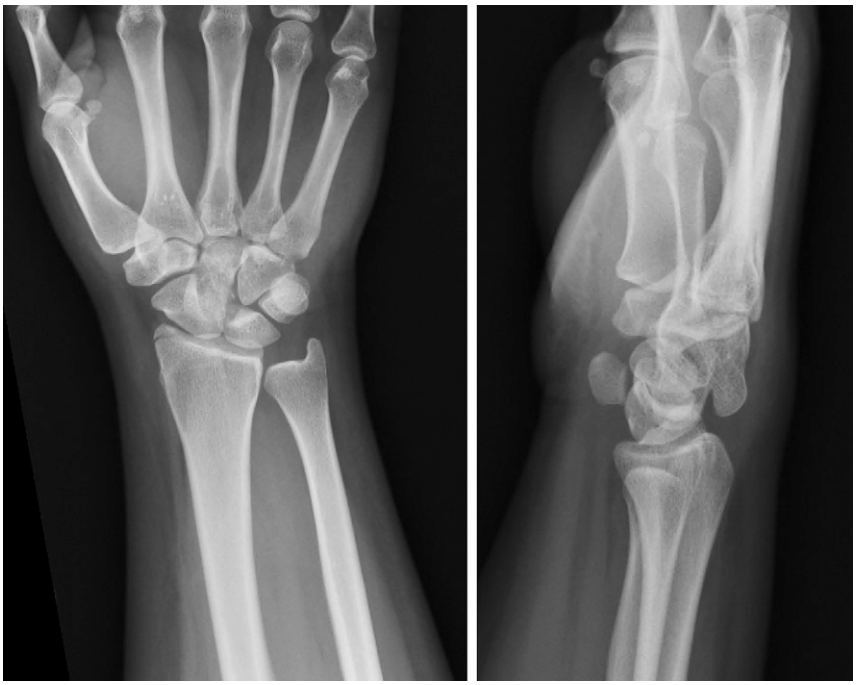

Fig. 1

Preoperative radiographs demonstrating the capitate fracture with dorsal displacement of the proximal fragment.

longitudinal incision that was centered over the dorsum of the capitate. A small rent was noted in the wrist capsule. The remaining capsule was sharply incised, revealing the fracture. Dorsally, the fracture consisted of 2 main fragments: 1 involving the articular surface to the third metacarpal and a larger proximal piece with substantial dorsal displacement. With

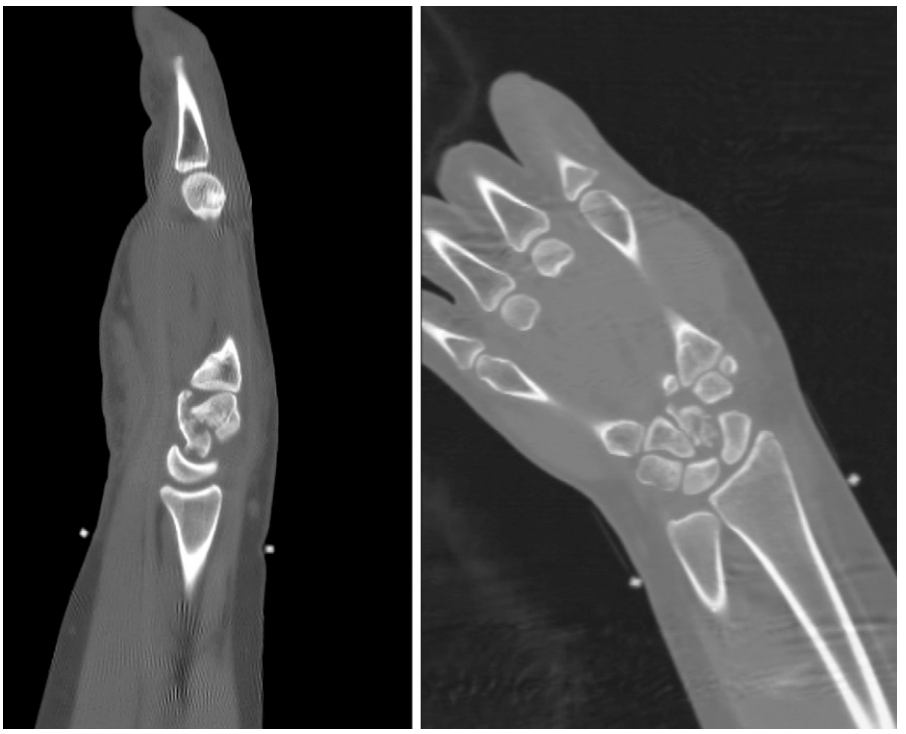

Fig. 2

Preoperative coronal (left) and sagittal (right) CT scans demonstrating a comminuted capitate fracture with coronal shear and depression of the carpometacarpal joint without associated carpal injuries.

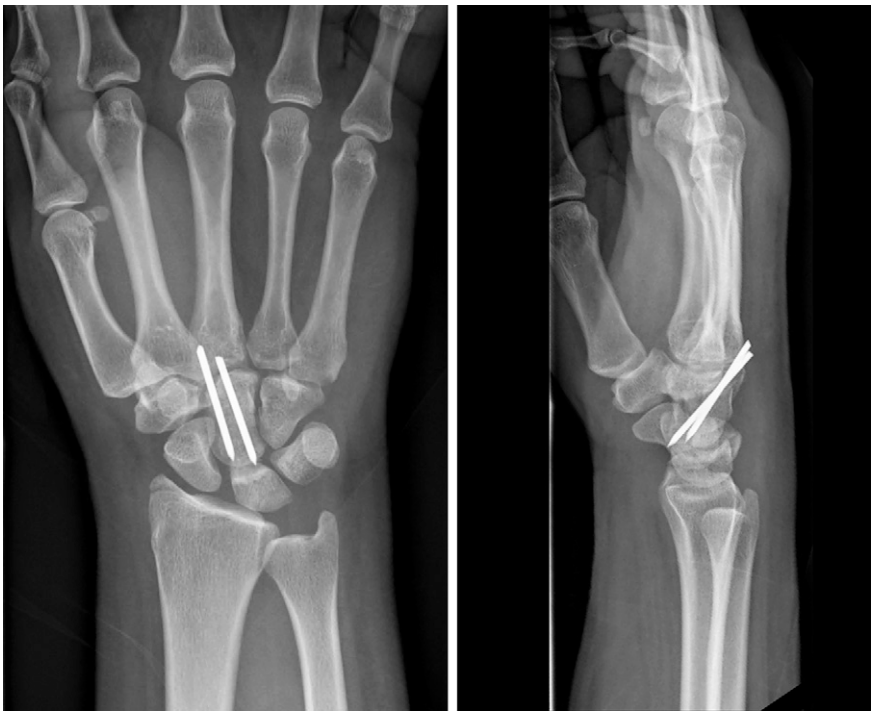

Fig. 3

Postoperative radiographs demonstrating adequate alignment of the capitate fracture with Kirschner wires.

manipulation of the 2 fragments, a coronal split that extended to the base of the capitate was identified. The volar portion of the capitate at the capitolunate articulation appeared to be maintained. Although moderate comminution was present, substantial bone loss was not appreciated. No identifiable intrinsic or extrinsic ligament injuries were noted. The main

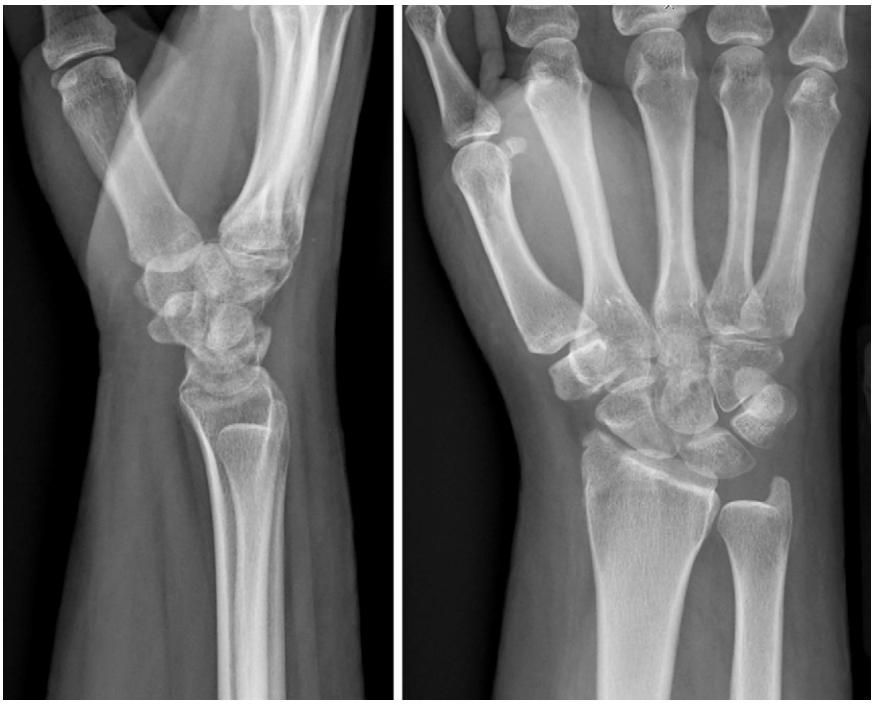

Fig. 4

Radiographs at 1 year postoperatively demonstrating the healed fracture of the capitate without evidence of carpal arthritis.

fragments were cleaned of hematoma and manipulated into an acceptable position. Given the substantial comminution and the coronal split, Kirschner wires were utilized. Two 0.062-in (0.157 cm) Kirschner wires were inserted in a retrograde fashion to hold the fracture fragments in place (Fig. 3). Intraoperative fluoroscopic images were obtained and showed that both wires were through the volar cortex, but without substantial protrusion into the carpal tunnel. With the capitate stabilized, an assessment of carpal stability was performed; intercarpal fixation was not indicated. The capsulotomy was repaired, and the wires were cut below the level of the skin. The wrist was placed in a well-padded volar splint; the patient was made non-weight-bearing and instructed to follow up as an outpatient.

Two weeks after the surgery, the patient was seen in the office and transitioned to a short arm cast with instructions to begin digital range of motion. Six weeks following the ORIF, she was transitioned to a removable wrist brace. The Kirschner wires were removed in the operating room at 8 weeks after the index procedure, and the wrist was placed in a short arm splint. Two weeks later, the sutures were removed, and radiographs demonstrated a well-healed fracture. Occupational therapy (OT) was started for wrist range of motion and strengthening. At the 14-week follow-up, she demonstrated full, nonpainful wrist range of motion. At 1 year after surgery, she continued to do well, was back to work, and reported being able to carry a 5-gallon (19-L) bucket without issue. She had no functional deficits or pain with daily activities. She demonstrated full pain-free range of motion about the wrist. Radiographs demonstrated a well-healed capitate fracture without evidence of surrounding arthritis (Fig. 4).

Discussion

Fractures of the capitate are rare injuries, accounting for only 1.3% of all carpal fractures[3-5]. Most commonly, capitate fractures occur in conjunction with other carpal injuries, including perilunate dislocations, scaphoid fractures, or scaphocapitate fracture syndrome[3,6,7]. Transscaphoid and transcapitate perilunate dislocations represent the most common pattern, in which the force is transferred through the scaphoid and the capitate, resulting in fracture of both[8]. An isolated capitate fracture, defined as a fracture through the capitate without evidence of perilunate dislocation or surrounding carpal fractures, is exceedingly rare[3,6]. In isolation, these injuries are typically nondisplaced and treated nonoperatively[1,3,8]. There is a paucity in the literature about the management of isolated comminuted capitate fractures.

Management of capitate fractures is dictated by the fracture pattern and surrounding carpal pathology. Additionally, similar to other carpal bones, the capitate receives a retrograde blood supply[10]. While rare, nonunion and osteonecrosis of the proximal pole have been reported following displaced capitate fractures, which need to be considered when evaluating treatment options[3,11]. Thus, cast immobilization is usually reserved for isolated nondisplaced fractures. ORIF with pinning or headless compression screws is needed for comminuted or displaced fractures with concomitant carpal injuries[1,4]. After consideration of surgical fixation alternatives for our patient, we elected to proceed with Kirschner wire fixation given the substantial comminution, the presence of a coronal split, and the dorsal displacement.

Kadar et al. described the treatment and outcomes of 53 patients with capitate fractures[8]. Of these, 11 were isolated injuries, with only 1 reported as comminuted. However, treatment for the comminuted capitate was not described. In their series, all isolated injuries were initially managed nonoperatively, with 2 ultimately requiring surgery for delayed union at a mean of 88 days. Conversely, Rebuzzi reported on the successful use of Kirschner wire fixation for a simple isolated capitate fracture with proximal pole dorsal dislocation, highlighting the importance of prompt treatment with adequate reduction and immobilization to prevent osteonecrosis[12]. While previous case reports have described both nonoperative and operative treatment modalities, to our knowledge, no cases regarding outcomes of surgically managed comminuted capitate fractures in the absence of concomitant carpal injuries have been reported in the literature. With our patient, because of the substantial amount of comminution, operative stabilization was undertaken.

Our patient had a comminuted capitate fracture without associated carpal injury, and was successfully treated with ORIF with use of Kirschner wires 1 day after injury. The finding of a radial styloid avulsion fracture confounded the treatment of the capitate because a greater-arc injury had to be considered. After careful evaluation, it was determined that there were no additional ligamentous or osseous carpal injuries, and the capitate would be treated in isolation. Monahan and Galasko describe the mechanism of scaphocapitate fracture syndrome in detail, in which the radial styloid impinges on the scaphoid, causing fractures of both the scaphoid and the radial styloid[13]. If the force is great enough, energy is transferred through the scaphoid, resulting in a concomitant fracture of the capitate. One can reason that without a concomitant scaphoid fracture or injury to the scapholunate ligament, it is implausible for scaphocapitate fracture syndrome to be the mechanism of injury. The presence of the small radial styloid fracture in our patient characterized this as a greater-arc injury; because there were no clinically noteworthy ligamentous injuries that necessitated treatment, this was a unique injury pattern. With this unique and previously unreported pattern, alternative mechanisms should be explored. One such theory involves impaction of the third metacarpal base with the midportion of the distal aspect of the capitate in the coronal plane. Feasibly, this could have resulted in the coronal split that was seen in this injury, as well as the joint depression that was noted at the carpometacarpal joint. Additionally, the force vector may have exited posteriorly within the capitate, resulting in 2 dorsal fragments and displacement without associated carpal disruption.

To our knowledge, no prior case of a comminuted capitate fracture without associated carpal injury has been reported. With a paucity of literature regarding management of this rare injury, outcomes following various treatment modalities

are merited. While treatment recommendations cannot be made based on a single case, we present a successful outcome following temporary Kirschner wire stabilization. We chose to remove the temporary fixation at 8 weeks after the index procedure and started OT at 10 weeks. The complications of carpal arthritis, osteonecrosis, and nonunion were not found with this treatment regimen. Union of the fracture did occur, and the patient was able to return to full preinjury function. ■

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Femoral Neck Fracture Fixation with a Medial Buttress Plate That Led to Impingement with Hip Flexion

A Case Report

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Abstract

Case: A 47-year-old man with an isolated femoral neck fracture was treated with open reduction and internal fixation with a medial femoral neck buttress plate and a dynamic hip screw. Union was achieved without osteonecrosis of the femoral head. However, hip arthroscopy that was performed for persistent hip pain following the fracture union revealed an intra-articular impingement of the buttress plate and a substantial anterior acetabular chondral injury.

Conclusions: To our knowledge, this is the first reported complication associated with the application of a medial buttress plate for a femoral neck fracture. This case report may help surgeons who employ this technique to avoid a similar complication.

Displaced femoral neck fractures are challenging to treat in young patients given the lack of periosteum and a vulnerable blood supply to the femoral head[1-3]. These injuries rely on direct bone-healing, and they have a risk of complications such as nonunion and osteonecrosis[4-13]. In young patients, treatment algorithms favor anatomic reduction and fracture fixation to preserve the native hip[14].

The primary goals of surgery include preservation of the femoral head, avoidance of osteonecrosis, and achievement of a stable union. In young patients, femoral neck fractures typically result from high-energy mechanisms that cause a vertically oriented shearing fracture pattern[15,16]. A number of fixation strategies have been employed to combat the fracture's angle of inclination, and controversy still exists regarding the best method of fracture fixation[17-25].

The medial buttress plate has been used as a modified construct option to combat the vertical shear force across these fractures[16,26]. Application of a medial buttress plate may aid in reduction and help to maintain anatomic alignment until union, therefore decreasing the high rate of complications associated with these injuries[26]. Numerous theoretical concerns regarding the use of a medial buttress plate have been proposed (e.g., an intracapsular implant, difficult hardware removal with a future salvage operation, injury to the remaining blood supply of the femoral head, and implant impingement), although, to our knowledge, no direct complication has been reported.

We describe a patient with a femoral neck fracture that was treated with a medial buttress plate; subsequently, union was achieved. However, the patient had persistent pain following union and eventually was treated with hip arthroscopy. The medial buttress plate was identified as a source of intra-articular impingement during the arthroscopic evaluation.

The patient was informed that data concerning the case would be submitted for publication, and he provided consent.

Case Report

Clinical Scenario

An active 47-year-old man sustained an injury to the right hip while calf-roping. No other associated injury was noted, and the patient had no history of hip pain. He was a nonsmoking rancher with no medical comorbidities. Physical examination revealed an externally rotated and shortened right lower extremity with tenderness at the hip.

