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REVIEW

Meniscus tears treatment: The good, the bad and the ugly-patterns classification and practical guide

Roberto Simonetta, Arcangelo Russo, Michelangelo Palco, Giuseppe Gianluca Costa, Pier Paolo Mariani

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Abstract

Over the years, several studies demonstrated the crucial role of knee menisci in joint biomechanics. As a result, save the meniscus has become the new imperative nowadays, and more and more studies addressed this topic. The huge amount of data on this topic may create confusion in those who want to approach this surgery. The aim of this review is to provide a practical guide for treatment of meniscus tears, including an overview of technical aspects, outcomes in the literature and personal tips. Taking inspiration from a famous movie directed by Sergio Leone in 1966, the authors classified meniscus tears in three categories: The good, the bad and the ugly lesions. The inclusion in each group was determined by the lesion pattern, its biomechanical effects on knee joint, the technical challenge, and prognosis. This classification is not intended to substitute the currently proposed classifications on meniscus tears but aims at offering a reader-friendly narrative review of an otherwise difficult topic. Furthermore, the authors provide a concise premise to deal with some aspects of menisci phylogeny, anatomy and biomechanics.

Key Words: Meniscus; Meniscus anatomy; Meniscus tear; Meniscus repair; Root lesion; Ramp lesion

Core Tip: Several studies investigated the effects of a meniscus tear and its optimal treatment. This review aims at providing a practical guide on this topic, including an overview of technical aspects, outcomes in the literature and personal tips.

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INTRODUCTION

Meniscal tears are among the most common injuries of the knee, significantly impacting on the healthcare annual expense[1-4]. It has been estimated that the frequency of arthroscopic procedures for treating meniscus tears is increased by 49% during the 1990s and 2000s[5], but it could reasonably be further expanded in the last years.

Historically, menisci were considered as vestigial remnants, with no significant impact on knee biomechanics[6]. As a result, total meniscectomy was considered the most valuable option for a long time. McMurray[7] claimed insufficient meniscus removal was the main cause of failure of meniscectomy. In 1948, Fairbank[8] reported the clinical outcomes of 107 patients after total meniscectomies and found degenerative knee changes in most of them. From then, several other studies demonstrated the detrimental effects of total meniscectomies on knee joint[9-13]. These studies significantly changed the treatment approach of meniscus tears. Feeley and Lau[14] proposed an algorithm to approach arthroscopic partial meniscectomy starting from the concept of maintaining as much meniscal tissue as possible. The authors quantified as 60% as the maximum amount of meniscus tissue that can be sacrificed. However, this concept can be questioned, since not only the size of the tears but also the location was proved to significantly affect the outcomes[15]. Save the meniscus has become the new imperative nowadays[16,17]. Several studies addressed this topic over many years, but the huge amount of data may create confusion in those who want to approach this surgery.

The aim of this paper is to provide a practical guide for treatment of meniscus tears, including an overview of technical aspects, outcomes in the literature and personal tips. Furthermore, the authors provide a concise premise to deal with some aspects of menisci phylogeny, anatomy and biomechanics. This can be useful for the reader to fully understand the factors affecting the fate of a meniscus tear.

PHYLOGENY AND ONTOGENY OF THE MENISCI

The knowledge of meniscus phylogeny and ontogeny can be useful to correlate meniscal gross anatomy to meniscal function.

Knee menisci are not unique to humans but can be found in several living tetrapods, including amphibians, reptiles, birds and mammals. In most of them, both menisci are massive structures fitted between the tibial and femoral surfaces and are connected anteriorly by an intermeniscal ligament. Only in mammals, regardless of the walking style or size, the menisci have the same semilunar shape[18]. The medial meniscus is very similar in all mammals, including primates. It is crescent shaped with two tibial insertions. By contrast, the lateral meniscus is more variable in shape and in the pattern of tibial insertions[19,20]. The presence of a double tibial insertion of the lateral meniscus is a particular feature of Homo sapiens, unique among living mammals. The second posterior insertion aids in preventing extreme anterior gliding of the lateral meniscus during frequent extension[21]. The presence of meniscofemoral ligaments reinforces the posterior fixation of the lateral meniscus, providing better stability. As a result, only humans are able to maintain a stable knee extension during bipedal stance. Other nonhuman primates cannot do likewise in bipedal walking, but only during quadrupedal gait. Therefore, humans' menisci are not only simple load distributers, but provide a fundamental contribution to knee stability during bipedal stance.

In humans, the meniscus is identifiable after about 8 wk[21,22], assuming its characteristic shape already at this stage. At no time the lateral meniscus takes a discoid shape. In the prenatal stage, the meniscus is highly cellular with a large nuclear/cytoplasmic ratio. Blood vessels are numerous throughout the substance of the foetal meniscus, mostly along the capsular attachment sites. The main postnatal change is the progressively decreasing vascularity and cellularity, with concomitant increase in collagen content[22].

MENISCI ANATOMY

The menisci are two fibrocartilaginous structures mainly composed of water (65%-75%), type I collagen (22%) and glycosaminoglycans (approximately 1%)[23]. The collagen bundles are combined in different orientations to oppose compressive, radial, and shear stresses. Specifically, radial bundles are more frequent in the inner part, which is more resistant to compression forces. Conversely circumferential bundles are mainly located in the outer two-thirds part of the meniscus, counteracting to radial tension forces. This may explain why radial tears typically start from the inner portion, whereas longitudinal tears are more frequent in the most peripheral zones of the meniscus[24]. Furthermore, fiber orientation affects the tensile properties of suture configurations. Vertical sutures showed a significantly higher pull-out strength than horizontal sutures[25-27]. It was assumed that vertical sutures captured more circumferential collagen fiber, thus providing higher failure strength. A third group of collagen fiber are located among the circumferential bundles and are called "tie fibers". These fibers are radially orientated, thus opposing to longitudinal splitting forces[24].

The medial meniscus has a stable fixation to the tibia due to the anterior and posterior root attachments, the meniscotibial (coronary) ligament around the entire perimeter of the meniscus and the deep medial collateral ligament. In 1998, Berlet and Fowler[28] described four distinct insertion patterns of the anterior horns of the medial meniscus. The type I insertion is the most common and seems to provide a very strong fixation to the tibia into the flat area called crista *areae intercondylaris anterior* by Jacobsen[29]. The type II insertion also provide a firm fixation, but more medially and closer to the articular surface. Type III insertion is very anterior and, even if firm, provides little resistance to anterior motion of the meniscus. The last one, type IV, has no firm fixation on the tibia, and the displacement of the anterior horn of the meniscus is controlled by coronary fibers. The superior part of the medial meniscus body is attached to the synovial tissue. In the posterior horn of the medial meniscus, the superior edge does not attach to the joint capsule, while the inferior part attaches to the tibia through the meniscotibial ligament. This ligament, together with the posterior joint capsule, forms the posteromedial femoral recess, defined as ramp area. The semimembranosus attachment to the posterior capsule seems to have a role on the pathogenesis of meniscus tears in this area. A fixation of the medial posterior horn to the capsule may potentially have an influence on the mobility of the medial meniscus, which subsequently might be responsible for poor long-term follow-up. A strictly anatomic medial meniscus repair with reconstruction only of meniscotibial attachment should be to be considered.