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Diagnostic Assessment

Imaging studies demonstrated an acute, displaced, comminuted, femoral neck fracture in the basicervical region (Fig. 1).

Treatment: Open Reduction and Internal Fixation (ORIF)

After discussion of both the short and long-term risks of surgical intervention, given the patient's age, lifestyle, and occupation, we proceeded with operative fixation of the femoral neck. Based on prior literature suggesting that the quality of reduction is an important variable that determines the outcome and the risk of postoperative complications, an open surgical approach to the femoral neck was performed[27-30]. A Smith-Petersen approach was used with the leg draped free on a radiolucent table. A combination of manual traction and manipulation of the femoral head yielded an anatomic reduction. This reduction was stabilized provisionally with guidewires for size 7.3-mm cannulated screws (Fig. 2). A 2.7-mm reconstruction plate was contoured and placed on the inferior aspect of the femoral neck; 2 screws were placed in the buttress position and 1 screw was placed into the femoral head. The screws were purposely placed into the posterior aspect of the femoral neck to allow for placement of a dynamic hip screw (DHS) anterior to this. Next, a direct lateral approach to the proximal aspect of the femur was performed, and the DHS was placed. A long-barrel, 2-hole side plate was positioned and secured on the proximal aspect of the femur with 2 screws. Direct visualization and fluoroscopic assessment demonstrated anatomic reduction.

Follow-up and Immediate Outcome

Postoperatively, the patient was touch-down weight-bearing for 10 weeks. Radiographs at 6 and 12 weeks demonstrated maintenance of the reduction and no evidence of osseous complications (Fig. 3). Repeat radiographs at 32 weeks demonstrated a healed fracture without evidence of osteonecrosis. The patient was able to work as a rancher; however, he returned to the clinic with sharp right anterior hip pain 20 months after the procedure. This discomfort was reproducible on physical examination with flexion, adduction, and internal rotation of the hip. No abnormality was noted on repeat radiographs.

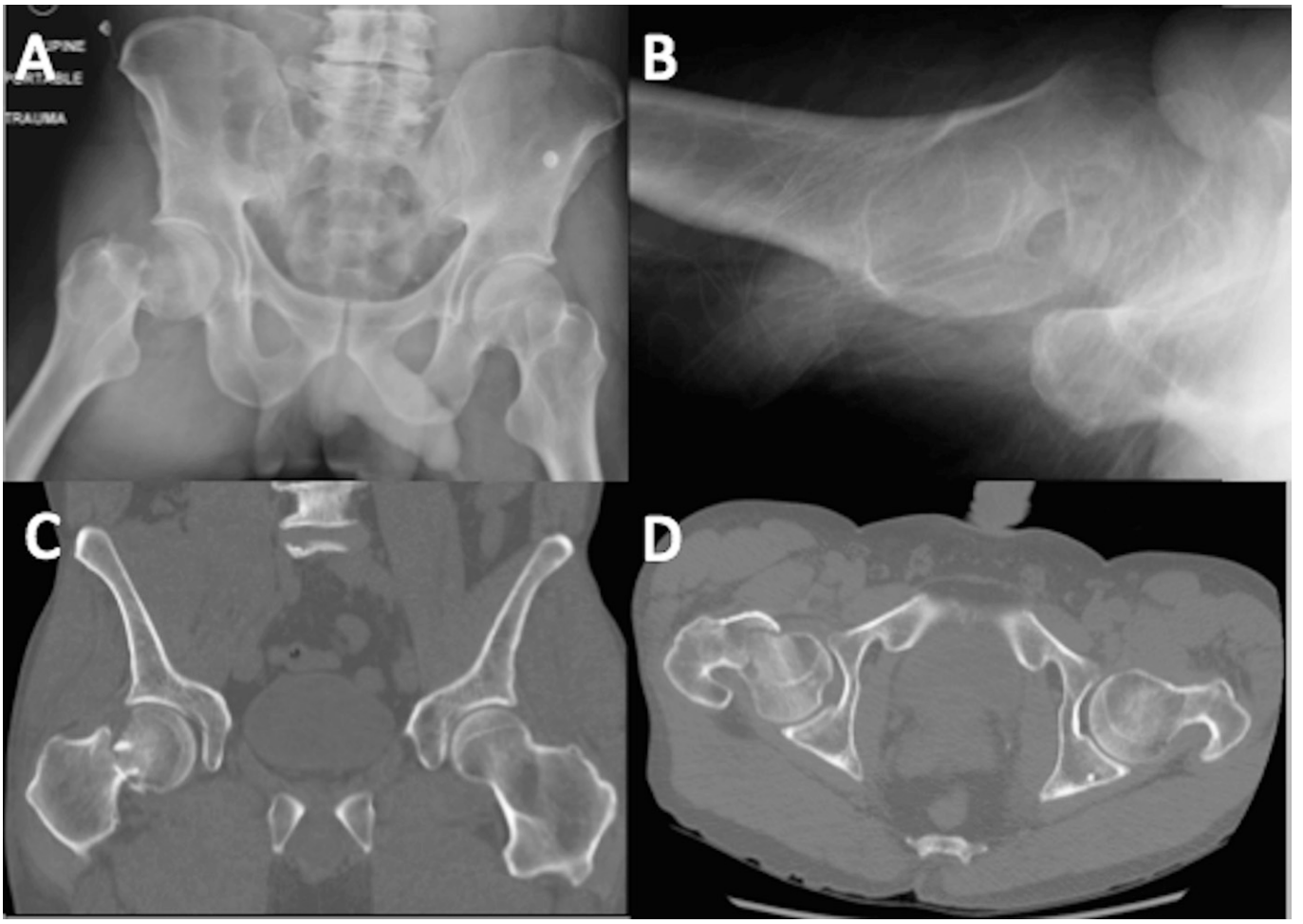

Fig. 1

Figs. 1-A through 1-D Anteroposterior pelvic radiograph (**Fig. 1-A**), cross-table lateral hip radiograph (**Fig. 1-B**), coronal computed tomography (CT) (**Fig. 1-C**), and axial CT (**Fig. 1-D**) demonstrating a displaced, comminuted, basicervical femoral neck fracture.

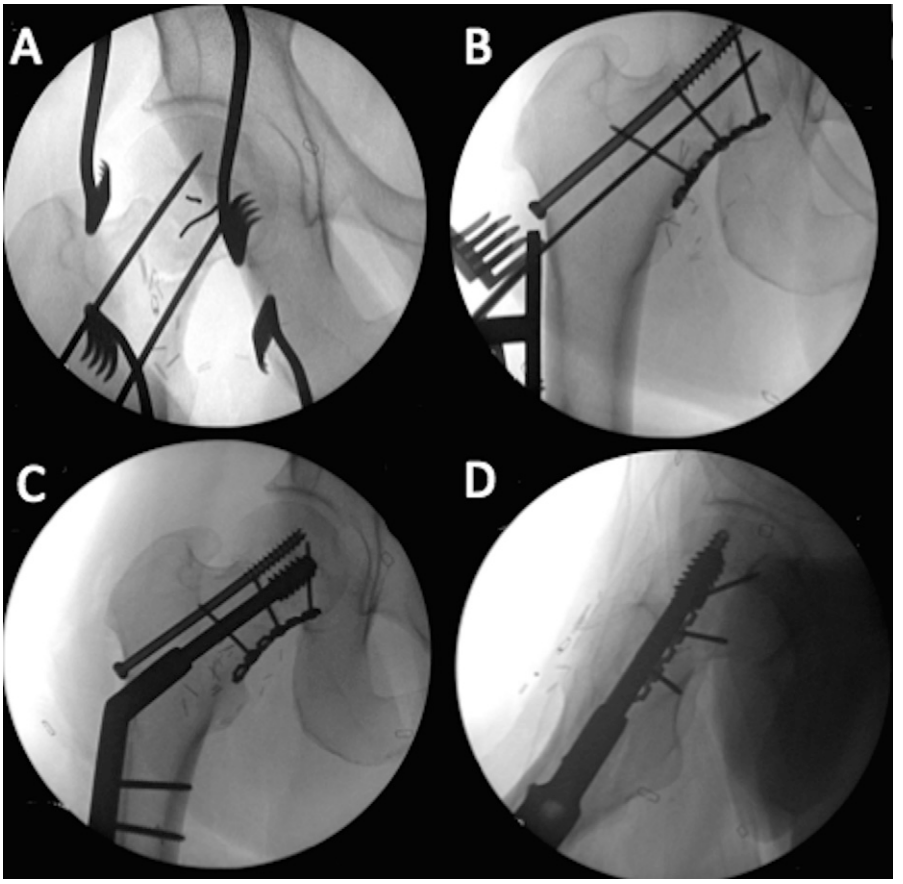

Fig. 2

Figs. 2-A through 2-D Intraoperative imaging. **Fig. 2-A** Anteroposterior image of the hip with provisional fixation, including 2 Kirschner wires. **Fig. 2-B** Anteroposterior image of the hip with a medial buttress plate. **Fig. 2-C** Anteroposterior image of the hip with final fixation, including the medial buttress plate, a derotation screw, and a DHS with a 2-hole side plate. **Fig. 2-D** Lateral image of the hip with the final fixation.

Given that the symptoms were intermittent and not persistent, the patient elected to continue with nonoperative management. At the 2-year follow-up, there was worsening right hip pain that was provoked with impingement testing. On radiographic evaluation, there was no evidence of osteoarthritis, and we believed that the symptoms could be from femoroacetabular impingement (FAI). Symptomatic hardware impingement was not considered as a possible diagnosis at this time, and given the classic physical examination findings suggestive of FAI, hip arthroscopy was indicated. Because of the location of the hardware, magnetic resonance imaging (MRI) was not obtained preoperatively.

Treatment: Hip Arthroscopy

The hip arthroscopy proceeded in a standard fashion[31]. During a diagnostic arthroscopic examination of the central compartment of the hip, a large grade-IV chondral defect involving the anterior-superior and anterior-inferior quadrants of the acetabulum was noted (Fig. 4). The lesion appeared to be an abrasive wear pattern with exposed osseous surface and eburnation. The surrounding articular surface was unaffected and the lesion was contained, but the anterosuperior aspect of labrum demonstrated marked mechanical wear.

The inferomedial aspect of the femoral head and neck were visualized, and the pelvic reconstruction plate from the previously described ORIF was visualized in the intra-articular space (Fig. 4). A dynamic arthroscopic examination was performed to confirm the location of the plate and its relationship to the chondral wear. With 60° of hip flexion, the proximal aspect of the plate was impinging on the labrum; with increasing flexion, the plate fully cleared beneath the labrum and was contacting the area on the acetabulum that corresponded with the previously visualized lesion (Fig. 4-C and Video 1). An attempt to arthroscopically remove the hardware was unsuccessful.

Follow-up and Subsequent Outcome

Following the unsuccessful attempt at arthroscopic removal of the medial buttress plate, the orthopaedic trauma team discussed the risks and benefits of proceeding with hardware removal versus conversion to total hip arthroplasty. The patient ultimately elected for open removal of all of the hardware 2 months later. Six months following the hardware removal, he

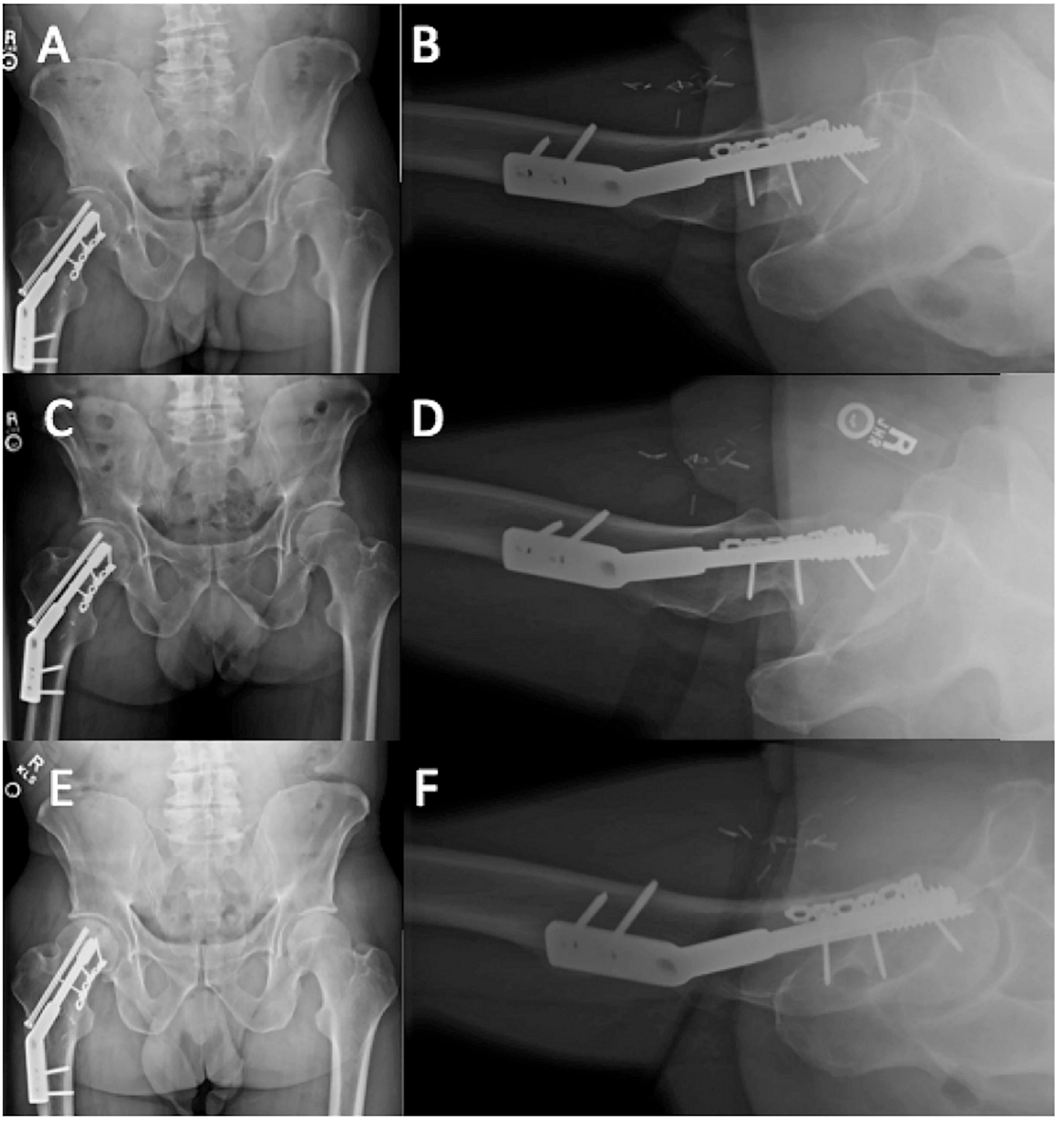

Fig. 3

Figs. 3-A through 3-F Follow-up radiographs. Anteroposterior pelvic (**Fig. 3-A**) and lateral (**Fig. 3-B**) radiographs of the right hip at 6 weeks, anteroposterior pelvic (**Fig. 3-C**) and lateral (**Fig. 3-D**) radiographs of the right hip at 12 weeks, and anteroposterior pelvic (**Fig. 3-E**) and lateral (**Fig. 3-F**) radiographs of the right hip at 32 weeks.

had minimal relief of the symptoms and no evidence of osteonecrosis on plain radiographs. The appearance of the femoral head remained stable throughout the course of treatment, and the chondral injury caused by the hardware impingement was believed to be the primary etiology of the symptoms. He was referred to an adult reconstruction specialist for a total hip arthroplasty (Fig. 5). He returned to work 2 months following the total hip arthroplasty with good pain relief from this

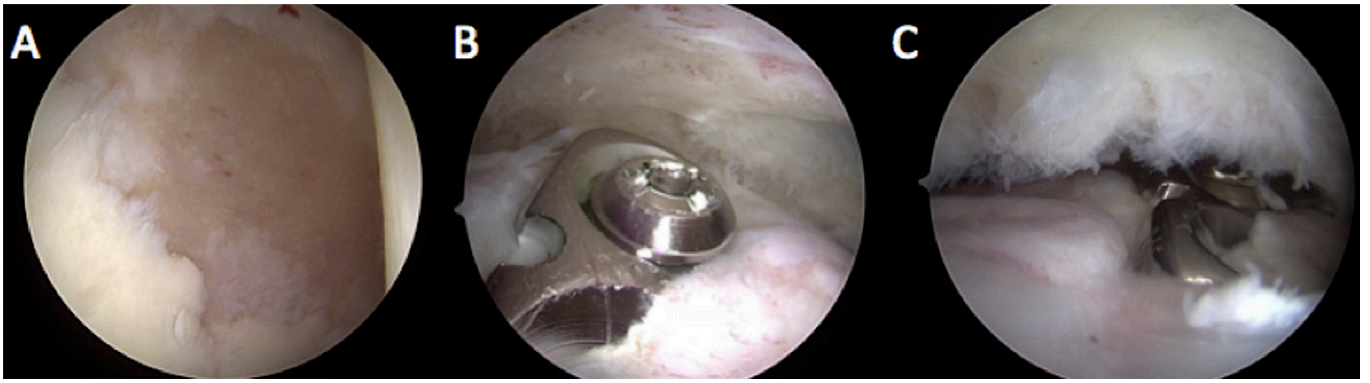

Fig. 4

Figs. 4-A, 4-B, and 4-C Arthroscopic imaging. **Fig. 4-A** Arthroscopic image of the central compartment demonstrating a grade-IV chondral defect of the acetabulum extending from the 12 o'clock to the 3 o'clock position. **Fig. 4-B** The intra-articular position of the reconstruction plate. **Fig. 4-C** The reconstruction plate impinging on the acetabular labrum.