The lateral meniscus has a looser attachment to the tibia and joint capsule, because of the presence of the hiatus popliteus. In this zone, the popliteomeniscal fascicules connect the lateral meniscus to the popliteus tendon and the joint capsule. An injury or the absence of such fascicules in discoid meniscus variations may produce an unstable tear causing a symptomatic meniscus hypermobility[30] (Figure 1). Posteriorly, lateral meniscus root attachment is reinforced by one or two meniscofemoral ligaments. These ligaments seem to have a significant contribution in preventing lateral meniscus extrusion[31].

Menisci vascularization is another important factor affecting the healing process. The major vascular support to the meniscus comes from the branches of superior and inferior geniculate arteries that make a subsynovial and perimeniscal capillary network infiltrating the periphery of the meniscus. Vascular supply is limited to the peripheral 10%–25% for the lateral meniscus and 10%–30% for the medial meniscus[32], but it seems to be wider in younger individuals[33]. Vascular penetration is fairly homogeneous in the lateral meniscus, whereas there is more variation within the medial meniscus, with the medial posterior horn having a significantly smaller vascularization[33]. According to the vascular supply, three different zones can be detected within the menisci: The red-red zone (the most peripheral and vascularized zone), the red-white zone (at the inner border of the vascularized zone) and the white-white zone (the inner and avascular zone)[32]. Evidently, tears in the most vascularized zones have higher healing potential and are amenable for repair, while tears in the inner portion are frequently subject to meniscectomy.

Nerve fibers follow closely the blood vessels in their course, with the vascular outer third of the menisci being the most innervated portion[34].

BIOMECHANICS OF THE MENISCI

Menisci play a critical role in load distribution, protecting the smooth hyaline cartilage on both the distal femur and proximal tibia. The medial meniscus covers up to 50%–60% of the medial tibial plateau[35], and it is responsive of about 50% of load transmission in the medial tibiofemoral compartment[36]. The lateral compartment is less congruent, since the lateral tibial plateau has a more convex morphology when compared to the medial compartment. For that reason, the lateral meniscus has a higher contribute to ensure joint congruency, transferring up to 70% of load in its compartments[37]. Indeed, lateral meniscectomy result in worse clinical and radiological outcomes than medial meniscectomy[38].

Menisci also provide a fundamental contribute to joint stability. Specifically, the medial meniscus has been shown to be a secondary restraint to anterior translation of the tibia[39], while the lateral meniscus notably restrains tibial rotation and the pivot-shift mechanism[40]. Both medial and lateral menisci

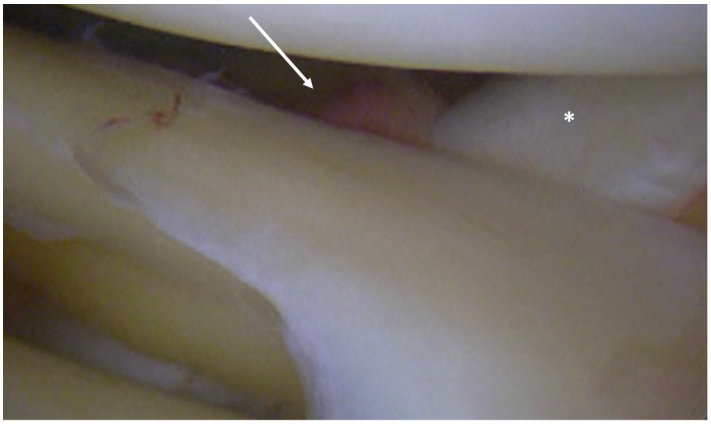

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Figure 1 Arthroscopic view of posterosuperior popliteomeniscal fascicule injury (white arrow). The lateral meniscus is no longer properly anchored to popliteus tendon (asterisk), causing meniscus hypermobility.

translate posteriorly on the tibial plateau during deep knee flexion. The posterior translation of the lateral meniscus (8.2 ± 3.2 mm) is greater than that of the medial one (3.3 ± 1.5 mm)[41]. This asymmetry of kinematics between the medial and lateral compartment is an established characteristic of human knees, resulting in an internal rotation of the tibia relative to the femur with increasing flexion.

At last, menisci are also thought to play roles in knee joint lubrication and nutrient distribution as well as knee proprioception[42,43].

A NEW PATTERNS CLASSIFICATION FOR MENISCUS TEARS: THE GOOD, THE BAD AND THE UGLY LESIONS

An ideal classification system should be simple, all-inclusive, reliable, reproducible, and treated-oriented[44]. Actually, numerous classifications of meniscus tears have been described, but the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine classification is most widely adopted[45,46]. It is based on tear depth, pattern, length, location and rim width, as well as quality of meniscal tissue. However, some important factors are missing, including prognosis of the lesion pattern.

Taking inspiration from a famous movie directed by Leone and Tigani[44], the authors classified the meniscus tears in three categories: The good, the bad and the ugly lesions. The inclusion in each group was determined by the type of injury, its biomechanical effects on knee joint, the technical challenge, and the prognosis. The meniscus tear patterns included in each cluster and the related treatment proposed by the authors are resumed in Table 1. This classification is not intended to substitute the currently proposed classifications on meniscus tears but aims at offering a reader-friendly narrative review of an otherwise difficult topic.

The good lesions

Small stable longitudinal tears (both partial and full thickness tears), as well as small oblique/flap tears can be classified as good lesions. This is mainly due to the poor impact on knee biomechanics[10], both in terms of maximum contact pressure and tibial contact area changes. However, if the tear is more than 15 mm and involves the posterior horn of the meniscus, a significant change of knee biomechanics has been reported[47]. Moreover, longitudinal tears were found to decrease the in-situ meniscus force[48], thus potentially impacting on meniscus function. In addition to this, longitudinal tears of medial meniscus were significantly correlated with meniscus extrusion[49], especially if the tear size increases. Probably, the same traumatic force causing longitudinal meniscus tears may produce a concomitant meniscotibial ligament lesion, which has been closely related to meniscus extrusion[50]. As a result, such lesions should not be overlooked because if they become larger, the knee functionality may be irreversibly impaired.

Either partial meniscectomy or arthroscopic repair can be performed, depending on the tear location and according to the vascular zones of the meniscus. A meta-analysis comparing meniscus repair and meniscectomy found better functional scores in the first group, but meniscectomy for unstable lesions in the white-white zone offered better short-term outcomes and a lower revision surgery rate[15]. The indication for surgical repair of small stable lesions in the peripheric zone of the medial meniscus is almost mandatory, due to the high risk of secondary meniscectomy if left alone[51]. On the other hand, for the lateral meniscus with peripheric small stable lesions, “leave the meniscus alone” can be the

Table 1 The classification of meniscus lesions and the recommended treatment for each tear pattern

	Suggested treatment	Secondary treatment
Good lesions		
Stable longitudinal tears	Repair of peripheral tears	Peripheric small tears of the lateral meniscus can be left in situ because of the low risk of subsequent meniscectomy
Small flap tears	Partial meniscectomy of small lesions in the avascular zone of the meniscus	
Bad lesions		
Bucket handle tears	Repair with dedicated technique according to the lesion features	Meniscectomy of isolated medial bucket handle tears must be discussed with patients
Ramp lesions	Conservative treatment should be considered as first-line for degenerative tears	Surgical treatment of degenerative tears should be considered when conservative approach failed or in presence of mechanical symptoms
Lateral posterior root tears		
Degenerative tears (big flap tears, horizontal tears, complex tears)		
Ugly lesions		
Radial tears	Repair must be attempted aiming at preserving meniscus function	Valgus or varus osteotomy needs to be considered in case of limb malalignment
Medial posterior root tears		
Anterior root tears		

preferred approach given the low risk of subsequent meniscectomy[52].