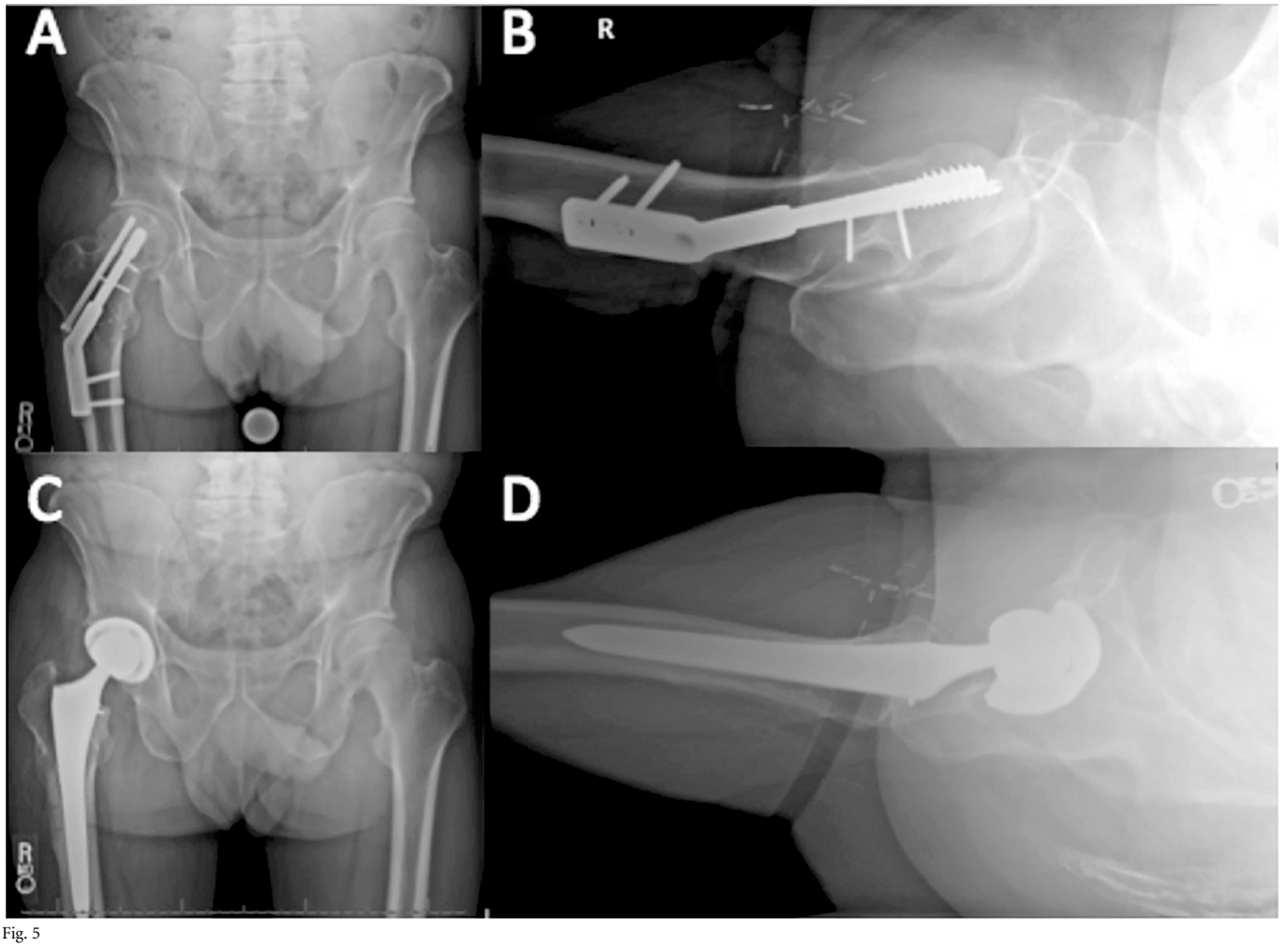

Fig. 5

Figs. 5-A through 5-D Follow-up imaging of the healed fracture after hardware removal and a total hip arthroplasty: anteroposterior pelvic (**Fig. 5-A**) and lateral (**Fig. 5-B**) radiographs of the right hip after removal of the medial buttress plate demonstrating a healed femoral neck fracture without evidence of osteoarthritis or femoral head necrosis, and anteroposterior pelvic (**Fig. 5-C**) and lateral (**Fig. 5-D**) radiographs of the right hip 6 months after the total hip arthroplasty.

procedure; there were no subsequent complications at 1 year postoperatively.

Discussion

Femoral neck fractures in young patients remain a challenge. Younger patients are typically more active, have minimal comorbidities, and have good bone quality, making ORIF an attractive treatment. High rates (12% to 85%) of femoral head osteonecrosis and nonunion remain a primary concern following ORIF[4-13].

It is generally accepted that anatomic reduction with stable fixation offers patients the best chance to heal a fracture without complication and to maintain the native hip. Anecdotally, our experience agrees with that of Ye et al. in that the addition of a medial buttress plate to fixation constructs resists shear forces and helps to prevent treatment failures[26]. Sometimes this is utilized as a reduction instrument, and sometimes it is added after reduction to aid in neutralizing the shear forces on the femoral neck. Therefore, we elected to apply this construct as outlined above. Application of the medial buttress plate in addition to the DHS construct resulted in a stable union without osteonecrosis or varus collapse. However, the patient did subsequently develop an unanticipated complication: intra-articular impingement of the buttress plate ultimately resulted in chondral injury and eventual treatment with a total hip arthroplasty.

In retrospect, subcapital femoral neck fractures are not the ideal fracture pattern for medial buttress plate application, and, if applied in this setting, the plate should be positioned as distal as possible. The cranial margin of the distal fragment in

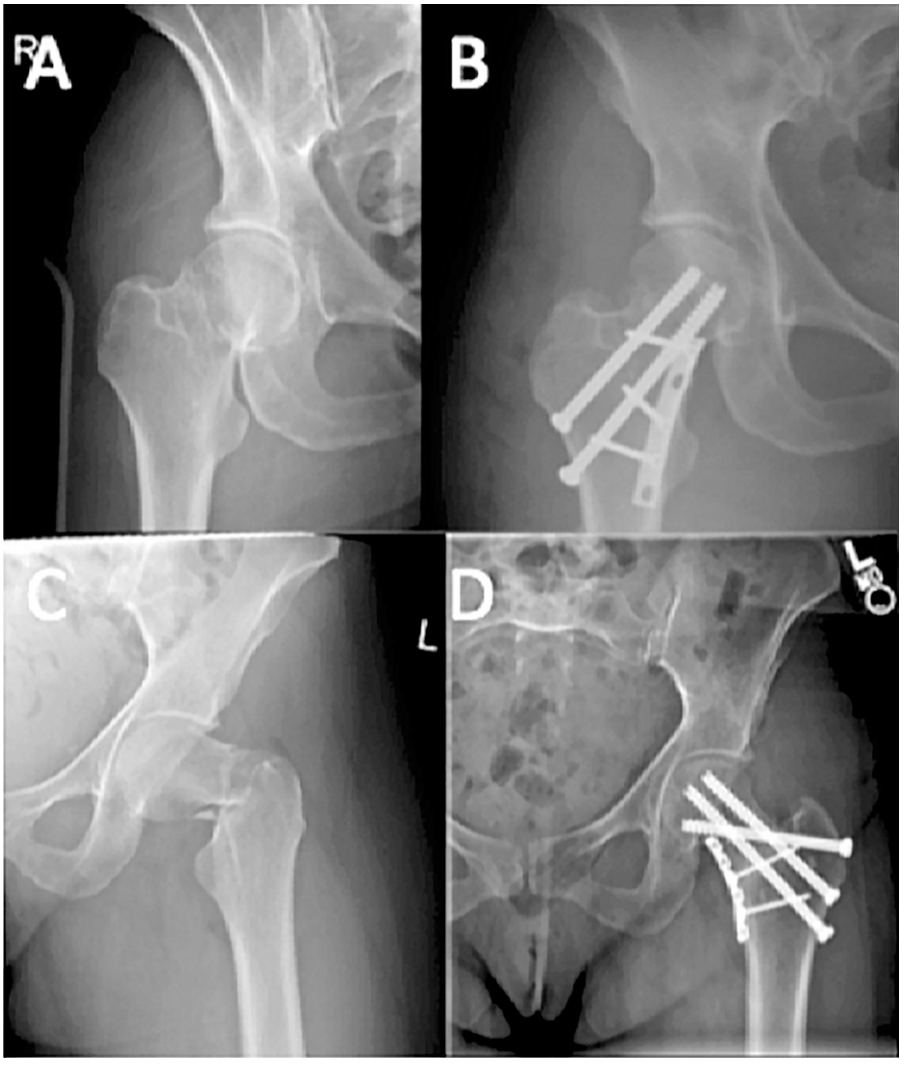

Fig. 6

Figs. 6-A through 6-D Injury and follow-up imaging of successfully employed medial buttress plates for femoral neck fractures in prior patients. **Fig. 6-A** Anteroposterior hip radiograph demonstrating a right transcervical femoral neck fracture. **Fig. 6-B** Follow-up radiograph demonstrating the healed fracture with successful use of a medial buttress plate. **Fig. 6-C** Anteroposterior hip radiograph demonstrating a left basicervical femoral neck fracture. **Fig. 6-D** Follow-up radiograph demonstrating the healed fracture with successful use of a medial buttress plate.

our patient was almost immediately subcapital, but the plate position was not suggestive of impingement when the hip was in extension. Transcervical and basicervical fracture patterns, which offer a larger footprint for hardware placement farther from the hip joint, are more amenable patterns to consider for the application of a medial buttress plate. We have used this technique on prior patients without complication (Fig. 6). It has been our experience that the medial buttress plate does improve construct mechanics and helps to prevent varus collapse and malunion at the fracture site without increasing the risk of osteonecrosis.

It remains unknown if our patient's fracture would have healed uneventfully without the addition of the medial buttress plate. This plate does have the theoretical benefit of providing improved mechanical strength; however, additional research is needed to determine the efficacy of this fixation strategy. To our knowledge, we have described the first complication associated with application of a medial buttress plate so that other surgeons may be aware of the potential problems with medially placed hardware, particularly in high-energy patterns with a subcapital exit. We recommend a dynamic hip examination to evaluate for hardware-related impingement when placing a medial buttress plate. ■

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ESSENTIAL SURGICAL TECHNIQUES

KEY PROCEDURES

The Isometric Quadriceps Contraction Method for Intra-Articular Knee Injection

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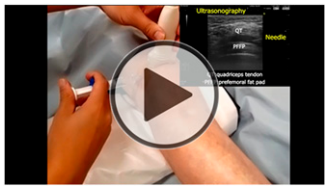
Published outcomes of this procedure can be found at: *JBJS Open Access*. 2018 Dec 20;3(4): e0003



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Abstract

The intra-articular injection is the most important technique for treating not only rheumatoid arthritis but also osteoarthritis of the knee. However, 1 problem is that the drug is often inaccurately injected outside of the joint, especially when no effusion is present. According to a previous systematic review by Maricar et al., the use of a superolateral patellar approach without ultrasonography had a higher success rate (87%) than both a medial midpatellar approach (64%) and an anterolateral joint-line approach (70%). For knees with little effusion, we devised a method of intra-articular injection in which the needle is inserted into the suprapatellar pouch while the patient maintains isometric contraction of the quadriceps. This method, which we call the isometric quadriceps contraction (IQC) method, is based on the concept that isometric contraction of the quadriceps induces contraction of the articularis genus muscle complex, thus expanding the volume of the suprapatellar pouch. The major steps of the procedure are (1) patient positioning and knee placement, (2) finding the puncture point, (3) isometric quadriceps contraction, and (4) needle approach to the suprapatellar pouch and injection. We also show the ultrasound evaluation of the suprapatellar pouch expansion under IQC and the accuracy of the IQC method compared with that of the non-activated quadriceps method. The results of this injection method indicate that the suprapatellar pouch is likely to expand during IQC, improving the probability of successful intra-articular injections. We believe that the IQC method is therapeutically effective and achieved a success rate of 93.3% despite the presence of little effusion and no use of ultrasonography.

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ESSENTIAL SURGICAL TECHNIQUES

KEY PROCEDURES

Latarjet Procedure for the Treatment of Anterior Glenohumeral Instability

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Published outcomes of this procedure can be found at: *J Bone Joint Surg Am.* 2016 Dec 7; 98(23):1954-61, *J Shoulder Elbow Surg.* 2013 Feb;22(2):286-92, and *J Shoulder Elbow Surg.* 2014 Oct;23(10):1473-80.

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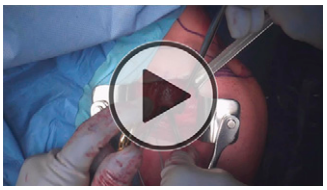

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Abstract

Anterior glenohumeral instability is common, with 21.9 first-time dislocations per 100,000 individuals per year. Recurrent instability is more likely to occur in patients who are younger, of male sex, and have bone defects or ligament laxity. The open Latarjet procedure is effective for the treatment of recurrent anterior glenohumeral instability and is preferred over arthroscopic Bankart repair in the presence of glenoid bone loss. The Latarjet procedure involves transferring the coracoid to the anterior aspect of the glenoid in the following steps. Step 1: Preoperative planning includes an assessment of glenoid deformation and the integrity of the rotator cuff. The degree of bone loss is measured with use of the circle-line method. Step 2: The patient is in the beach-chair position with the arm in a pneumatic arm holder. A parallel drill guide system with 3.75-mm cannulated screws is utilized. Step 3: A 5-to-6-cm incision is made along the anterior axillary line. The deltopectoral interval is established, and the cephalic vein is mobilized laterally. The coracoacromial ligament is transected 15 mm lateral to the coracoid to allow later repair to the anterior capsule. The pectoralis minor is released subperiosteally off the medial coracoid. A 90° oscillating saw is used to transect the coracoid medially to laterally. The coracohumeral ligament is released. Step 4: Two 4.0-mm drill-holes are made 1 cm apart through the coracoid. The undersurface is decorticated. Step 5: The subscapularis is split at the junction of the upper two-thirds and lower one-third. A longitudinal capsulotomy is performed parallel to the glenoid. Step 6: Soft tissue, including the capsule and labrum, is removed from the anterior aspect of the glenoid. The bone is decorticated with an osteotome and a rasp. Step 7: The coracoid is positioned flush or 1 mm recessed relative to the glenoid. Two 1.6-mm guidewires are placed with use of a parallel drill guide followed by a cannulated reamer and two 3.75-mm cannulated screws. Step 8: The coracoacromial ligament is repaired to the capsule. Step 9: The subscapularis split is repaired laterally. The deltopectoral interval and skin are closed in a standard fashion. A standardized rehabilitation protocol is employed postoperatively. The Latarjet procedure results in significantly lower rates of recurrent glenohumeral instability and

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revision compared with the arthroscopic Bankart procedure (3% and 1% compared with 28.4% and 21%, respectively); however, complication rates as high as 30% have been reported, as well as a risk for nerve injury. The videos included in this article highlight the critical steps required to optimize outcomes and minimize complications when performing the Latarjet procedure.

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Comparison of Management of Developmental Dysplasia of the Hip in a Pavlik Harness by Orthopaedic Surgeons, Orthopaedic Pediatricians, and Advanced Practice Providers

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Abstract

Developmental dysplasia of the hip (DDH) is common, with high success rates of treatment in a Pavlik harness for children less than 6 months old. We performed a retrospective review, analyzing the outcomes of patients with DDH managed in a Pavlik harness by orthopaedic surgeons, an orthopaedic-trained physician, and advanced practice providers (APPs). There was no significant difference among provider types in patients requiring operative procedures of any kind. A straightforward treatment of DDH can be performed by orthopaedic-trained pediatricians and APPs, with referral to an orthopaedic surgeon if the patient fails treatment in a Pavlik harness.

Developmental dysplasia of the hip (DDH) is common, with reported incidence rates varying between 1 and 20 per 1,000 births[1]. The natural history of DDH depends on both the type and the severity of the hip abnormality. Early detection is crucial as delay in treatment can result in significant long-term morbidity, generally related to early-onset degenerative arthritis. The gold standard for the treatment of DDH detected before 6 months of age in a patient with a reducible hip dislocation is a Pavlik harness. The Pavlik harness is initially applied and adjusted by the treating provider, and weekly evaluations of the child's hip are performed. If the hip is not reduced and stable by 2 to 4 weeks, other treatment options such as a different orthoses or closed reduction and spica casting are considered. If the hip is stable by 2 to 4 weeks, follow-up visits to confirm continued stability of the hips in the Pavlik harness and adjust the harness are scheduled every 2 weeks[1]. Generally, total treatment time is the child's age when the hip is successfully reduced plus 3 months. Overall, the Pavlik harness has a success rate of 90%[2,3] and depends on the age at initiation of treatment and time spent in the harness.