Recent systematic reviews confirmed the good healing potential, regardless of the surgical technique [53,54]. Meniscal zones and timing from trauma have been reported as predictors of meniscal repairs outcomes[55,56]. Even arthroscopic repair of the meniscus tear in the red-white zone of the meniscus showed low failure rates[57]. Biological enhancements like platelet-rich plasma and bone marrow mesenchymal stem cells were found to improve the healing process in the white-white zone in canine models[58], but these data need to be confirmed in clinical setting. Once again, location would seem to affect outcomes, since lateral meniscus repairs showed lower failure rate than medial repairs[15]. There is still controversy regarding the influence of patients' age on failure rate[59]. This is probably because cartilage status as well as activity level may play a more significant role[60].

The bad lesions

The bad lesions are defined as tears causing a significant loss of meniscus function and significantly altering knee biomechanics. However, prognosis can be good when promptly treated. Big longitudinal tears, bucket-handle tears, ramp lesions, posterior lateral root tears and complex degenerative tears can be included in this group.

Large longitudinal tears worth being counted among bad lesions for the biomechanical reasons stated above[47-49]. Arthroscopic repair of such lesions is to be attempted, since meniscectomy would result in great loss of meniscus function[14]. Bucket-handle tears are peculiar longitudinal tears with unstable fragment causing pain and mechanical symptoms. A particular variant is the ''hypermobile lateral meniscus'', that is a very peripheral longitudinal tear causing the detachment of the lateral meniscus from the capsule in the region of the popliteus tendon hiatus. Traumatic or microtraumatic rupture of the meniscopopliteal fascicles is called upon, allowing excessive meniscal mobility[30,61]. High index of suspicion is needed because diagnosis can be easily misled with the magnetic resonance imaging (MRI).

Preservation of the meniscal tissue is of utmost importance in this setting. Resection of bucket-handle tears drastically increases the mean and peak contact pressures in both medial and lateral tibiofemoral compartments, whereas arthroscopic repair of a bucket-handle tear more closely restores native tibiofemoral biomechanics[62]. However, the healing process of bucket-handle tears can be challenging because of the size and the complexity of the lesion[15]. A recent meta-analysis[63] showed that failure rate after arthroscopic bucket-handle meniscus tears repair ranges between 11.3%-18.3%, that is significantly higher than longitudinal tears. Medial tears and isolated tears are found to significantly increase the risk of failure within 2 years[63]. On the other hand, higher is the number of stitches, lower is the risk of failure[63]. Literature supports arthroscopic repair of such lesions, especially the bucket-handle tears of the lateral meniscus and during concomitant anterior cruciate ligament (ACL) reconstruction[16,17]. A combination of all suture techniques (all-inside, inside-outside and outside-inside) is desirable to improve the mechanical strength of the repair (Figure 2). The use of vertical sutures every 5 to 7 mm is preferred, because horizontal sutures are placed parallel to the meniscus collagen fibers and can easily pull out by separating such fibers. Either circumferential compression sutures[64] with dedicated devices or double-sided all-inside suture repair[65] (both in the superior and in the inferior surface of the meniscus) can produce overall compression of the tear, thus promoting

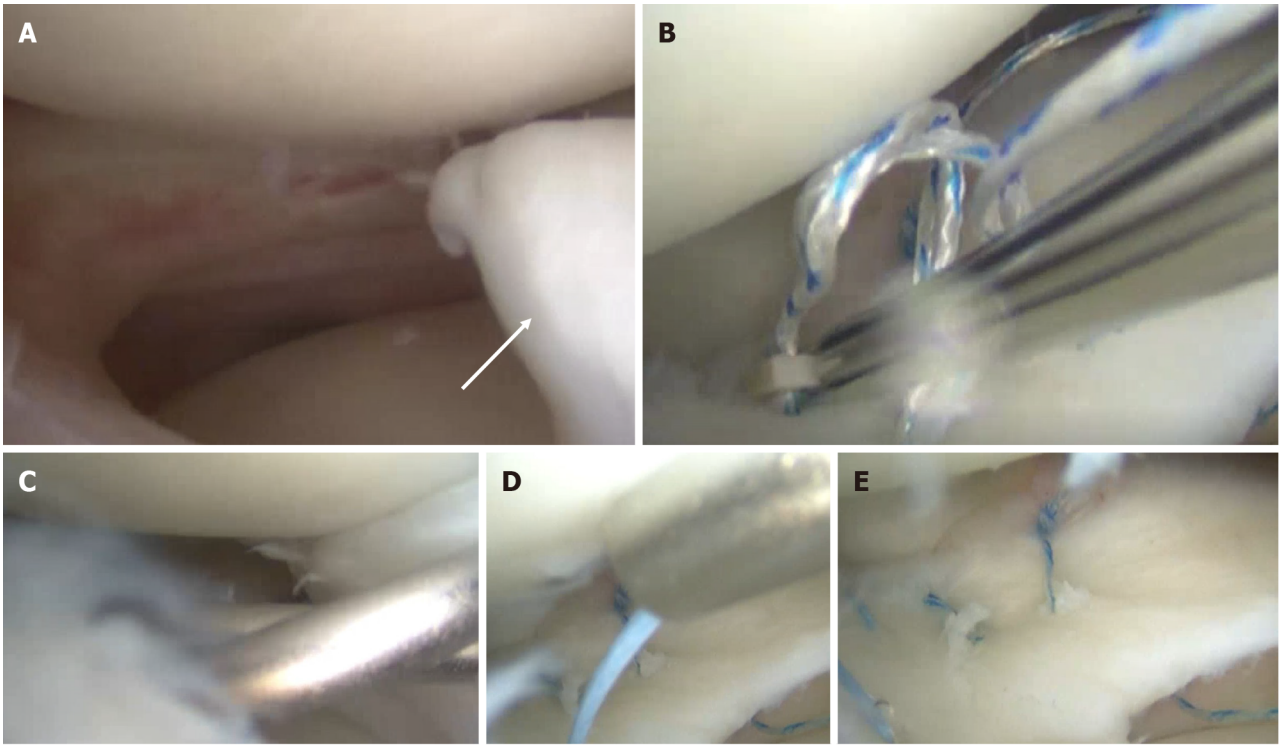

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Figure 2 Isolated lateral meniscus bucket-handle tear in an 18-year-old male patient. A: Arthroscopic findings with the unstable bucket-handle fragment (white arrow); B: Arthroscopic repair of the posterior horn using an all-inside technique; C: Repair of the anterior third using an outside-in technique; D: Repair of the meniscal body with an inside-out technique; E: Final aspect of the meniscal repair.

complete healing (Figure 3). Isolated medial meniscus bucket-handle tears pose a treatment dilemma with no easy solution[66]. The good short-term outcomes as well as the high return-to-play rates after partial meniscectomy must be balanced against the long-term degenerative consequences. Patient's age and activity level need to be taken into consideration. The decision to perform either a meniscectomy or a repair must be made in agreements with the patient, discussing risks and benefits of each option.