With increasing awareness of DDH, more pediatricians and advanced practice providers (APPs), such as nurse practitioners and physician assistants, are involved in the care of these patients. Whereas a screening examination for DDH is usually performed by the primary care provider, management of infants, children, and adolescents with DDH is a common and appropriate referral to a specialist[4]. Given the limited access to pediatric orthopaedic surgeons, there is an increasing need for APPs to provide care for children with musculoskeletal ailments. With growing demands in the United States for musculoskeletal care, the American Orthopaedic Association endorses the use of nurse practitioners and physician assistants to address the need for more musculoskeletal care providers[5]. Furthermore, nonphysicians are increasingly becoming primary care providers for underserved

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSJOPA/A86).

populations[6]. Multiple studies have demonstrated that patients of different racial and ethnic backgrounds, those from non-English-speaking households, and those with public insurance are more likely to have difficulty obtaining specialty care[7-13]. APPs may provide the window of opportunity for connecting these underserved populations to pediatric orthopaedic care. The utility of APPs has been previously shown in different orthopaedic care settings, including Veterans Health Administration outpatient clinics, community based Level II trauma systems, and even pediatric fracture care[14-17]. Outside of pediatric fracture care, there is scant literature about pediatric orthopaedic care provided by APPs, and to our knowledge, there are no prior studies specifically looking at the treatment of DDH by providers other than orthopaedic surgeons.

The goal of this study is to analyze the need for additional bracing or operative management of patients with DDH managed in a Pavlik harness by orthopedic surgeons, an orthopaedic-trained pediatrician, and APPs. Our hypothesis is that there is no difference in need for additional interventions between DDH patients treated in a Pavlik harness regardless of provider seen.

Materials and Methods

The medical records of all patients who presented to our pediatric orthopedics clinic with DDH during the 5-year period from July 2006 to November 2011 were reviewed. Patients were included in the study if they were less than 6 months of age at the initial visit and if they wore a Pavlik harness as part of their treatment for DDH (Fig. 1). Exclusion criteria consisted of patients who had an abnormal examination or ultrasound findings in the early neonatal period but normalized without treatment within the first 12 weeks of life, hip dysplasia or dislocation associated with other disorders (i.e., myelomeningocele, cerebral palsy, and arthrogryposis), and patients with follow-up less than 6 months. Six months minimum follow-up was chosen to try to capture patients who had completed their course in the Pavlik harness, as most patients are only placed in a Pavlik harness until 6 months of age.

A retrospective chart review was performed on all patients meeting the inclusion criteria. Age at presentation, laterality, sex, provider type at initial visit, number of visits with each type of provider, approximation of length of time in a Pavlik harness, and the length of follow-up were obtained. All 3 types of providers saw patients in a pediatric orthopaedic clinic setting. For patients seen by several different providers (orthopaedic surgeon, APP, or orthopaedic-trained pediatrician), the type of provider was determined based on the provider who saw the patient for the most visits while in the Pavlik harness. If a patient saw 2 types of providers for an equivalent number of visits while in the Pavlik harness, the patients were designated into the group of the provider who initially placed them in the Pavlik. Failure of the Pavlik harness was defined as the need for additional bracing, either a hip abduction brace or a rhino brace; a closed or open reduction and spica casting; or additional operative procedures.

Chi-square tests were used to evaluate for differences between the 3 groups. If the groups were found to be nonequivalent, 2-proportion z-tests were run between pairs to assess for statistical significance.

Results

A total of 457 patients with DDH presented to our clinic during the 5-year study period. Three hundred and eight patients met the inclusion criteria; 81 patients were excluded for presenting at greater than 6 months, and 21 patients were excluded as they were not treated in a Pavlik harness. An additional 47 patients were excluded for a follow-up of less than 6 months. Three of the 308 patients saw 2 types of providers for an equivalent number of visits while in the Pavlik harness, and none of these patients required further treatment. Eighty-three percent of the patients included were female. Average follow-up was 2.7 ± 1.7 years.

Fig. 1
Child undergoing treatment in a Pavlik harness.

A total of 103 patients (33.4%) were treated by orthopaedic surgeons, 91 (29.5%) by an orthopaedic pediatrician, and 114 (37.0%) by APPs. There were no cases of documented Pavlik harness disease, and only one instance of femoral nerve palsy among all patients. Fifty-five patients (17.9%) underwent additional bracing with an abduction orthosis, either a hip abduction brace or a rhino brace. Twenty-three patients (7.5%) required reduction and spica casting, with 11 patients (3.6%) requiring open reductions. Four patients (1.3%) underwent additional procedures, including one patient (0.3%) who underwent bilateral Pemberton osteotomies, one patient (0.3%) who underwent a unilateral Pemberton osteotomy, one patient (0.3%) who underwent a Salter innominate osteotomy, and one patient (0.3%) who underwent an open reduction after a failed closed reduction. All 4 of these patients also had additional bracing or reduction procedures before these secondary procedures.

There was a statistically significant difference in patients treated with additional bracing depending on the type of provider seen while in the

TABLE I Outcomes of Treatment Based on Provider Type*

Provider Type	Total No. Patients Treated	Underwent Additional Bracing	Underwent Operative Intervention
Orthopaedic Surgeon	103	14 (13.6%)	9 (8.7%)
Pediatrician	91	25 (27.5%) p = 0.008	5 (5.5%) p = 0.62
APP	114	16 (14%) p = 0.46	10 (8.8%) p = 0.62

*APP = advanced practice provider.

Pavlik, with the orthopaedic pediatrician more likely to treat patients with abduction orthoses. Of patients subsequently treated with abduction orthoses, 27.5% were treated by an orthopaedic pediatrician vs. 13.6% treated by orthopaedic surgeons ($p = 0.008$) and 14.0% treated by APPs ($p = 0.008$). There was no significant difference in patients requiring operative procedures of any kind, including closed and open reductions or subsequent osteotomies, by the provider seen. Of patients ultimately requiring operative intervention, 8.7% of patients were treated by orthopaedic surgeons, 8.8% of patients treated by APPs, and 5.5% of patients treated by an orthopaedic pediatrician required operative intervention, $p = 0.62$ (Table I).

Of the 25 patients treated with additional bracing by an orthopaedic-trained pediatrician, 21 patients (84%) required no additional treatment, with 4 patients (16%) requiring additional procedures (Table II). Eighty percent of patients treated by an orthopaedic pediatrician requiring additional procedures underwent a trial of abduction bracing preoperatively. All 14 patients (100%) treated by orthopaedic surgeons in an abduction brace were definitively treated and none of these patients required additional procedures. None of the patients managed by orthopaedic surgeons who required additional procedures were treated with an abduction orthosis preoperatively. Sixty-two percent of patients treated by APPs with abduction orthoses were successfully treated. Seventy percent of patients treated by APPs who required operative treatment were treated with an abduction orthosis preoperatively.

Discussion

There was no difference in need for operative intervention, regardless of the type of provider managing Pavlik treatment. Patients treated by an orthopaedic-trained pediatrician were more likely to be placed in additional bracing, but this did not affect need for operative intervention for closed or open reduction or subsequent osteotomies.

Although 27.5% of patients seen by an orthopaedic-trained pediatrician while in the Pavlik harness were subsequently treated with abduction orthoses, only 13.6% treated by orthopaedic surgeons were ($p = 0.008$). Furthermore, all of the patients treated in a Pavlik harness by orthopaedic surgeons that were managed with additional bracing were treated definitively with the abduction orthosis and avoided surgery. Conversely, 16% of patients placed in an abduction brace by an orthopaedic-trained pediatrician and 38% by APPs still ended up requiring surgery. Increased rates of abduction bracing by the orthopaedic-trained pediatrician may reflect a provider preference to try additional conservative measures within their scope of practice before referral for surgery.

Of the patients needing operative intervention, those who were managed in a Pavlik harness by orthopaedic surgeons did not undergo preoperative bracing in an abduction orthosis after failing treatment in a Pavlik. In contrast, 80% of patients needing operative intervention who were managed in a Pavlik by an orthopaedic-trained

TABLE II Outcomes of Patients Managed with Additional Bracing*

Provider Type	Patients Treated with Additional Bracing Who Ultimately Needed Operative Management	Patients Managed Operatively Who Underwent Preoperative Bracing with an Abduction Orthosis
Orthopaedic Surgeon	0†	0†
Pediatrician	4/25 (16%)	4/5 (80%)
APP	6/16 (38%)	7/10 (70%)

*APP = advanced practice provider. †Additional bracing was used by our orthopaedic surgeons in 14 patients; however, none of these patients proceeded to operative management.

pediatrician and 70% of patients who underwent operative management whose Pavlik harness was overseen managed by an APP who ultimately underwent operative treatment were treated with an abduction orthosis before surgery. The variation in abduction brace use may reflect different thresholds for additional bracing between surgeons and the nonoperative providers. As orthopaedic surgeons perform the operative procedures, they may recognize the indications for an operative intervention sooner and feel less inclined to offer an additional conservative measure before surgery.

In the study, patients were grouped based on the type of provider who provided the most care while the patient was in a Pavlik harness. Patients who failed treatment were referred to orthopaedic surgeons; however, the timing of referral was not uniform. Referral was often after the child was placed in an abduction orthosis or had failed an abduction orthosis. In our group, clinics are often shared by all types of providers, facilitating a collaborative environment, which may have contributed to the comfort of the orthopaedic-trained pediatrician and APPs in managing patients in abduction orthoses after failing Pavlik harness treatment. However, these providers had less success in regard to treatment with abduction orthoses. Management of patients who already failed 2 to 4 weeks of Pavlik harness treatment was more variable among provider type, suggesting that referral to the surgeon might be appropriate once the patient fails the harness.

Strengths of the study include a wide variety of providers and a fairly even distribution of patients between the orthopaedic surgeons, orthopaedic-trained pediatrician, and APPs. The patients included in the study were from a diverse, heterogeneous population in terms of geography and socioeconomic status. To our knowledge, this study is the first of its kind to compare outcomes of nonoperative management of DDH by APPs and an orthopaedic-trained pediatrician with orthopaedic surgeons.

Prior studies have found APPs to be effective in managing certain musculoskeletal conditions. Furthermore, additional literature has found that the use of APPs is cost-effective, with shorter outpatient wait times and decreased length of stay in the inpatient setting[18-20]. Patient satisfaction surveys reveal that patients are amenable to receiving screening and follow-up care with APPs instead of a physician[21,22]. Outcomes of pediatric orthopaedic care by APPs are limited as most patients included in existing studies are adults, although a couple of studies have shown effective forearm fracture management performed by physician assistants and nurse practitioners[16,17].

Limitations of the study include the short follow-up time for patients. As the study was done at a tertiary referral center, with a significant number of patients from geographically remote regions, there were a moderate number of patients who were lost to follow-up. Forty-seven patients (10.3%) were excluded for follow-up less than 6 months. Average follow-up was 2.7 ± 1.7 years, which may not be long enough to capture all patients needing additional procedures. Providers often follow patients with DDH for 10 years after normalization of the patient's hips on imaging or into puberty to ensure there are no late sequelae of the dysplasia. The retrospective nature of the study prevents randomization and may create bias, possibly with more straightforward patients treated by the orthopaedic-trained pediatrician or APPs. Some patients were managed by multiple types of providers and did not receive all their care in the Pavlik harness by one type of provider. However, there was a clear primary practitioner coordinating care for most patients, based on the number of visits. There were only 3 of the 308 patients who had an equal number of visits by 2 types of providers, and none of these patients required interventions other than a Pavlik harness. The statistical analysis of the data without including these 3 patients did not alter the overall findings. Additionally, there was no uniform protocol for length of time in the Pavlik harness after patients' hips normalized on imaging, no standardized time for long-term follow-up nor a uniform timeframe for referral to a surgeon. All Pavlik management was performed within a pediatric orthopaedic clinic setting where the APPs and pediatrician could easily consult a surgeon, making it difficult to generalize results for all APPs and pediatricians in other settings, such as primary care clinics.

Our study indicates that there is no difference in the need for later operative interventions between DDH patients treated in a Pavlik harness managed by orthopaedic surgeons, an orthopaedic-trained pediatrician, or APPs. The results of our study suggest that the treatment of straightforward DDH in children younger than 6 months of age with a Pavlik harness can be managed successfully by nonsurgeons, with referral to orthopaedic surgeons if patients fail harness treatment. Although this study focused on an orthopaedic clinical setting, these findings suggest an opportunity to expand nonoperative DDH management beyond an orthopaedics and into the community by training more APPs or pediatricians to deliver Pavlik harness care.

Appendix

The orthopaedic surgeons had all completed a pediatric fellowship in addition to their orthopaedic surgery residency. One of the 2 APPs in this study included one with 3 years of pediatric orthopaedics experience at the start of the study period and the other APP joined the practice partway through the study period. Our orthopaedic-trained pediatrician had been working exclusively in the pediatric orthopaedics clinic for 4 years at the start of the study period. The APPs and pediatrician in this study all

received their focused pediatric orthopaedic training as on-the-job training after joining the department.

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Image Quiz: Achilles Rupture

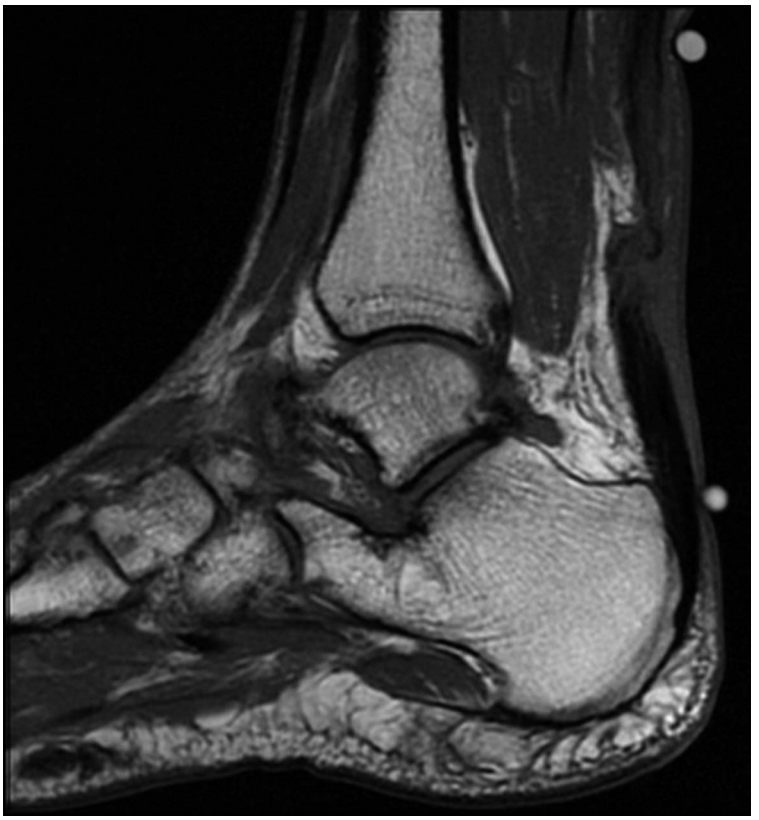

Fig. 1
Sagittal MRI of the left ankle.

A 66-year-old male presents to the office with left ankle pain after an injury 2 days ago. The injury occurred during a racquetball match when he jumped quickly and felt a "pop" in the left heel. He has no pain now but is unable to plantar flex the left foot. Sagittal magnetic resonance imaging (MRI) of the left ankle is shown in Figure 1.

Which statement below is true regarding the treatment of this patient?

A. Surgical repair and nonoperative treatment offer similar clinical outcomes.
B. Nonoperative treatment offers an earlier return to work compared to open surgical repair.
C. Nonoperative treatment and surgical repair result in similar plantar flexion strength at 1 year.
D. The patient is more likely to rerupture with nonoperative treatment, regardless of the rehabilitation protocol.

Achilles rupture is a common injury seen in recreation athletes, with a peak incidence in 30- and 40-year-olds. Despite being the largest and strongest tendon in the body, the Achilles tendon is also the most frequently torn. Patients often describe the injury as a sudden "pop" in the heel during a running or jumping maneuver. Complete ruptures take away the ability to plantar flex the foot resulting in difficulty with ambulation. Physical examination findings often establish a definitive diagnosis without the need for diagnostic imaging. Physical examination findings associated with a complete rupture include increased passive ankle dorsiflexion at rest and a palpable defect 3 to 6 cm from the calcaneal insertion site. A positive Thompson test, indicated by the absence of passive ankle plantar flexion when the calf is compressed in a supine position, has a 96% predictive value for a complete rupture. MRI is often used to confirm the diagnosis in

patients whose clinical examination findings remain inconclusive. Ultrasound can also be a useful tool for complete ruptures; however, diagnostic accuracy of partial tears is inferior to MRI.

Achilles ruptures can occur at the calcaneal insertion site, at the tendon midsubstance, and at the musculotendinous junction. The most common location of rupture is at the vascular watershed area of the tendon midsubstance, 3 to 6 cm proximal to the calcaneal attachment. Insertion Achilles ruptures are treated with primary repair, and musculotendinous tears are treated nonoperatively. Treatment of midsubstance Achilles ruptures is more controversial. Open surgical repair has been the treatment of choice in most cases, as rerupture rates were found to be much higher than with the classic, conservative, non-weighting cast treatment. The rerupture rate of 12.6% after nonoperative non-weight-bearing cast treatment far exceeds the 3.5% rerupture rate after surgical treatment. However, newer nonoperative rehabilitation protocols that include early motion and weight-bearing have shown similar clinical outcomes to Achilles ruptures treated operatively. Accelerated rehabilitation protocols include weight-bearing as tolerated in a walking boot as early as 1 week after injury. These accelerated weight-bearing protocols have reduced the rerupture rate to 4.6%. The theory that weight-bearing stress improves tendon healing and strength, may explain the improved rerupture rate. With similar outcomes between nonoperative treatment and surgical repair, patients can avoid the postoperative risks of wound infection and skin breakdown. A benefit of surgical repair over conservative treatment includes an increase in plantar flexion strength at 1 to 2 years. However, this increase may be noticeable in athletes but clinically insignificant for the general population. Surgical patients also benefit from an earlier return to work, with an average return-to-work of nearly 20 days sooner than nonoperative treatment. Minimally invasive surgical techniques, such as a percutaneous repair, have recently shown improved outcomes compared to the standard open approach. However, there is a need for more randomized controlled trials comparing percutaneous repair to nonoperative treatment.

A typical accelerated rehabilitation protocol for nonoperative treatment includes 1 week in a posterior splint after injury, followed by 1 to 2 weeks of protected weight-bearing in a boot with a 2-cm heel lift, then 2 to 6 weeks of weight-bearing as tolerated in a boot with the same heel lift. Patients should avoid dorsiflexion past neutral for the first 6 weeks. The heel lift can be removed at 6 weeks and the boot discontinued at 8 weeks. Dynamic weight-bearing exercises and sport-specific retraining generally starts at 3 months. A gradual return to low impact activities starts at 6 months and a return to jumping sports at 9 months.

Answer: A

Suggested Reading

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Posterior Malleolar Ankle Fractures

An Effort at Improving Outcomes

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Background: There is increasing acceptance that the clinical outcomes following posterior malleolar fractures are less than satisfactory. We report our results of posterior malleolar fracture management based on the classification by Mason and Molloy.

Methods: All fractures were classified on the basis of computed tomographic (CT) scans obtained preoperatively. This dictated the treatment algorithm. Type-1 fractures underwent syndesmotic fixation. Type-2A fractures underwent open reduction and internal fixation through a posterolateral incision, type-2B fractures underwent open reduction and internal fixation through either a posteromedial incision or a combination of a posterolateral with a medial-posteromedial incision, and type-3 fractures underwent open reduction and internal fixation through a posteromedial incision.

Results: Patient-related outcome measures were obtained in 50 patients with at least 1-year follow-up. According to the Mason and Molloy classification, there were 17 type-1 fractures, 12 type-2A fractures, 10 type-2B fractures, and 11 type-3 fractures. The mean Olerud-Molander Ankle Score was 75.9 points (95% confidence interval [CI], 66.4 to 85.3 points) for patients with type-1 fractures, 75.0 points (95% CI, 61.5 to 88.5 points) for patients with type-2A fractures, 74.0 points (95% CI, 64.2 to 83.8 points) for patients with type-2B fractures, and 70.5 points (95% CI, 59.0 to 81.9 points) for patients with type-3 fractures.

Conclusions: We have been able to demonstrate an improvement in the Olerud-Molander Ankle Score for all posterior malleolar fractures with the treatment algorithm applied using the Mason and Molloy classification. Mason classification type-3 fractures have marginally poorer outcomes, which correlates with a more severe injury; however, this did not reach significance.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

The classical treatment of posterior malleolar fractures, which limits open reduction and internal fixation of the posterior malleolar fragment to those with an articular fracture consisting of one-third or greater of the distal tibial articular surface, originates from a report by Nelson and Jensen[1]. This study from 1940 showed their treatment and follow-up of 8 cases. They termed all other posterior malleolar fractures as "minimal" and concluded that all could be reduced and held in a plaster cast, with considerable offset not precluding a good result. Two recent systematic reviews of posterior malleolar fractures negate the findings of this early study, with general long-term outcomes of posterior malleolar ankle fractures reported to be poor[2,3]. Both reviews concluded that the size of the posterior malleolar fracture had no bearing on outcome.

Unfortunately, many published studies of these fractures have been limited by considering them to be one homogenous group. Attempts have been made to categorize these fractures by the pathoanatomy of their primary fracture fragment[4-6]. However, Mason et al. described the posterior malleolar fracture fragment in relation to the pathomechanism and how it integrated into the pattern of the ankle injury as a whole[7]. Our aim in this study was to use this classification system by Mason et al. to develop a treatment algorithm and assess the functional outcomes.

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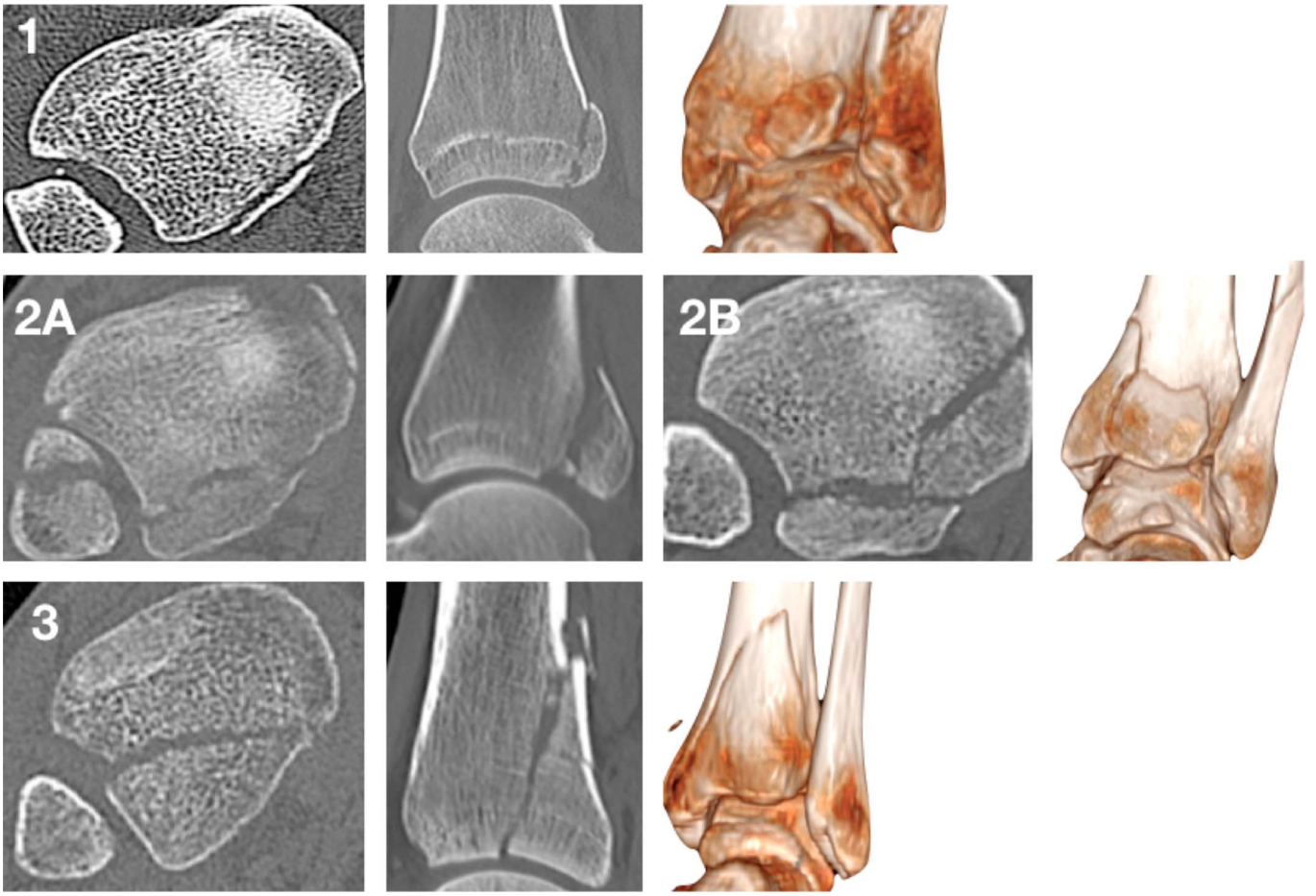

Fig. 1

Illustration of the different types of posterior malleolar fractures as described by Mason et al.[7]. The images represent axial CT views 5 mm proximal to the tibial plafond, sagittal CT views 1 cm medial to the incisura, and 3-dimensional surface rendering of the different types.

Materials and Methods

We performed a retrospective study of prospectively acquired data involving all posterior malleolar fractures treated by the 2 senior authors in a level-I major trauma center in the United Kingdom between May 2015 and August 2016. Only fractures in adults were considered for this study. As is routine for all ankle fractures treated in our unit, all fractures underwent initial plaster cast application and initial investigation with anteroposterior, mortise, and lateral radiographs. When a posterior malleolar fracture was noted, further investigation using computed tomographic (CT) imaging was performed. The CT imaging was analyzed using the graphics package present on the hospital's Picture Archiving and Communication System (Carestream Vue PACS; Carestream Health), and the fracture pattern was categorized using the classification proposed by Mason et al. (Fig. 1)[7].

Based on the classification of the fracture pattern, the patient was surgically treated as dictated by the treatment algorithm in Table I. The surgical procedures were completed by surgeons of differing grades, directly supervised by 1 of the 2

TABLE I Posterior Malleolar Treatment Algorithm as Dictated by the Mason Classification

Classification	Treatment	Surgical Approach to Posterior Malleolus
1	Syndesmotic fixation	
2A	Open reduction and internal fixation	Posterolateral
2B	Open reduction and internal fixation, posteromedial fragment first	Posteromedial or posterolateral and medial posteromedial
3	Open reduction and internal fixation	Posteromedial

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senior authors. A surgical procedure was undertaken only when the soft-tissue envelope was such that it was safe to proceed. If satisfactory reduction was not possible in the plaster cast application, the patients underwent temporary spanning external fixation, until the soft-tissue envelope allowed safe internal fixation. The routine postoperative treatment included a non-weight-bearing plaster cast for 6 weeks, followed by mobilization. Physiotherapy referral was made if stiffness was a concern on removal of cast immobilization.

All patients were contacted by postal follow-up at 1 year, using the Olerud-Molander Ankle Score[8] patient-related outcome measure and the EuroQol-5 Dimensions (EQ-5D) standardized instrument for measurement of health-related quality of life. The Olerud-Molander Ankle Score is scored out of 100 points, with higher scores indicating better outcomes. The EQ-5D-5L (5 Levels) was used, with 5 levels of severity combined with the visual analog scale for health. The EQ-5D index was calculated on the basis of general population valuation surveys in the United Kingdom[9]. Patients who did not respond to the initial questionnaire were contacted with a repeat postal questionnaire and a telephone call. Postoperative complications and further surgical procedure data were prospectively collected.

Surgical Approaches

Our treatment algorithm contains 3 surgical approaches to achieve visualization of the posterior malleolar fracture fragment (Fig. 2). In our practice, where possible, a surgical procedure for posterior malleolar fixation is undertaken with the patient in the prone position. The posterolateral approach allows access to the posterior aspect of the fibula, the posterior incisura, and the posterolateral corner of the tibia. The approach is marked 50% of the way between the posterior edge of the fibula and the lateral edge of the Achilles tendon. The sural nerve and short saphenous vein are at risk and should be identified and protected superficial to the investing fascia. The investing fascia is then opened, revealing the fascia superficial to the flexor hallucis longus and peroneal compartments. When approaching the fibula, it is important to proceed through the base of the peroneal compartment and not elevate the subcutaneous fat outside the compartment to prevent wound problems. The tibia and posterior incisura are approached through opening the deep fascia over the flexor hallucis longus muscle and elevating this muscle off the posterior aspect of the tibia from lateral to medial. The periosteum is then incised and is elevated off the back of the tibia, preserving, where possible, the insertion of the posterior inferior tibiofibular ligament and intramalleolar ligament.

The posteromedial approach allows access to most of the posterior aspect of the tibia; however, there is restricted access to the posterior incisura and posteromedial edge of the tibia. This approach is marked on the medial edge of the Achilles tendon. Being careful to avoid the Achilles tendon paratenon, the investing fascia is opened, revealing the fascia superficial to the flexor hallucis longus. The fascia over the flexor hallucis longus is opened as far laterally as is allowed by the incision. Care is taken on opening this fascial layer as medial to the flexor hallucis longus is the posteromedial neurovascular bundle. The flexor hallucis longus muscle belly is elevated off the posterior aspect of the tibia from lateral to medial, thus using the flexor

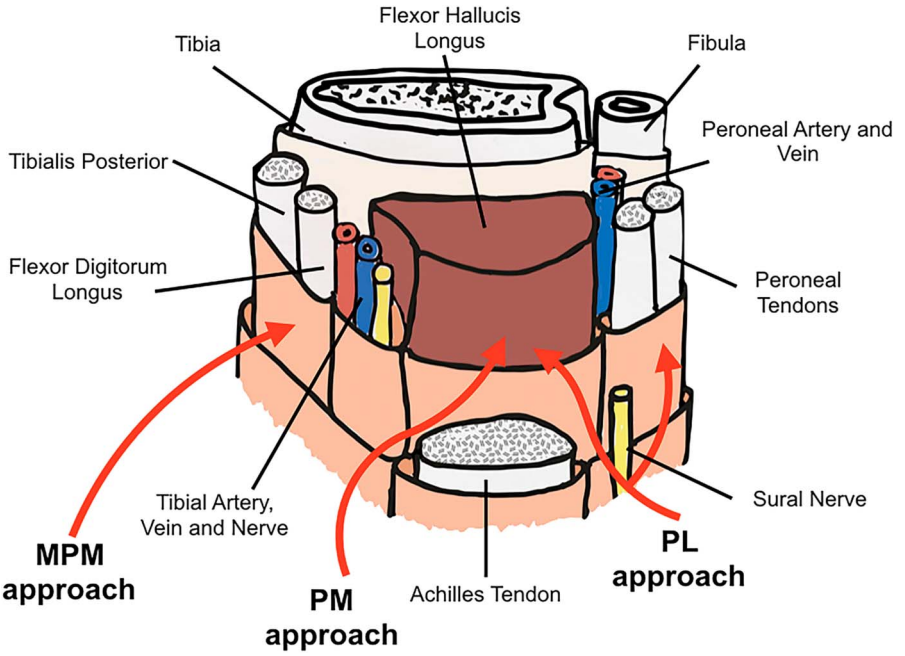

Fig. 2

Schematic of the 3 approaches to the posterior aspect of the distal part of the tibia. PL = posterolateral, PM = posteromedial, and MPM = medial posteromedial.

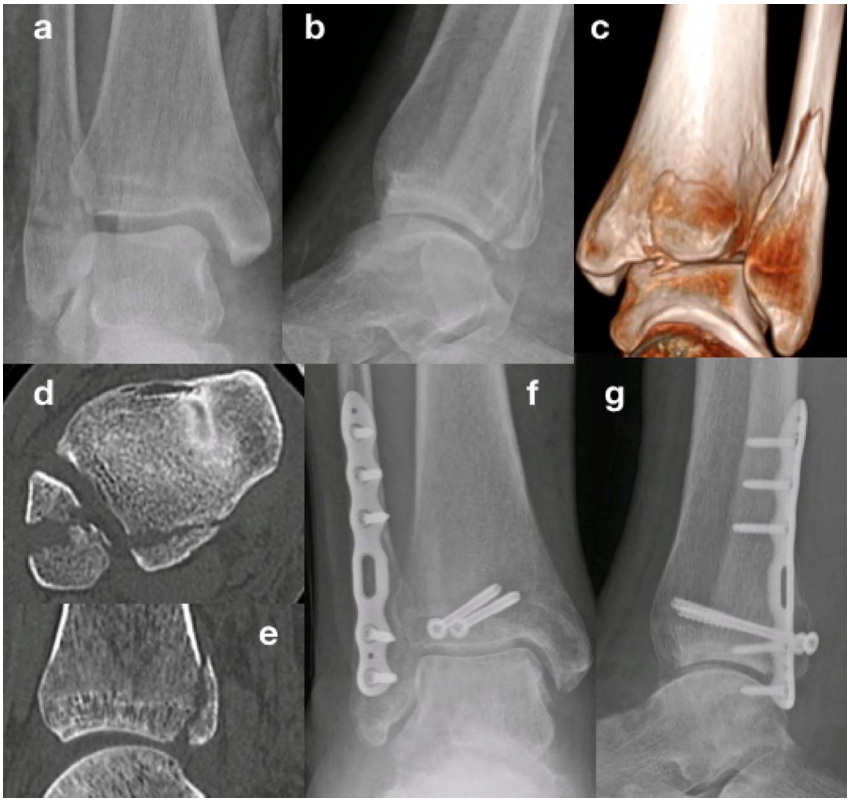

Fig. 3

Preoperative radiographs (**Figs. 3-A and 3-B**) and CT imaging (**Figs. 3-C, 3-D, and 3-E**) of a type-2A posterior malleolar fracture and postoperative radiographs (**Figs. 3-F and 3-G**) showing fibular fixation and fragment-specific fixation of the posterior malleolus with lag screw compression of the joint through a posterolateral incision.