Ramp lesions represent a further variant of bad lesion. These longitudinal peripheral tears of the posterior horn of medial meniscus produce a meniscocapsular or meniscotibial disruption, increasing the anterior tibial translation, internal and external rotation, and the pivot shift in ACL-deficient knees [67]. An isolated ACL reconstruction cannot adequately restore native tibiofemoral biomechanics but requires concomitant meniscocapsular and meniscotibial repair[67]. Furthermore, it has been reported that unrepaired ramp lesions may evolve in medial bucket handle meniscus tears at long-term follow-up[68]. As a result, a proper diagnosis and treatment of such lesion is fundamental. However, this type of injury can be often missed, both during MRI reading and due to its "blind" point of arthroscopic vision. It is crucial to perform a systematic exploration of the posteromedial compartment of the knee using a specific trans-notch approach. As these lesions occur in a well-vascularized zone of the meniscus, small (less than 10 mm) and stable tears may be amenable to trephination alone[69]. For unstable tears, arthroscopic repair is recommended. Reported failure rates range between 2.6% and 12.0%[70]. Several surgical techniques have been proposed, including inside-outside technique[71], all-inside[72] technique with standard devices introduced from the anterior portals, and all-inside technique using a suture hook[73] introduced from a posteromedial portal (Figure 4). The type of suture would seem associated with failure of the ramp lesion repair, with a significantly higher risk with the all-inside device than with suture hook repair sutures[74]. A hybrid repair is recommended in large lesions involving the most medial part of the ramp area in order to enhance structural stability[75]. Even the suture material has been called into question, and an absorbable monofilament suture is advocated for such repair to reduce the risk of failure[70].

Lateral meniscus posterior root tear (LMPRT) is a further bad lesion typically occurring in ACL-deficient knees. Such lesions create altered load distribution and transmission functions[76], also contributing to increase anterior tibial subluxation of the lateral compartment[77]. Compared with the medial ones, LMPRTs occur in younger male patients with lower body mass index, less cartilage degeneration and less extrusion on MRI. The better functional outcomes after LMPRTs repair than medial root repair suggest that differences in injury and patient characteristics may contribute to differences in these results[78,79]. Repair of LMPRT can be performed with a side-to-side reconstruction or a trans-tibial pull-out technique, according to the type of the lesion. If the repair occurs during

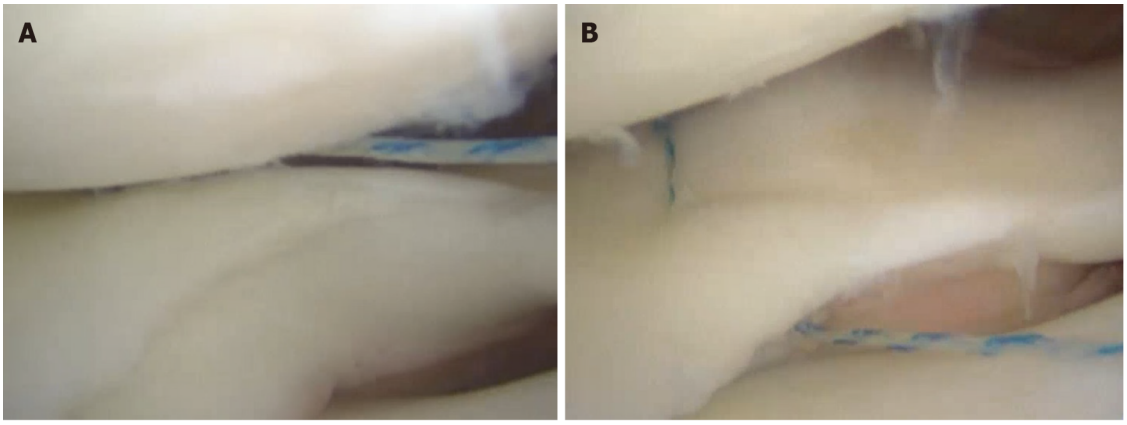

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Figure 3 All-inside repair of a longitudinal meniscus tear. A: Superior suture placement creates a non-uniform compression of the tear; B: A second suture placed in the inferior portion of the meniscus rebalance the repair compression forces, thus correcting the superior meniscus displacement secondary to the first suture.

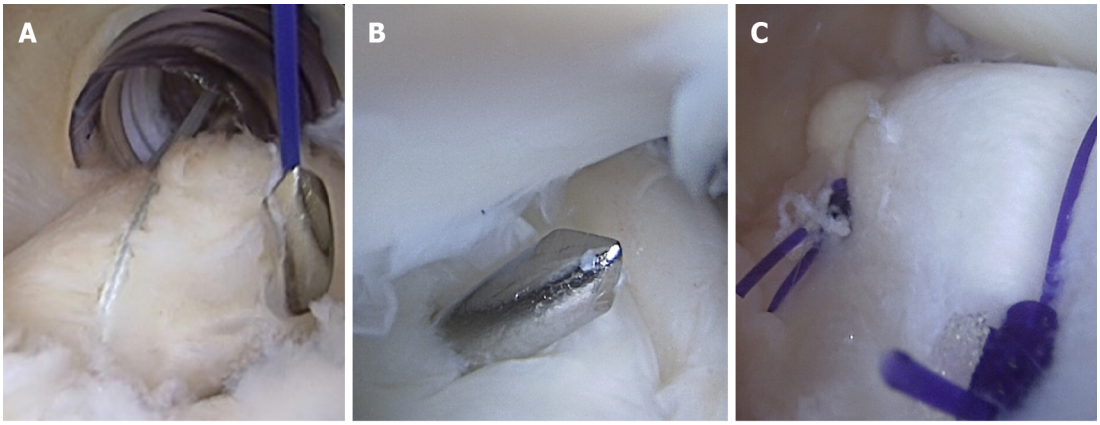

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Figure 4 Ramp lesion repair from the posteromedial portal using a suture hook. A: The suture is passed through the posteromedial capsule and the posterior meniscotibial ligament; B: The hook is advanced until reaching the posterior portion of the medial meniscus; C: A sliding-knot is used to secure the repair (view from the posteromedial portal).

concomitant ACL reconstruction, the risk of convergence of the posterior root tunnel and the tibial ACL tunnel is high. Some authors recommend drilling the meniscal root tunnel from the anterolateral tibia [80]. Other authors suggest using the ACL tunnel to fix the meniscus suture[31] (Figure 5). A personalized technique using a suture anchor[81] was previously described, in order to eliminate this risk in selected cases.