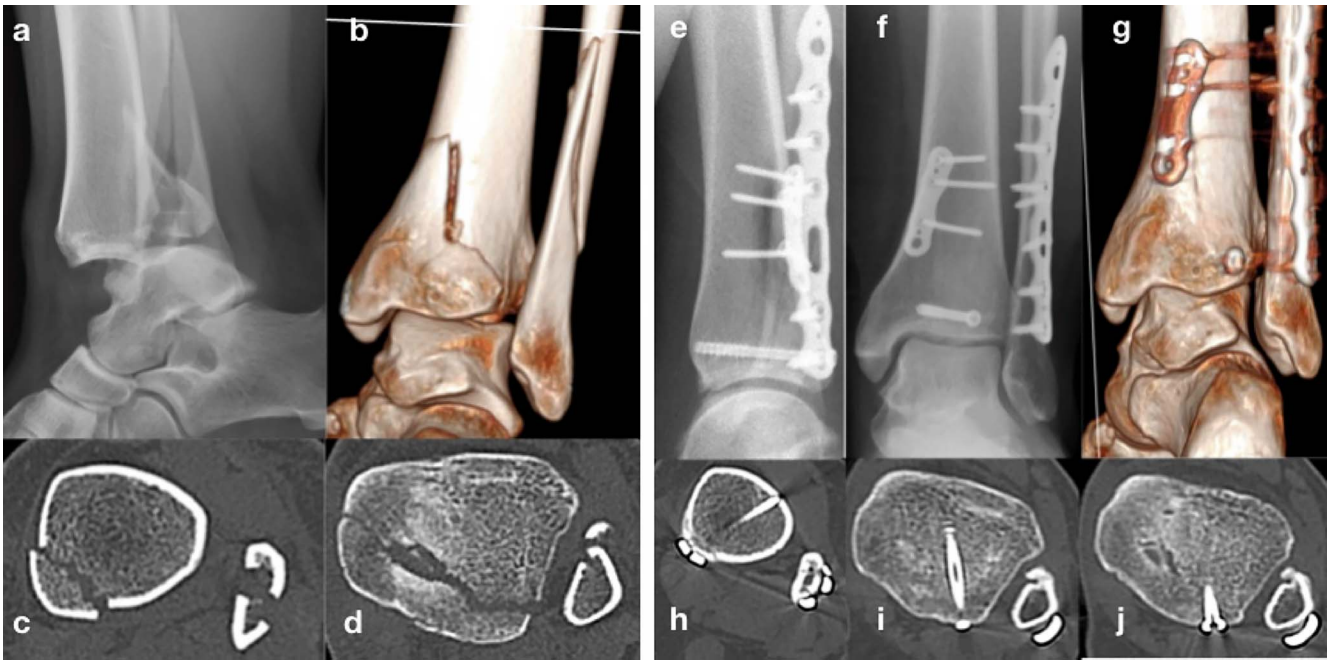

Fig. 4

Preoperative radiograph (**Fig. 4-A**) and CT imaging (**Figs. 4-B, 4-C, and 4-D**) of a type-2B posterior malleolar fracture and postoperative radiographs (**Figs. 4-E and 4-F**) and CT imaging (**Figs. 4-G through 4-J**).

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hallucis longus muscle as a barrier to the posteromedial neurovascular bundle. The same periosteal precautions should be taken as in the posterolateral approach.

The medial posteromedial approach allows access to the posteromedial tibial edge and restricted access to the posteromedial aspect of the tibia, especially at the point that the tibialis posterior tendon fully enters its groove. This approach is especially useful in fractures with a large posteromedial fragment with an apex exiting medially. The approach is marked along the posteromedial edge of the tibia. The tibialis posterior tendon is located in its sheath, and the sheath is opened longitudinally.

Fibular and medial malleolar fractures are approached separately, except where the posterolateral approach can satisfactorily allow access to the fibular fracture.

Fixation Techniques

It is our normal practice to access and fix, where possible, the posterior malleolar fractures before fibular and medial malleolar fracture reduction and fixation. This provides a number of

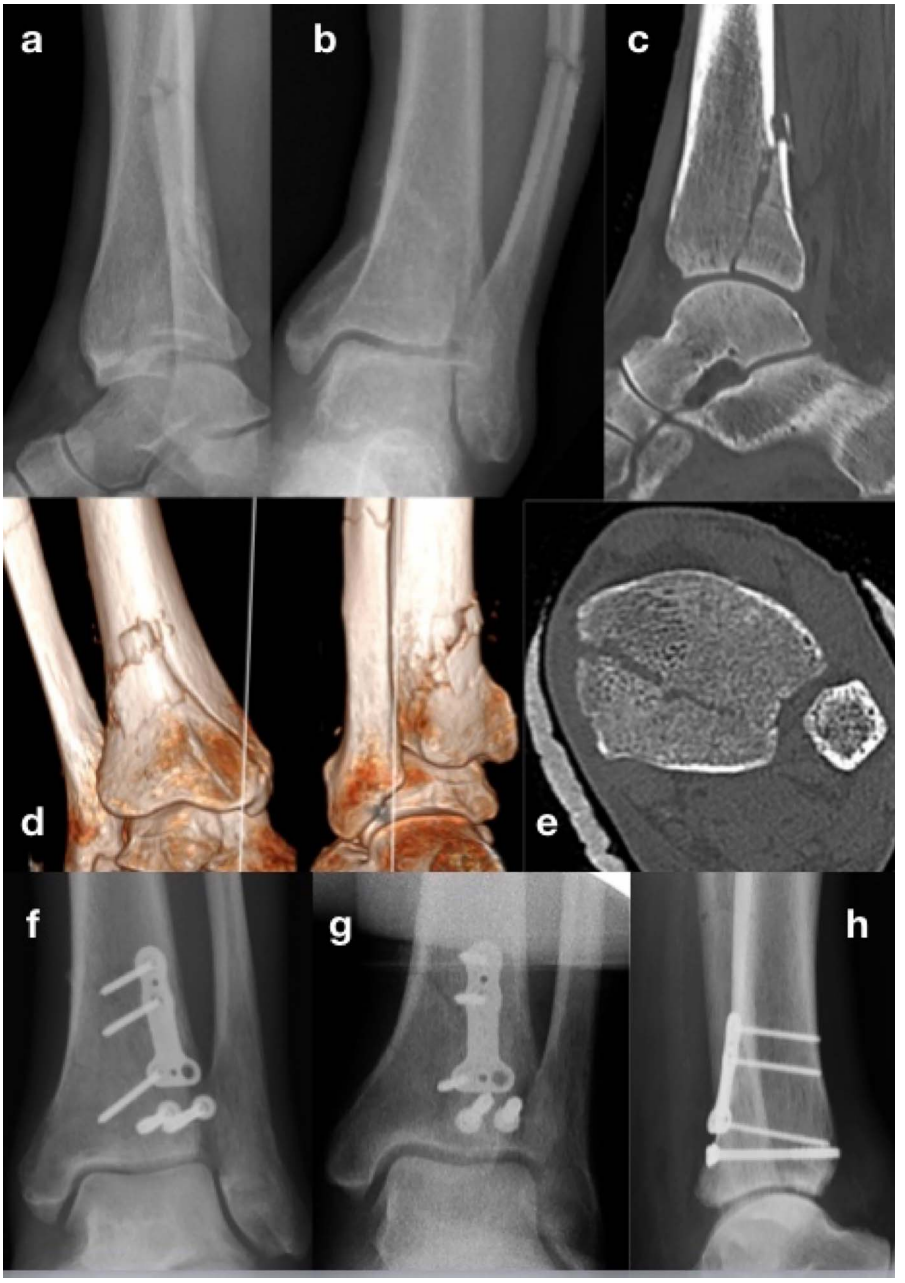

Fig. 5

Preoperative radiographs (**Figs. 5-A and 5-B**) and CT imaging (**Figs. 5-C, 5-D, and 5-E**) of a type-3 posterior malleolar fracture and postoperative radiographs (**Figs. 5-F, 5-G, and 5-H**).

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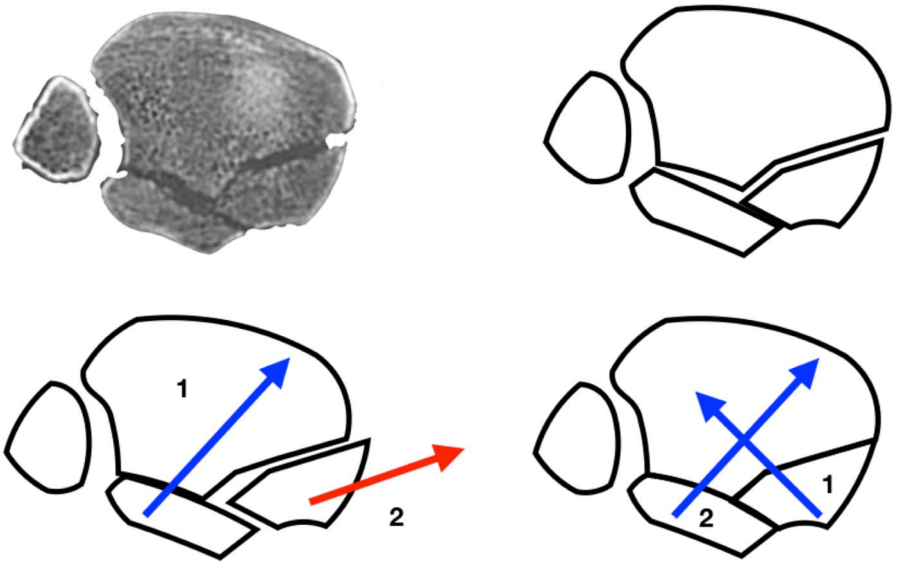

Fig. 6

Schematic of a type-2B fracture showing the medial translation of the posteromedial fragment if the posterolateral fragment if compressed first. This is due to the deeper position of the posteromedial fragment and obliquity of the fracture. If the posteromedial fragment is fixed first, this does not affect the subsequent compression of the posterolateral fragment.

advantages, including achieving fibular length, allowing visualization of the fracture without implant interference on radiographs, and stabilizing the large fragment of Y-shaped medial malleolar fractures to then allow keying-in of the separate anterior collicular fracture. For Mason and Molloy classification type-1 fractures, syndesmotic reduction and fixation was undertaken following OTA/AO[10] surgical principles. For Mason and Molloy classification type-2 and 3 fractures, the posterior malleolar fracture was reduced and was orthogonally fixed prior to any syndesmotic instability testing or subsequent fixation. The fixation of the posterior tibial fragments in Mason and Molloy classification type-2 and 3 fractures was fragment-specific, with articular surface compression achieved by lag screws and/or a small anti-glide plate applied to each fragment (Figs. 3 through 5). In Mason and Molloy classification type-2B fractures, the posteromedial fragment was fixed first, because of the risk of medial translation of the posteromedial fragment when the posterolateral fragment is compressed (Fig. 6). Concomitant fibular and medial malleolar fractures were fixed using OTA/AO surgical principles.

Statistics

All data were assessed using SPSS version 20.0 (IBM). Binary data were entered into contingency tables to allow cross-tabulation of the results. For data cells of >5, differences were tested using the chi-square test; otherwise, the Fisher exact test was used. Numerical data were tested using a Student t test if parametric or a Mann-Whitney test if nonparametric. A 1-way analysis of variance (ANOVA) test was used for groupwise analysis of parametric data.

Results

Of 61 patients included in this study, 1-year patient-related outcome measures were obtained for 50 patients (82%). The dropout rate was a consequence of the major trauma setting and large tertiary referral base. There were 22 male patients and 28 female patients. According to the Mason and Molloy classification, there were 17 type-1 fractures (34%), 12 type-2A fractures (24%), 10 type-2B fractures (20%), and 11 type-3 fractures (22%). The mean age of this cohort of patients was 46.8 years (range, 21 to 87 years). Categorizing by the Mason and Molloy classification, the mean age was 46.8 years

TABLE II Functional Results of Posterior Malleolar Fixation Techniques, Comparing the Current Study with Our Previous Multicenter Ankle Fracture Outcome Study

Study	No. of Patients	Age* *(yr)*	Sex *(M:F)*	Olerud-Molander Ankle Score† *(points)*
Roberts[11]	16	52.9 (20 to 69)‡	3:13‡	54.3 (33.9 to 74.7)
Current study	50	46.8 (21 to 87)‡	22:28‡	74.1 (69.1 to 79.1)

*The values are given as the mean, with the range in parentheses. †The values are given as the mean, with the 95% CI in parentheses. ‡The comparison of the means was significant at $p < 0.05$.

TABLE III Comparison of 1-Year Olerud-Molander Ankle Scores Between the Mason Classification Groups

Classification	No. of Patients	Olerud-Molander Ankle Score* *(points)*
All	50	74.1 (69.1 to 79.1)
1	17	75.9 (66.4 to 85.3)
2A	12	75.0 (61.5 to 88.5)
2B	10	74.0 (64.2 to 83.8)
3	11	70.5 (59.0 to 81.9)

*The values are given as the mean, with the 95% CI in parentheses.

for patients with type-1 fractures, 55.0 years for patients with type-2A fractures, 49.7 years for patients with type-2B fractures, and 43.3 years for patients with type-3 fractures. Using nonparametric group statistical analysis, there was no significant difference in age among the groups.

The overall Olerud-Molander Ankle Score for all posterior malleolar fractures in this cohort was 74.1 points (95% confidence interval [CI], 69.1 to 79.1 points). Comparing this study's functional results with the functional results of our previous multicenter trial[11], in which posterior malleolar fractures were treated using the traditional method (ankle fracture fixation using OTA/AO principles, in which posterior malleolar fractures were not fixed if they were <25%), there was an improvement in outcome (Table II). The categorizing of the outcomes by the Mason classification is illustrated in Table III. Using a 1-way ANOVA test, there was no significant difference ($p = 0.886$) between groups or within groups. However, there was a trend that a lower Mason and Molloy classification had higher Olerud-Molander Ankle Score outcomes.

The overall mean 1-year EQ-5D index for this cohort of patients was 0.88 (95% CI, 0.82 to 0.95). The mean visual analog scale score for this patient group was 77.5 points (95% CI, 70.0 to 84.9 points). Categorizing the outcomes by the Mason and Molloy classification, the mean EQ-5D index was 0.88 (95% CI, 0.77 to 0.99) for patients with type-1 fractures, 0.79 (95% CI, 0.57 to 1.0) for patients with type-2A fractures, 0.91 (95% CI, 0.80 to 1) for patients with type-2B fractures, and 0.96 (95% CI, 0.90 to 1) for patients with type-3 fractures. The mean visual analog scale score for health was 83.3 points (95% CI, 72.0 to 94.6 points) for patients with type-1 fractures, 69.2 (95% CI, 47.0 to 91.3 points) for patients with type-2A fractures, 80.8 points (95% CI, 64.2 to 97.4 points) for patients with type-2B fractures, and 74.5 points (95% CI, 57.8 to 91.3 points) for patients with type-3 fractures. Using nonparametric group statistical analysis, there was no significant difference in the EQ-5D or the visual analog scale score either within or between the groups.

Discussion

The functional outcomes of posterior malleolar fractures are reported to be significantly worse than the outcomes for unimalleolar and bimalleolar ankle fractures[2]. In our previous study, we presented a significant clinical difference between unimalleolar fractures and their trimalleolar counterparts, with a difference between them of >20 points on Olerud-Molander Ankle Score functional outcomes[11]. In that study by Roberts et al.[11], true posterior Pilon fractures (Mason and Molloy classification type 3) were not included. In their study, Roberts et al. reported Olerud-Molander Ankle Score functional outcomes that were equivalent to those reported in the literature in other large outcomes studies, with mean Olerud-Molander Ankle Score functional results ranging from 75 to 95 points for unimalleolar fractures and 56 to 85 points for bimalleolar fractures[12-16]. In the current study, posterior pilon fractures were included, which makes the 20-point increase in functional outcomes, to near unimalleolar fracture functional results, even more dramatic. There were no other differences in treatment between the previous study and the current study, as all included fractures underwent surgical fixation of the medial and lateral malleolar fractures.

The mean EQ-5D index in the current study is equivalent to the general population results reported in both the United Kingdom and the United States[17,18]. There was no significant difference either within or between the groups; nevertheless, there was a trend of reduced health markers in the type-2A fracture group. This is likely to represent the increase in the mean age in this group compared with the other fracture groups in our study. Similarly, the Olerud-Molander Ankle Score functional outcomes did not have a significant difference either within or between the groups of the fracture classification. However, there was a trend that indicated a possible prognostic application of the Mason and Molloy classification, with an increasing type indicating an increase in complexity and a decreasing functional result. Type-3 fractures have a larger impaction injury to the tibial plafond, and it makes logical sense that the cartilage injury is likely to be more substantial. The lack of significant difference between the groups is likely to represent the sample size of this study, although it could also represent the general improvement in outcomes across all of the groups.

As shown in previous literature, there are clear indicators that posterior malleolar fractures are variable in their nature, and as such should not be grouped together for analysis[2,3,7]. Each fracture type has its own injury associations, which in themselves can determine the management and final outcomes of these fractures. This study has illustrated the value of the Mason and Molloy classification system and the subsequent treatment algorithm in its guidance of treatment. The knowledge of the mechanism and its associated injury patterns allows thorough treatment planning. Our algorithm has developed over the treatment of many previous posterior malleolar fractures and is established in our unit, although every fracture pattern should be taken on its own merit.

All of the type-1 fractures represented in this study were confirmed to have a syndesmotic injury on live screening intraoperatively. As indicated in the study by Mason et al., a proportion of these injuries will be partial syndesmotic injuries

with the avulsion of the posterior inferior tibiofibular ligament[7]. This is not apparent on the commonly reported syndesmotic tests used, and an internal rotation test should be undertaken under live screening. In type-2 and 3 fractures, syndesmotic stabilization clinically can be achieved with reduction and fixation of the posterior malleolar fragment if the anterior-inferior tibiofibular ligament has remained intact. Miller et al. reported a rate of 2.1% for syndesmotic instability after fixation of the posterior malleolar fracture fragment with the patient prone compared with a rate of 48.3% for ankle fractures treated without posterior fixation and with the patient in a supine position[19]. This has also been demonstrated in a cadaveric study by Gardner et al.[20], who reported that posterior malleolar fixation resulted in 70% of cases of syndesmotic stability compared with 40% of cases that achieved syndesmotic stability with screw fixation. However, caution should be used because any elevation of the posterior-inferior tibiofibular ligament on approach to the posterior malleolar fragment may eliminate some of the stabilizing force. As reported by Kim and Lee, posterior-inferior tibiofibular ligament release is often required, sometimes only partially, to reduce the posterior malleolar fragment[21].

The approach to the posterior malleolar fracture has been included in our treatment algorithm, as a means to guide others who are unfamiliar with posterior hindfoot approaches. The preoperative CT imaging is helpful in determining the optimal surgical approach. The posterolateral and posteromedial approaches have both been reported to be safe in terms of both wound management and radiographic follow-up[22,23]. Our experience is that the direct approach to the posterior malleolar fracture should be performed where possible, rather than the indirect approach and anterior-to-posterior fixation. This direct approach has been shown by Shi et al. to be superior in terms of both anatomical fixation and functional outcomes[24].

We acknowledge a number of limitations to this study. First, this study showed the functional outcomes to a minimum of 1 year after the injury. However, these functional outcomes may change with time. Second, postoperative management using non-weight-bearing was employed, in theory to allow better regeneration of the tibial cartilage. This is in contrast to an increasing practice to allow early weight-bearing and a functional orthosis in an attempt to allow quicker rehabilitation and earlier return to work. There is limited clinical evidence regarding early weight-bearing in the treatment of posterior malleolar fractures, although, in a small study including a joint model, Papachristou et al. reported good functional return by 3 months[25]. Their joint model illustrated minimal load passing through the posterior malleolar fracture fragment with weight-bearing. Third, a proportion of our type-1 fracture patterns displayed only partial syndesmotic disruptions. In a randomized controlled trial, Andersen et al. reported on suture button and screw fixation for syndesmotic injury and showed an improved functional result with the use of suture button syndesmotic fixation[26]. Interestingly, their screw fixation group had a higher proportion of posterior malleolar fractures, which displayed a worse functional outcome.

In conclusion, we demonstrated an improvement in the Olerud-Molander Ankle Score for all posterior malleolar fractures with the treatment algorithm applied using the Mason and Molloy classification compared with our previous study. Mason and Molloy classification type-3 fractures have marginally poorer outcomes, which correlates with a more substantial injury. However, this difference did not reach significance. ■

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HOPE-Trial: Hemiarthroplasty Compared with Total Hip Arthroplasty for Displaced Femoral Neck Fractures in Octogenarians

A Randomized Controlled Trial

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Background: The choice of primary hemiarthroplasty or total hip arthroplasty in patients ≥80 years of age with a displaced femoral neck fracture has not been adequately studied. As the number of healthy, elderly patients ≥80 years of age is continually increasing, optimizing treatments for improving outcomes and reducing the need for secondary surgery is an important consideration. The aim of the present study was to compare the results of hemiarthroplasty with those of total hip arthroplasty in patients ≥80 years of age.

Methods: This prospective, randomized, single-blinded trial included 120 patients with a mean age of 86 years (range, 80 to 94 years) who had sustained an acute displaced femoral neck fracture <36 hours previously. The patients were randomized to treatment with hemiarthroplasty (n = 60) or total hip arthroplasty (n = 60). The primary end points were hip function and health-related quality of life at 2 years. Secondary end points included hip-related complications and reoperations, mortality, pain in the involved hip, activities of daily living, surgical time, blood loss, and general complications. The patients were reviewed at 3 months and 1 and 2 years.

Results: We found no differences between the groups in terms of hip function, health-related quality of life, hip-related complications and reoperations, activities of daily living, or pain in the involved hip. Hip function, activities of daily living, and pain in the involved hip deteriorated in both groups compared with pre-fracture values. The ability to regain previous walking function was similar in both groups.

Conclusions: We found no difference in outcomes after treatment with either hemiarthroplasty or total hip arthroplasty in active octogenarians and nonagenarians with a displaced femoral neck fracture up to 2 years after surgery. Hemiarthroplasty is a suitable procedure in the short term for this group of patients.

Level of Evidence: Therapeutic Level I. See Instructions for Authors for a complete description of levels of evidence.

The choice of surgical procedure for elderly patients with displaced femoral neck fractures remains controversial[1-4]. Despite extensive research and the publication of several randomized controlled trials (RCTs) comparing hemiarthroplasty and total hip arthroplasty, the question remains regarding whether there is any advantage of replacing a healthy acetabulum with a cup in healthy elderly patients[5-11]. Several published RCTs have indicated better outcomes after total hip arthroplasty compared with hemiarthroplasty[5,7,8,10]. With few exceptions[8,9,11], those studies included a relatively large population of patients <80 years of age. As the number of healthy, elderly patients ≥80 years of age is continually increasing, it is important to study this patient group to assess whether they receive the same benefit as patients <80 years of age.

Disclosure: The study was funded by grants from the regional agreement on medical training and clinical research (ALF) between Stockholm County Council and Karolinska Institutet. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A94).

A **data-sharing statement** is provided with the online version of the article (http://links.lww.com/JBJSOA/A95).

We hypothesized that total hip arthroplasty would be associated with superior hip function and health-related quality of life, without increasing the rates of complications and reoperations, when compared with hemiarthroplasty for the treatment displaced femoral neck fractures in cognitively intact elderly patients ≥80 years of age.

Materials and Methods

Study Design, Setting, and Location

This single-center, single-blinded, prospective RCT followed the guidelines of good clinical practice and the CONSORT (Consolidated Standards of Reporting Trials) statement[12] and was performed between 2009 and 2018 (inclusion period, September 2009 to April 2016) at the Orthopaedic Department, Danderyd Hospital, Stockholm, Sweden. The study was approved by the Ethics Committee of the Karolinska Institute, and all patients gave informed consent to participate in the trial.

Participants

All patients with a displaced femoral neck fracture who were admitted to Danderyd Hospital were screened for participation in the study. The inclusion criteria were an acute displaced femoral neck fracture (Garden 3 or 4) that had occurred <36 hours previously, an age of ≥80 years, the ability to walk independently with or without walking aids, and intact cognitive function with a Short Portable Mental Status Questionnaire (SPMSQ) score of 8 to 10 points[13]. Patients with a pathological fracture or osteoarthritis, patients with rheumatoid arthritis in the fractured hip, and patients who were non-walkers or who were deemed unsuitable for participation in the study for any reason were excluded[14].

Randomization and Blinding

The patients were block-randomized in groups of 10 in a 1:1 ratio to receive either hemiarthroplasty or total hip arthroplasty. We used sealed envelopes, and the randomization was stratified for sex to ensure that the sex distribution would be the same in both groups. The participants were blinded to the choice of treatment, but the surgeons and staff were not. They were, however, mindful that patients were blinded and were instructed to not reveal allocation to the patients. The physiotherapy and other care did not differ between the groups. The

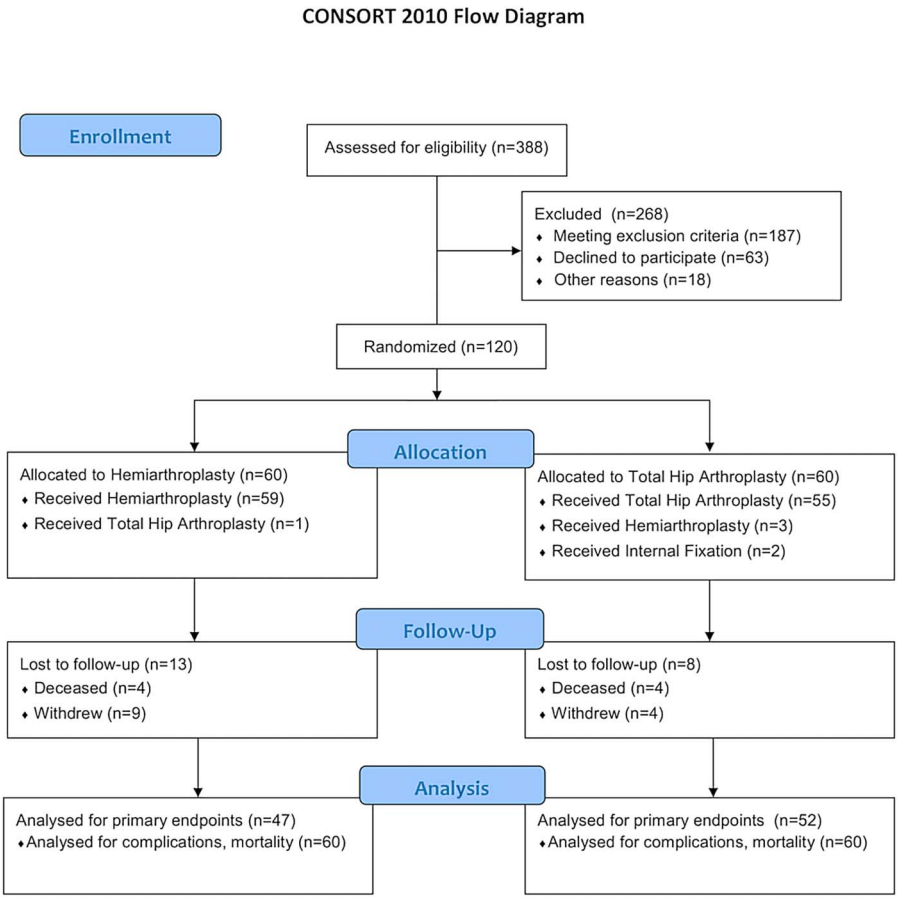

Fig. 1

CONSORT flowchart of the patients in the study. One patient in the hemiarthroplasty group was managed with total hip arthroplasty because of the surgeon's choice during surgery. Two patients in the total hip arthroplasty group were managed with closed reduction and internal fixation because of a suspected urinary tract infection. Another 3 patients in the total hip arthroplasty group were managed with hemiarthroplasty because of the surgeon's choice during surgery.

patients were not allowed to view their radiographs. To verify that blinding was maintained during the study, the patients were asked if they knew their assigned treatment at the 2-year follow-up.

Data Collection and Follow-up

A research nurse interviewed the patients and obtained baseline data for the last week prior to the fracture. The patients were then followed at 3 months and at 1 and 2 years. In the case of withdrawal of consent, the subjects were followed according to the standard procedures of our institution. Functional outcome scores were self-reported by the patients. We used the Swedish unique personal identification number to identify all hip-related complications during the study period. We searched digital medical charts at Danderyd Hospital, the Swedish Hip Arthroplasty Register, and the Swedish Patient Registry. All hip-related complications in the study were managed and registered at our department, and no other reoperations or complications were found to have occurred at other hospitals in Sweden. All study data were collected in a digital case report form using REDCap (Research Electronic Data Capture) tools provided by Karolinska Institute[15].

Surgical Intervention

All operations were performed either by a consultant orthopaedic surgeon or by a registrar with assistance from a consultant with use of a direct lateral approach with the patient in the lateral decubitus position. The modular, collarless, polished, tapered cemented femoral component (CPT; Zimmer) was used until 2014. On the basis of the high incidence of early periprosthetic fractures reported in association with this stem in patients with femoral neck fracture[16,17], we changed the implant to an anatomically shaped cemented stem (Lubinus SP2; Waldemar Link) according to a decision made at our institution. A unipolar head replacement was used in the hemiarthroplasty group, and a 32-mm cobalt-chromium head was used in the total hip arthroplasty group. A cemented highly cross-linked polyethylene acetabular component was used in all patients in the total hip arthroplasty group. A vacuum-mixed low-viscosity cement with gentamicin (Palacos with gentamicin; Schering-Plough) was used in all patients. All patients received antibiotic and anticoagulant prophylaxis (3 doses of 2-g cloxacillin and low-molecular-weight heparin for 30 days postoperatively). All patients were allowed to bear weight as tolerated with use of crutches and were mobilized the day after surgery without any restrictions.

Primary End Points

The primary end points were hip function status as assessed with the Harris hip score (HHS) and health-related quality of life as assessed with the EuroQol-5 Dimensions (EQ-5D) at 2 years. The HHS has been validated for patients with femoral

TABLE I Baseline Data

	Hemiarthroplasty Group (N = 60)	Total Hip Arthroplasty Group (N = 60)
Sex *(no. of patients)*		
Female	45	45
Male	15	15
Age* *(yr)*	86 ± 4	85 ± 4
ASA classification *(no. of patients)*		
1-2	20	30
3-4	40	30
Body mass index* *(kg/m^2)*	25 ± 4	24 ± 4
Charnley functional classification *(no. of patients)*		
A	50	46
B	4	9
C	6	5
Mobility: no walking aid or just 1 stick *(no. of patients)*	29 (48%)	30 (50%)
Living condition *(no. of patients)*		
Independent living	57	58
Service buildings/senior housing	3	2
Operative data*		
Surgical time *(min)*	77 ± 19	99 ± 25
Bleeding *(mL)*	324 ± 216	355 ± 202
Discharged to geriatric ward *(no. of patients)*	52	53

*The values are given as the mean and the standard deviation.

TABLE II Functional Outcomes During the Study Period*

	Intention to Treat			Per Protocol		
	Hemiarthroplasty Group† (N = 60)	Total Hip Arthroplasty Group† (N = 60)	Mean Difference (95% CI)	Hemiarthroplasty Group† (N = 59)	Total Hip Arthroplasty Group† (N = 55)	Mean Difference (95% CI)
Harris hip score *(points)*						
Baseline	88 ± 12 (n = 59)	89 ± 10 (n = 60)	−1 (−5 to 3)	88 ± 12 (n = 59)	89 ± 10 (n = 55)	−1 (−5 to 3)
3 mo	69 ± 14 (n = 54)	70 ± 13 (n = 57)	−1 (−6 to 4)	69 ± 14 (n = 54)	70 ± 14 (n = 53)	−1 (−6 to 5)
1 yr	71 ± 16 (n = 50)	74 ± 16 (n = 56)	−3 (−9 to 3)	71 ± 16 (n = 50)	73 ± 16 (n = 52)	−2 (−9 to 4)
2 yr	74 ± 14 (n = 47)	76 ± 15 (n = 56)	−2 (−4 to 2)	74 ± 14 (n = 47)	75 ± 15 (n = 49)	−1 (−7 to 5)
EQ-5D						
Baseline	0.67 ± 0.34 (n = 59)	0.75 ± 0.26 (n = 60)	−0.08 (−0.19 to 0.02)	0.67 ± 0.34 (n = 59)	0.75 ± 0.26 (n = 55)	−0.08 (−0.19 to 0.04)
3 mo	0.67 ± 0.24 (n = 54)	0.65 ± 0.26 (n = 57)	0.02 (−0.07 to 0.11)	0.67 ± 0.24 (n = 54)	0.65 ± 0.25 (n = 53)	0.02 (−0.08 to 0.11)
1 yr	0.66 ± 0.27 (n = 50)	0.68 ± 0.30 (n = 56)	−0.02 (−0.13 to 0.09)	0.66 ± 0.27 (n = 50)	0.67 ± 0.31 (n = 52)	−0.01 (−0.12 to 0.10)
2 yr	0.55 ± 0.36 (n = 47)	0.66 ± 0.27 (n = 52)	−0.11 (−0.23 to 0.02)	0.55 ± 0.36 (n = 47)	0.65 ± 0.27 (n = 49)	−0.11 (−0.23 to 0.03)
Pain numerical rating scale						
Baseline	0.4 ± 1.6 (n = 59)	0.38 ± 1.3 (n = 60)	0.0 (−0.5 to 0.5)	0.4 ± 1.6 (n = 59)	0.3 ± 1.2 (n = 55)	0.1 (−0.5 to 0.6)
3 mo	2.3 ± 1.9 (n = 54)	1.9 ± 1.7 (n = 57)	0.3 (−0.4 to 1.0)	2.3 ± 1.9 (n = 54)	2.0 ± 1.7 (n = 53)	0.3 (−0.5 to 0.9)
1 yr	1.6 ± 1.8 (n = 50)	1.3 ± 1.8 (n = 56)	0.3 (−0.4 to 0.2)	1.6 ± 1.8 (n = 50)	1.3 ± 1.8 (n = 52)	0.3 (−0.4 to 1.0)
2 yr	1.5 ± 1.9 (n = 47)	1.5 ± 1.9 (n = 56)	0.0 (−0.8 to 0.8)	1.5 ± 1.9 (n = 47)	1.5 ± 2.0 (n = 49)	0.0 (−0.8 to 0.8)
Activities of daily living						
Baseline	90% (53/59)	93% (56/60)		88% (52/59)	93% (51/55)	
3 mo	69% (37/54)	68% (39/57)		69% (37/54)	68% (36/53)	
1 y mo	68% (34/50)	64% (36/56)		68% (34/50)	63% (33/52)	
2 y mo	72% (34/47)	65% (34/52)		64% (30/47)	65% (32/49)	

*There was no significant difference between the groups in any of the analyses. †The Harris hip score, EQ-5D, and pain numerical rating scale data are given as the mean and standard deviation, with the number of patients with available data in parentheses The activities of daily living data are given as the proportion of patients who were fully independent in activities of daily living, with the numerator and denominator in parentheses.

neck fractures and for self-reporting[18,19]. Health-related quality of life was assessed before fracture and at the time of follow-up with a generic instrument, the health section of the $EQ\text{-}5D_{index}$ score[20].