The list of the bad lesions is completed with complex tears, that are a combination of different degenerative tear patterns including oblique tears, big flaps and horizontal cleavage of the meniscus. These lesions are counted among this group because they can be indicators of early-stages osteoarthritis. Knee malalignment, obesity and functional overloading may be responsive for degenerative meniscal matrix changes, thus leading to meniscal fatigue, loss of function and extrusion. Such lesions in their turn further undermine knee joint, by increasing peak compressive and shear stress of both cartilages and menisci[82]. Degenerative tears of the medial meniscus seem to have a greater impact on knee biomechanics, by inducing larger stress and extrusion than the lateral meniscal tears[82]. There is a consensus in the literature promoting conservative treatment as the first-line approach for such lesions [83,84]. This should include activity modification, intra-articular injections, physical therapy with specific rehabilitation, gait analysis and supportive orthoses[85-87]. Surgical treatment is recommended only in case of pain no longer responsive to medical therapy or in presence of mechanical symptoms, such as clicking or briefly locking knees. Surgical indication must be confirmed with radiographic and MRI investigation, to rule out signs of advanced osteoarthritis, meniscal extrusion, extensive cartilage damage or bone marrow lesions, which may negatively impact on arthroscopy outcomes. Due to the degenerative nature of the lesion and the poor biological potential of healing, arthroscopic partial meniscectomy has been recommended as the main surgical option. Partial meniscectomy should be limited to the unstable fragments but preserving as much healthy meniscal tissue as possible. A

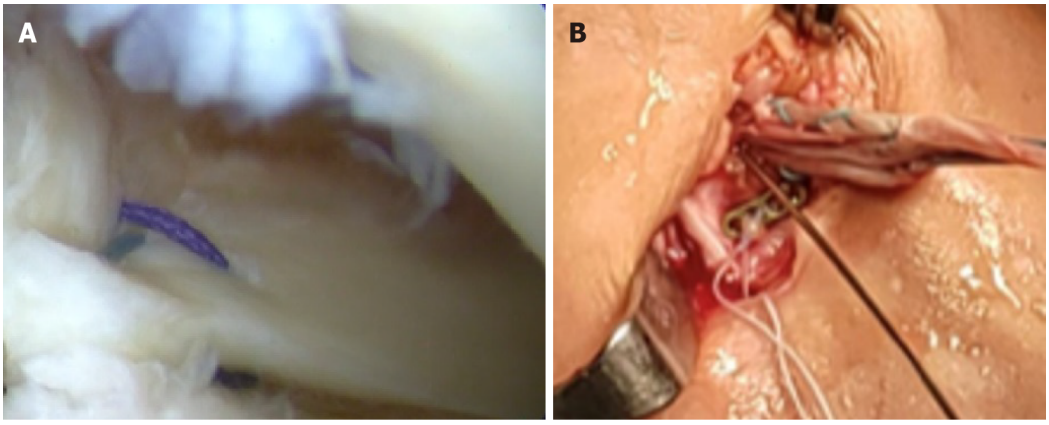

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Figure 5 Arthroscopic repair of the lateral meniscus posterior root repair. A: Arthroscopic view of the repair; B: The suture is passed in the same anterior cruciate ligament tibial tunnel and knotted on a dedicated plate.

complete resection of such tears would subsequently result in a subtotal meniscectomy, further accelerating the joint degenerative process[82]. This also applies in case of degenerative horizontal tears. In a biomechanical study on 10 cadaveric knees, both single leaflet and double leaflet resection was found to significantly reduce contact area and increase contact pressure in the knee[88]. Only a suture repair of such horizontal cleavage tears returns the contact area and contact pressure to nearly normal [88]. As a result, the repair of such lesions is recommended using a vertical mattress stitch configuration following minimum edge resection, if the quality of the meniscal tissue is adequate[89]. Biological augmentation has been proposed in the literature to enhance healing potential of such degenerative lesions[90,91], but further studies with higher methodologic quality are needed to confirm this option.

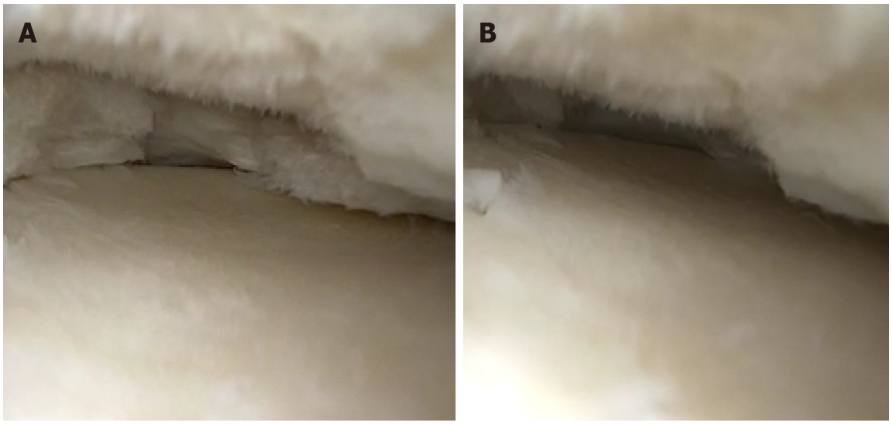
The ugly lesions

The ugly lesions represent the worst scenario for knees, since this group include meniscus tears with the poorest prognosis. All meniscus injuries causing a damage of the meniscus ring are considered ugly lesions, because the interruption of this structure means a complete loss of meniscal function.

Radial tears represent the first type of ugly lesions, because create unfavourable knee dynamic contact mechanics that are not significantly different from those resulting from meniscectomy[11,76] (Figure 6 and Video 1). Such lesions seem to have a lower potential for healing than longitudinal tears [92]. Despite this, the focus on preservation of meniscal tissue has become increasingly imperative even in this context. This has led to the emergence of several arthroscopic repair techniques. Inside-outside or outside-inside horizontal repairs have been considered for long time as the gold standard. However, a recent systematic review demonstrated that a combination of all-inside horizontal or crossed stitches reinforced with suture parallel to the tear as ripstop (defined as hashtag or crosstag technique, respectively) may improve the repair strength[93]. Radial meniscus tear repairs can be further strengthen by creating a transtibial tunnel augmentation[93]. Even a suture anchor can be used to reinforce the radial meniscus repair (Figure 7), but biomechanical data are needed to confirm the validity of this technique.

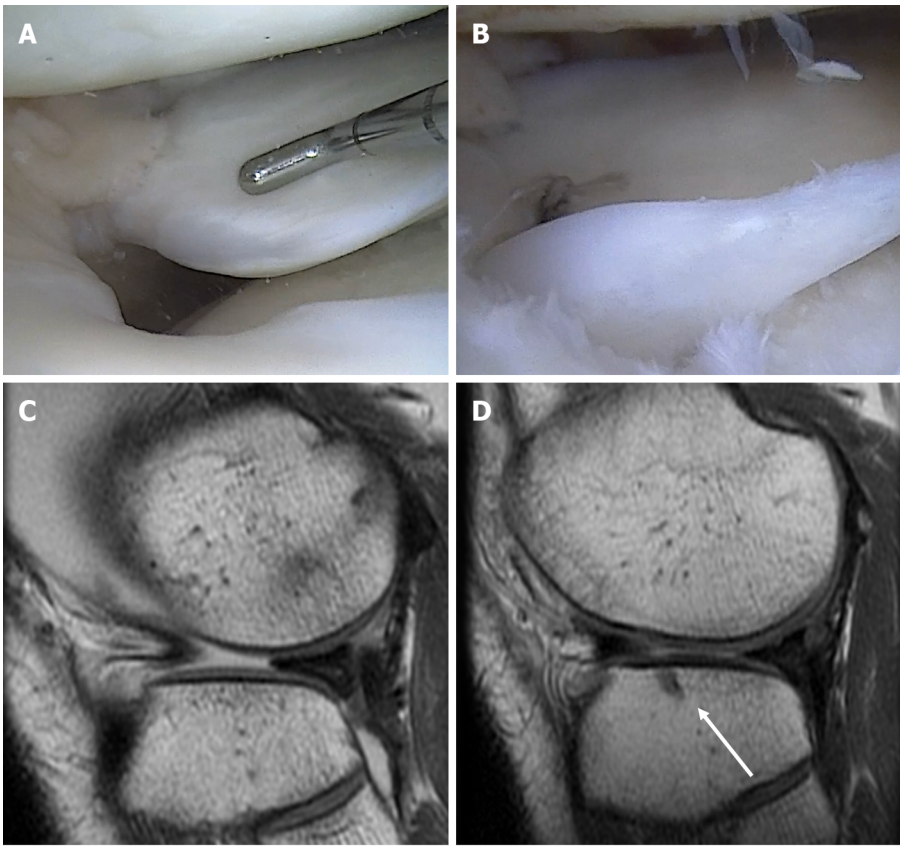
Medial meniscus posterior root tears (MMPRTs) represent a further variant of ugly lesions. This is because creates an interruption of the meniscus ring with subsequent effects on knee kinematics, load transmission and stability[94-96]. In addition, this injury can be responsive of meniscus extrusion[94] (Figure 8), thus leading to a complete meniscus loss of function. Differently to LMRTs, the medial tears are typically associated with high-grade chondral lesions and severe varus knee alignment, which are well-recognized risk factors for poor outcomes[78,97]. According to the current literature, MMPRT repairs result in favourable clinical improvements, but meniscus extrusion seems not to be significantly reduced[98]. Furthermore, the progression of joint degeneration seems to not be completely prevented [98]. The arthroscopic meniscus centralization associated with MMPRT repair has been proposed (Figure 9), resulting in good short terms outcomes and significant reduction of extrusion distance[99]. However, the beneficial long-term effects have yet to be demonstrated. In such circumstances, surgeons' efforts should not only focus on the meniscus tear, but also on limb alignment. A concomitant valgus osteotomy needs to be considered in cases of severe varus knees. This has been demonstrated to improve meniscus healing process, although clinical and radiological outcomes seem not to significantly differ from isolated valgus osteotomies[100].