Secondary End Points

Secondary end points included hip function status as assessed with the HHS and health-related quality of life as assessed with the EQ-5D at 3 months and 1 year, hip-related complications and reoperations, activities of daily living, pain in the involved hip, mortality, surgical time, intraoperative bleeding, and the ability to regain previous walking function. We recorded adverse events, including cardiovascular events.

Sample Size and Power Analysis

Before the start of the study, sample size calculations were performed on the 2 primary outcome variables (HHS and EQ-5D). Two-sided power analysis was used. On the basis of a previous trial from our research group, we assumed that a mean difference (and standard deviation) of 10 ± 15 points[21] in the HHS was the smallest effect that would be clinically relevant. We calculated that a total of 80 patients (40 in each group) would have a power of 80% to yield a significant result. This calculation also allowed an 80% power to prove non-inferiority of EQ-5D with a sample of 40 patients in each group, with the assumption of a mean EQ-5D value (and standard deviation) of 0.73 ± 0.18 and a non-inferiority limit of 0.1. The significance level was set at 2.5% ($p < 0.025$) to handle multiplicity because we performed 2 sample-size calculations. We planned to include 60 patients in each group (120 patients total) to allow for the loss of patients to follow-up.

Statistical Methods

The analyses of outcomes were based on the intention-to-treat principle, and all patients were analyzed in their randomized group regardless of any other surgical intervention. A per-protocol analysis, including only those patients who received their allocated treatments, was also performed. Descriptive statistics (means and standard deviations) were used to describe the patient characteristics and outcome variables at the measurement points. The chi-square test was used to test correlations between ordinal data. The Student t test was used to compare the HHS and EQ-5D between the groups. Analysis of covariance (ANCOVA) of the primary end points was used to reduce variance, with adjustments for exposure variable (hemiarthroplasty or total hip arthroplasty) and stratification (male or female). The data are presented with mean differences and odds ratios (ORs), and the uncertainty estimation is presented with 95% confidence intervals (CIs). A p value of <0.05 was considered significant. Statistical analysis was performed with use of SPSS software (version 22.0; IBM).

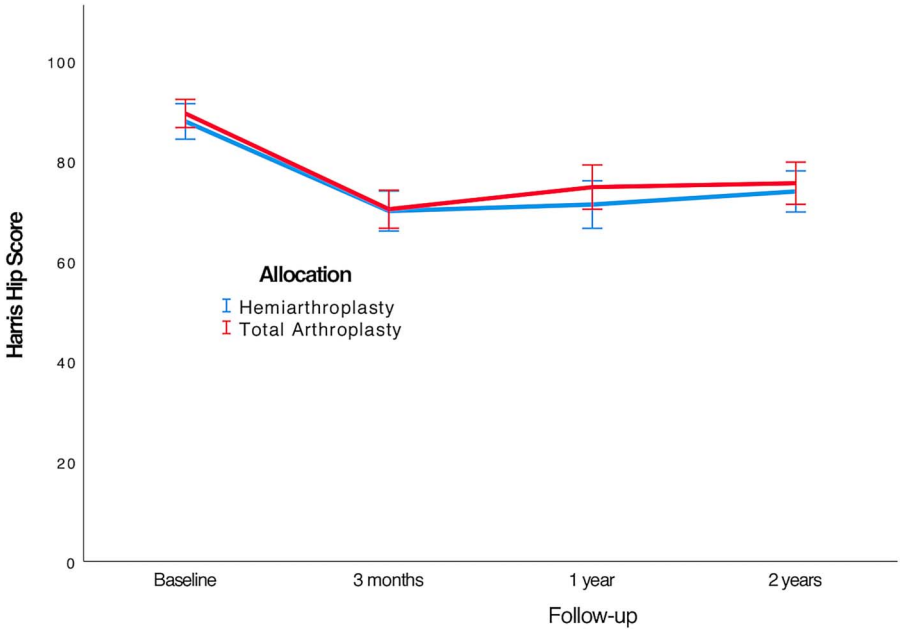

Fig. 2
Line graph showing the mean HHS (and 95% CIs) for hip function during the study period.

Registration
The trial is registered at ClinicalTrials.gov (NCT02246335) and a detailed study protocol has been published previously[14]. The complete study period is up to 10 years but with the prespecified primary end points at 2 years.

Both the HHS and EQ-5D were, from the study start, set as primary end points as specified in the study protocol and used in the sample size calculation prior to the start of the study. In the ClinicalTrials.gov registration, only the HHS is listed as the primary endpoint.

Results

Patient Flow and Baseline Data
We enrolled 120 patients, 60 in the hemiarthroplasty group and 60 in the total hip arthroplasty group (Fig. 1). The study group included 90 women and 30 men with a mean

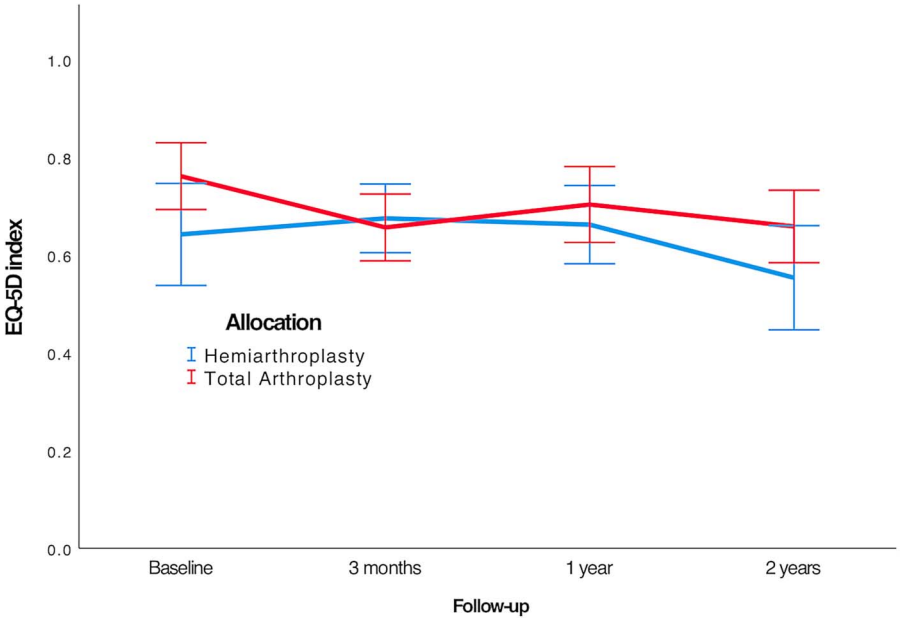

Fig. 3
Line graph showing the mean EQ-5D index scores (and 95% CIs) for health-related quality of life during the study period.

TABLE III Adverse Events Up to 2 Years After Surgery

	Hemiarthroplasty (N = 60)	Total Hip Arthroplasty (N = 60)
Hip-related complications		
Dislocation	1	0
Superficial infection	0	3
Deep periprosthetic infection	3	0
Non-healing fracture	0	1
Total number of hip complications	4	4
Number of patients with any hip complication	4	4
Reoperation		
Closed reduction	1	0
Surgical debridement and 1-stage revision	2	0
Another major reoperation	0	1
Total number of major reoperations	2	1
General complications		
Pneumonia	7	4
Pulmonary embolism	1	1
Myocardial infarct	1	2
Cerebral vascular lesion	3	6
Acute kidney failure	0	1

age of 86 years (range, 80 to 94 years). The baseline characteristics of the groups were similar, but with a slightly higher proportion of patients in the hemiarthroplasty group having an American Society of Anesthesiologists (ASA) classification of 3 or 4. The mean surgical time was 22 minutes shorter in the hemiarthroplasty group. We found no difference between the groups in terms of perioperative bleeding (Table I). Six patients (1 in the hemiarthroplasty group and 5 in the total hip arthroplasty group) did not receive their allocated treatment because of a decline in medical status between randomization and surgical treatment. Two patients were managed with closed reduction and internal fixation with use of cannulated screws (Fig. 1). Eight patients, 4 in each group, died during the study. No deaths occurred during surgery.

Primary End Points

In the intention-to-treat analysis, both the HHS and the EQ-5D score deteriorated from baseline during the study period, but we found no clinically relevant or statistically significant differences in the primary end points between the groups up to 2 years after surgery. These findings remained after both the per-protocol analysis and the ANCOVA analysis of the primary end points (Table II, Figs. 2 and 3). The ASA classification at baseline did not affect the primary end point. Patients with a higher walking ability prior to fracture had a higher HHS at 2 years, but there was no difference in the change of scores between total hip arthroplasty as compared with hemiarthroplasty.

Secondary End Points and Adverse Events

There was no significant difference between the groups in terms of the prevalence of all hip-related complications and reoperations up to 1 year postoperatively. We found 4 hip-related complications in each group, including 1 dislocation and 3 deep periprosthetic infections in the hemiarthroplasty group and 3 superficial infections and 1 nonunion in the total

TABLE IV Testing for Blinding, as Assessed by the 99 Patients Who Completed the 2-Year Follow-up

	Actual Allocation *(no. of patients)*	
	Hemiarthroplasty (N = 47)	Total Hip Arthroplasty (N = 52)
What procedure were you allocated to?		
Hemiarthroplasty	13 (28%)	8 (15%)
Total hip arthroplasty	7 (15%)	17 (33%)
"Don't know"	27 (57%)	27 (52%)

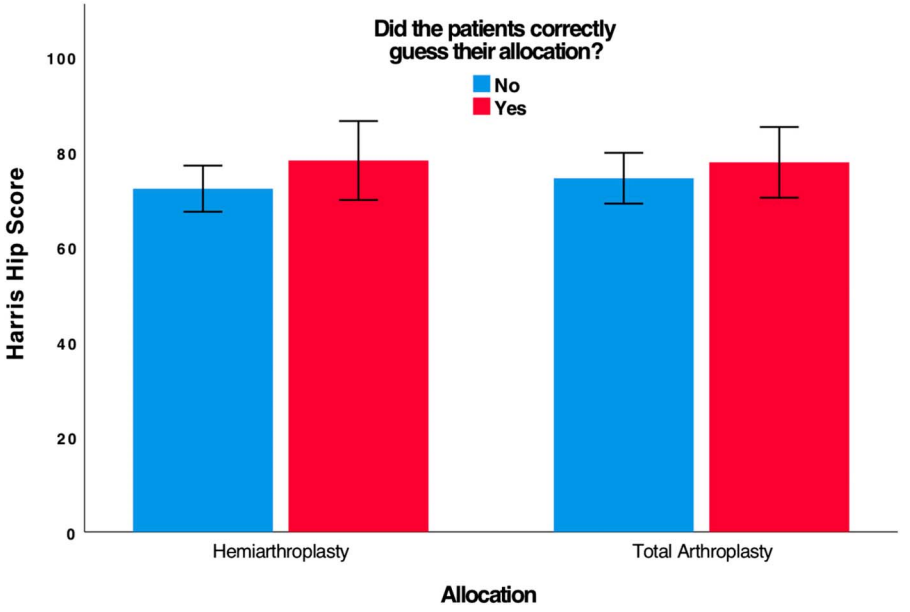

Fig. 4

Bar graph showing the mean HHS (and 95% CIs) for hip function at the 2-year follow-up for the patients who correctly guessed their allocation (n = 30) as compared with those who did not (n = 66).

hip arthroplasty group (Table III). Of the 2 patients managed with closed reduction and internal fixation, 1 developed nonunion and underwent reoperation with a hemiarthroplasty. Two of the 3 patients in the hemiarthroplasty group who had deep periprosthetic infections were managed surgically, whereas the third was managed conservatively with antibiotics for 3 months. The surgical procedure was 1-stage revision involving surgical debridement, removal of the prosthesis, and recementing of a new implant (Table III). We found no difference between the groups in terms of the activities of daily living and pain scores during the follow-up period. However, both of these scores deteriorated in both groups (Table II).

Two patients in each group were bedridden or wheelchair-bound at the 1-year follow-up. During the study period, 26 (47%) of 55 patients in the hemiarthroplasty group and 24 (42%) of 57 patients in the total hip arthroplasty group were able to regain their previous walking function.

Blinding Success

Of the 99 patients who were available at the 2-year follow-up, 30 correctly guessed their allocation, 15 guessed incorrectly, and 54 answered "don't know" (Table IV). There was no significant difference between the groups when testing for blinding ($p = 0.1$, chi-square test). In addition, those patients who correctly guessed their allocation did not have a clinically relevant or statistically significant difference in outcome from those who did not (Fig. 4).

Patients Who Declined Participation

The 63 patients who declined to participate in the study did not differ from the study subjects with regard to sex ($p = 0.6$), age ($p = 0.5$), or ASA classification ($p = 0.2$)[22].

Discussion

In this prospective randomized study of octogenarians and nonagenarians with a displaced femoral neck fracture that was treated with hemiarthroplasty or total hip arthroplasty, we found no difference at 2 years in any relevant outcome variables. Hip function, health-related quality of life, pain in the operatively treated hip, activities of daily living, and ability to regain previous walking function deteriorated at 2 years in both groups compared with the pre-fracture values.

The strengths of the present study are its prospective, blinded, randomized controlled design, the use of both intention-to-treat and per-protocol analyses, the randomization process stratified by sex to ensure equal sex distributions, and strict adherence to the pre-study-determined hypothesis, outcome measurements, and published study protocol[14].

In addition, we included an analysis of how successful we were with the blinding of the patients and also presented the results for patients who chose to not participate in the study. To our knowledge, this is also the first RCT comparing hemiarthroplasty and total hip arthroplasty for the treatment of displaced femoral neck fractures in patients ≥80 years of age.

As is the case in many RCTs in medicine, our cohort had a lower mortality compared with non-participants, but the functional results did not differ between participants and non-participants, indicating that our trial had good external validity. We have described these results in a separate report, the first in the orthopaedic literature to evaluate the external validity of an RCT involving patients with hip fractures[22].

The main limitation of the present study was the short-term follow-up period. A 2-year follow-up possibly was not sufficient time for the development of acetabular erosion in

patients ≥80 years of age, who may have limited activity. Therefore, radiographic measurements of erosion of the acetabular cartilage are not presented but will be performed during later follow-up examinations. Other limitations included the use of a single disease-specific patient-reported outcome measure as the HHS has been shown to be limited by ceiling effect[23]. The age-related decline due to factors other than hip function might have affected the usefulness of the HHS in the present population. However, the HHS is widely used and has been validated for patients with a femoral neck fracture[18].

There have been several RCTs to date comparing hemiarthroplasty with total hip arthroplasty in elderly patients, but the results of those trials have been heterogeneous. Several studies with short and intermediate-term follow-up failed to show any functional difference between hemiarthroplasty and total hip arthroplasty, which is consistent with the findings of the present study. van den Bekerom et al., in a study of 252 patients[11], demonstrated no difference in hip function between hemiarthroplasty and total hip arthroplasty at 1 and 5 years of follow-up. Their findings at the 1-year follow-up concurred with ours, although the dislocation rate in that study was high. We used the direct lateral approach in all patients, whereas those authors used both direct lateral and posterolateral approaches. This factor may explain the difference in the dislocation rate. Avery et al.[6] found that the significant functional benefits afforded by total hip arthroplasty over hemiarthroplasty at the 3-year follow-up were no longer present at 7 to 10 years. Tol et al., in another long-term RCT, reported results comparable with those of the present study, with no differences between the total hip arthroplasty and hemiarthroplasty groups in terms of hip function, the complication rate, and the revision rate[24].

In contrast to our findings, several RCTs with short-term follow-up have shown that total hip arthroplasty is superior to hemiarthroplasty for the treatment of mobile, independent patients[5,7-10]. Blomfeldt et al.[9] found significantly better hip function in the total hip arthroplasty group at 1 year despite no signs of acetabular erosion in any of the patients in the bipolar hemiarthroplasty group. The HHS at the 1-year follow-up was lower in both groups in our study compared with the patients in the study by Blomfeldt et al.[9]. Similarly, Baker et al.[7] found significantly lower hip function and shorter self-reported walking distance in the hemiarthroplasty group compared with the total hip arthroplasty group. Those findings may be explained by the fact that healthy, relatively younger active patients with walking ability were included. Hedbeck et al.[10] showed that the difference in hip function in favor of the total hip arthroplasty group that had been previously reported at 1 year persisted and seemed to increase over time through a 4-year follow-up period. The difference in health-related quality of life, which was not significant at 1 year, was statistically significant at 4 years. Mouzopoulos et al.[25] found no significant difference at 1 and 4 years of follow-up between hemiarthroplasty and total hip arthroplasty groups with regard to functional outcome but recommended total hip arthroplasty for patients >70 years of age who had good cognitive status because of its association with less pain and lower reoperation rates.

Two meta-analyses showed that total hip arthroplasty may lead to lower reoperation rates and better functional outcomes compared with hemiarthroplasty among older patients, but both studies demonstrated a higher dislocation rate in the total hip arthroplasty group[26,27]. However, the findings were not conclusive, and further studies were recommended. A Cochrane review demonstrated no difference between total hip arthroplasty and hemiarthroplasty in terms of the level of pain, ambulation, or use of walking aids; however, the evidence was insufficient and further RCTs were recommended[26].

In conclusion, we found no difference in outcomes after treatment with either hemiarthroplasty or total hip arthroplasty in active octogenarians and nonagenarians with a displaced femoral neck fracture up to 2 years after surgery. Hemiarthroplasty is a suitable procedure in the short term for this group of patients. ■

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