Medial and lateral anterior root tears need a separate mention. Injuries to the anterior root of the menisci are less common and frequently iatrogenic, such as during arthroscopic portals creation, ACL tibial tunnel reaming or tibial nailing for traumatic fractures[96]. In the authors' experience, medial anterior root tear can be associated with medial bucket-handle tear (Figure 10). As a result, the biomech-



DOI: 10.5312/wjo.v14.i4.171

Figure 6 Arthroscopic view of a radial tear of the medial meniscus. A: Medial meniscus in no-weightbearing condition; B: After applying a compression force, the medial meniscus is totally extruded, thus losing is protective function in the knee joint.



DOI: 10.5312/wjo.v14.i4.171

Figure 7 Radial tear of the lateral meniscus. A: Arthroscopic visualization of the radial tear of the lateral meniscus; B: Tear repair using an all-suture anchor; C: Preoperative T1 sagittal magnetic resonance imaging (MRI) view, showing the extrusion of the anterior portion of the lateral meniscus; D: Six-month follow-up T1 sagittal MRI view, showing the relocation of the anterior portion and the all-suture anchor used for the repair (white arrow).

anical effect of such lesions remains unclear. Although most of the reported literature refers to posterior meniscal root tears, it would stand to reason that anterior root tears will have the same fate if not anatomically repaired. Repair of such lesions can be extremely challenging. Anatomical tibial tunnel positioning or the use of suture anchor can be needed. The creation of accessory portals and the use of dedicated devices can make the procedure easier.

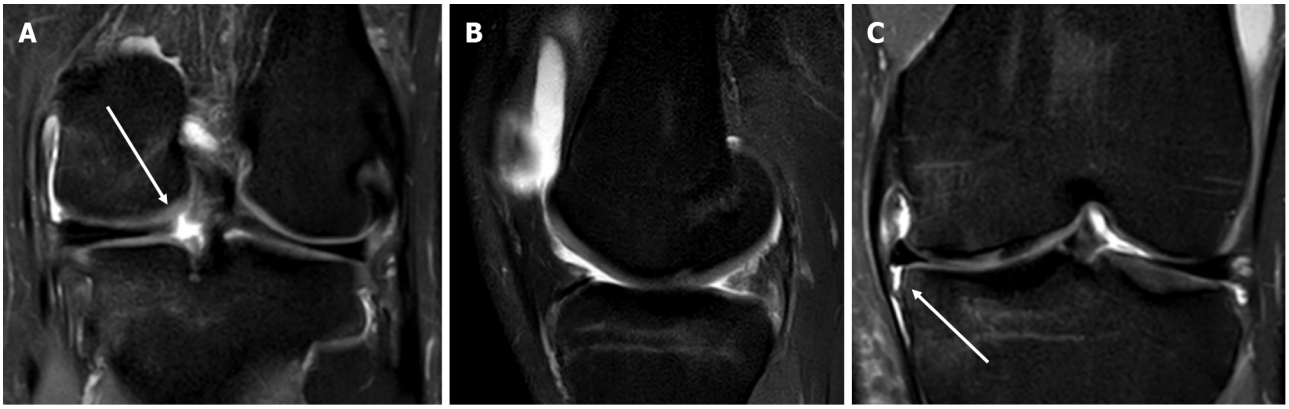


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Figure 8 Isolated posterior root tear of the medial meniscus. A: T2 Fat-Sat coronal magnetic resonance imaging (MRI) view, showing disruption of the meniscus ring (white arrow); B: T2 Fat-Sat sagittal MRI view, with the "ghost sign", highly suggestive for posterior root tear; C: T2 Fat-Sat coronal MRI view, showing detachment of the medial meniscotibial ligament (white arrow) and meniscus extrusion.

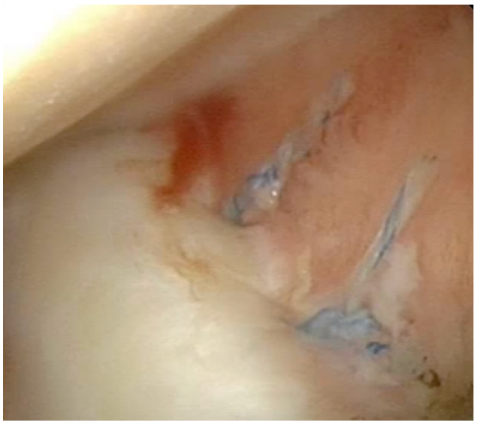

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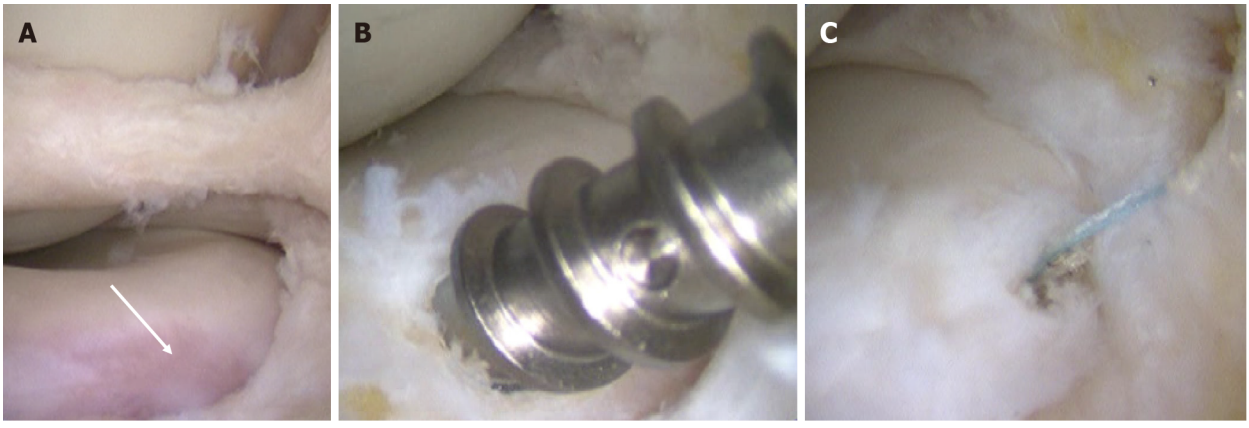
Figure 9 Arthroscopic view of medial meniscus centralization with two all-suture anchors.



DOI: 10.5312/wjo.v14.i4.171

Figure 10 Anterior root detachment of the medial meniscus, with concomitant bucket handle tear. A: Arthroscopic finding with the tibial avulsion site (white arrow); B: Repair of the lesion using a 3.5 metallic suture anchor; C: Final view of the repair.

CONCLUSION

This review aims at representing a practical and updated guide for treatment of meniscus tears. Several factors should be considered when approaching meniscus surgery. Biomechanical aspects, technical challenges and long-term outcomes need to be considered before deciding the most appropriate

therapeutic approach. Further biomechanical studies as well as rigorous clinical research with high methodologic quality are welcome to improve the current knowledge on this fascinating but challenging topic.

FOOTNOTES

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MINIREVIEWS

Effects of different pelvic osteotomies on acetabular morphology in developmental dysplasia of hip in children

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Abstract

Developmental dysplasia of hip seriously affects the health of children, and pelvic osteotomy is an important part of surgical treatment. Improving the shape of the acetabulum, preventing or delaying the progression of osteoarthritis is the ultimate goal of pelvic osteotomies. Re-directional osteotomies, reshaping osteotomies and salvage osteotomies are the three most common types of pelvic osteotomy. The influence of different pelvic osteotomy on acetabular morphology is different, and the acetabular morphology after osteotomy is closely related to the prognosis of the patients. But there lacks comparison of acetabular morphology between different pelvic osteotomies, on the basis of retrospective analysis and measurable imaging indicators, this study predicted the acetabular shape after developmental dysplasia of the hip pelvic osteotomy in order to help clinicians make reasonable and correct decisions and improve the planning and performance of pelvic osteotomy.

Key Words: Developmental dysplasia of the hip; Pelvic osteotomy; Acetabular morphology; Re-directional osteotomies; Reshaping osteotomies; Salvage osteotomies

Core Tip: Developmental dysplasia of hip seriously affects the health of children, and pelvic osteotomy is an important part of surgical treatment. Improving the shape of the acetabulum, preventing or delaying the progression of osteoarthritis is the ultimate goal of pelvic osteotomies. This manuscript reviewed influences of different pelvic osteotomy on acetabular morphology and the acetabular morphology after osteotomy. Accurate prediction of acetabular shape after pelvic osteotomies can help clinicians to make reasonable and correct decisions and improve the planning and performance of pelvic osteotomies.

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INTRODUCTION

Developmental dysplasia of the hip (DDH) leads to loss of the normal anatomical relationship between the femoral head and acetabulum due to developmental defects of the acetabulum, resulting in abnormal morphology and position of the hip joint[1-3]. DDH is the most common hip deformity in children. The global incidence rate is 1‰–2‰. Surgical correction is still the most challenging problem for pediatric orthopedic surgeons[4,5]. Delayed diagnosis of DDH means that more complex and higher failure rates of treatment are needed, so early diagnosis and treatment are important[6]. The main goal of DDH treatment is to achieve and maintain concentric reduction of the femoral head and acetabulum, to ensure the normal development of the hip joint, and to avoid osteonecrosis of the femoral head and reoperation[7,8]. Surgical treatment of DDH is usually determined according to the age, imaging examination and clinical symptoms of the child. In patients with progressive acetabular dysplasia, pelvic osteotomyis necessary to minimize the risk of hip dislocation in adults[9]. Common surgical procedures for DDH patients include pelvic osteotomy, open reduction, capsular arthroplasty and femoral osteotomy[10]. To restore the anatomical morphology and mechanical structure of the pelvis and ensure normal development and life of children, pelvic osteotomy is almost inevitable[11,12]. Morphology of the acetabulum after pelvic osteotomy is closely related to prognosis of DDH. Many researchers have proposed their own methods of pelvic osteotomy that have their own characteristics, indications and clinical effects. There are three common types of pelvic osteotomy: Redirectional, reshaping and salvage[11]. On the basis of retrospective analysis and measurable imaging indicators, this study predicted the acetabular shape after DDH pelvic osteotomy in order to help clinicians make reasonable and correct decisions and improve the planning and performance of pelvic osteotomy.

NORMAL ACETABULAR MORPHOLOGY IN CHILDREN

The hip joint consists of a round head of the femur and a cup-shaped acetabulum, which forms a unique ball and fossa shape that helps stabilize the joint and allows a dynamic range of rotational motion[13]. The normal acetabular structure consists of the upper ilium, the anterior pubic bone and the posterior ischial bone. In early infants, the acetabulum consists of a cartilage complex composed of Y-type and acetabular cartilage. The acetabular cartilage is located at the outer two thirds of the acetabular fossa, and the Y-type cartilage is located at the junction of the pubic bone, ischium and ilium[14,15]. With the growth and development of infants, the ossification center in acetabular cartilage appears and develops successively; the pubic ossification center develops and forms the anterior wall of the acetabulum; the ossification center of the ischium develops and forms the posterior wall of the acetabulum; and the ossification center of the ilium develops and forms the superior wall of the acetabulum. The cartilage complex of the normal acetabulum fuses at the age of 12–16 years, completely forming the fossa of the joint, and covering the entire femoral head. The stress direction determines whether the growing hip joint tends to concentric growth, and determines the morphology and structure of the acetabulum under stress[16]. The acetabular cup usually faces downward, lateral and anterior, opposite to the upper, medial and lateral direction of the femoral head, forming a stable spherical joint structure of the hip joint[17]. Acetabular cartilage is interrupted in the center of the acetabular fossa and is also known as lunate cartilage because it is similar to a crescent shape. Lunate cartilage is located on the lateral and superior articular surface of the acetabulum, which is thicker and stronger than femoral head cartilage [18]. The glenoid labrum is a fibrocartilage structure that surrounds the outer edge of the bony structure of the acetabulum, which functionally deepens the acetabular cup and improves the stability of the hip joint[19,20].

ACETABULAR MORPHOLOGY DURING DDH

Morphological changes of the acetabulum and proximal femur during DDH includes acetabular cartilage degeneration, acetabular fossa shallower, acetabular roof tilted, acetabulum lost its normal and nearly round shape[21,22]. Subluxation or dislocation of the hip is characterized by widening of teardrops, loss of lateral depression of the acetabulum, elongation of the posterior upper edge of the acetabulum, increase of the ratio of long diameter to short diameter of the acetabulum, and loss of normal concentric circle relationship between the proximal femur and the acetabulum[5,23]. Due to the reduction of the contact area between the acetabulum and femoral head, the load of the acetabulum increases, and the structure of the acetabulum propagates laterally under stress, resulting in excessive anteversion of the femoral neck and varying degrees of hip varus[24,25]. The structural changes of the hip joint also cause compensatory changes in the pelvis and spine, leading to a variety of clinical symptoms. It was believed that dislocation of the hip joint during DDH was caused by insufficient depth and excessive tilt of the acetabulum, which could not accommodate the femoral head. However, recent studies have shown that the development between the acetabulum and femoral head follows the Wolff rule[26]. Accordingly, the arrangement of bone trabeculae is affected by the dynamic distribution of bone load, and the mechanical pressure on the bone is conducive to stimulating bone development. When the acetabulum loses the centripetal pressure from the femoral head, the structural development of the acetabulum is affected, and the depth, width and inclination of the acetabulum become abnormal, and even acetabular cartilage degenerates. With the development of DDH, the anatomical morphology of the acetabulum is completely lost and the hip joint is totally dislocated. In the case of total dislocation of the hip, the normal acetabulum loses the pressure from the femoral head, resulting in hypertrophy of the articular pelvis, and the hypertrophic pelvis adheres to the joint capsule and ligaments, which further affects the reduction of the femoral head.

EVALUATION OF ACETABULAR MORPHOLOGY BY COMPUTED TOMOGRAPHY

Computed tomography (CT) is a widely used method for evaluation of the hip joint. Because acetabular dysplasia is not just a simple malrotation or anterolateral defect, three-dimensional (3D) CT imaging can help doctors to determine the exact shape of the acetabulum[27]. Because of the simplicity and speed of obtaining images, CT has become an important method for the diagnosis of hip joint structural changes, preoperative evaluation and postoperative re-examination[25]. The traditional 3D reconstruction of CT can observe the acetabular morphology of DDH in many directions, accurately measuring the acetabulum, and carrying out further quantitative analysis, so as to better evaluate the pathological changes of DDH and morphology of the acetabulum after osteotomy. Some parameters that cannot be measured by conventional X-ray films can be measured by3D CT, such as bony acetabular index and anteversion. Therefore, CT and 3D reconstruction scanning have important guiding significance for clinicians. The bone reconstruction model of 3D CT provides an omnidirectional and multiangle observation index for clinicians to observe the pathological changes of the hip joint and the curative effect of surgery, and has value for guiding surgical planning and prediction of postoperative acetabular shape[28]. Li *et al*[29] used computer-aided design for quantitative dynamic analysis of hip joint morphology, and found that it was a better guide for surgical planning and evaluation of treatment results. Some clinical studies have found that the value and safety of using 3D CT to guide pelvic osteotomy is higher than that of ordinary CT[30]. In addition, 3D CT can also be combined with finite element analysis method to carry out biomechanical analysis of acetabular morphology after DDH, which has important guiding significance for the evaluation of surgical efficacy and improvement of surgical methods of DDH[31].

EVALUATION OF ACETABULAR MORPHOLOGY BY X-RAY FILM

X-ray film can dynamically observe the changes of bone structure during child growth and development, which is the most basic imaging method to evaluate the structural changes of the hip joint, and is important for guiding screening and evaluation of acetabular morphology[32-34]. The following are the main parameters in the evaluation of acetabular morphology by X-ray film[35,36]: Degree of acetabular anteversion, central edge angle (CEA), Acetabular index (AI), sharp angle, angle of iliac wall, and acetabular coverage. The normal acetabulum is usually tilted forward, and it is of clinical importance when the angle is increased by > 7° compared with normal[24]. CEA is an important index to describe the shape of the acetabulum[37,38]. It is normal when the CEA is > 25°, but abnormal when it is < 20°, suggesting that the acetabulum is incomplete. When CEA is between 20° and 25°, it is necessary to closely follow up and observe its changing trends. AI is an objective measurement index of acetabular dysplasia, which can be used to judge the severity and therapeutic effect of DDH. The normal range of AI before age 2 years is 20°–25°, and AI > 30° after 2 years is considered abnormal[38, 39]. The sharp angle reflects the development of the acetabulum and coverage of the hip joint on the

femoral head. It is used to diagnose and predict the progress of hip dislocation. The normal value is 33°–38°. Dynamic observation is needed when the value is 42°–47°, and abnormality can be diagnosed when it is > 47°[40]. The angle of the iliac wall is the angle between the line from the anterior inferior iliac spine to the outer upper edge of the acetabulum and the Y-shaped cartilage line on both sides of the acetabulum. The normal value of the infant is about 55°. The iliac wall angle increases slowly with infant age, and there is little difference between the normal value and the outlier range, so it is necessary to compare the two sides on the X-ray film[41]. The acetabular coverage rate[42] reflects accommodation of the acetabulum to the femoral head. It is the ratio of the distance from the inner edge of the femoral head to the vertical line of the upper edge of the acetabulum to the diameter of the femoral head, and the normal value is > 75%. X-ray film is a simple, fast and economic examination method, which can quickly diagnose DDH from a large number of pelvic films, effectively reduce the misdiagnosis rate and evaluating the shape of the pelvis and acetabulum after surgery.

PELVIC OSTEOTOMYAND ACETABULAR MORPHOLOGY

The ability of acetabular remodeling has an age limit, and previous studies have shown that the acetabulum can be remodeled under the age of 5 years[43]. Acetabular dysplasia over a certain age needs to be corrected by pelvic osteotomy. Different methods of pelvic osteotomy depend on the age of DDH patients and the degree of deformity[44,45]. Normal development of the acetabulum depends on the femoral head under the concentric circle position, but DDH changes the biomechanical structure of the hip joint, which limits the morphological development of the acetabulum in children, so the purpose of the operation is to restore the concentric reduction of the hip joint[46]. Pelvic osteotomy can improve deformity of the acetabulum, increase the stress area of the hip joint, restore the coverage of acetabular cartilage, and reconstruct the biomechanical relationship of the hip joint[47]. When acetabular dysplasia is associated with subluxation or dislocation, pelvic osteotomy is necessary to minimize the risk of hip dislocation in adults[11]. The older the onset of DDH, the worse the prognosis. It is generally believed that osteotomy has a lot of complications in patients aged > 8 years[48]. The effects of different pelvic osteotomy on acetabular morphology are different, which provides a basis for different patients to formulate specific osteotomy methods[49]. The current imaging technology has been able to measure the relevant indicators of acetabular morphology, but the operations process of different patients can't be total the same, so it is difficult to measure acetabular morphology accurately by different osteotomies. Previous researchers used the lateral CEA to assess acetabular developmental defects, but Daniel *et al*[50] found that acetabular deficiency in borderline hip dysplasia can be underestimated by lateral CEA alone. Some researchers used 3D printing technology to measure the relevant indexes of acetabular morphology after different osteotomies. The real proportional anatomical model can accurately measure the AI before and after surgery, and it provides conditions for optimizing the surgical plan and improving the method. Researchers had described many types of pelvic osteotomy. Different pelvic osteotomies have different advantages and indications, and the shape of the acetabulum after osteotomy is also different. There are three common types of pelvic osteotomy: Redirectional, reshaping and salvage[11]. We will describe the effects of the different types of pelvic osteotomy on the morphology of the acetabulum.

REDIRECTIONAL OSTEOTOMY

Redirectional osteotomy of the pelvis changes the direction of the acetabulum, increases the contact area between the acetabulum and the femoral head, and increases the area of hyaline cartilage in the weight-bearing area of the acetabulum. It is characterized by repositioning the acetabulum to improve the anterolateral acetabular cover without changing the size and shape of the hip, which is an incomplete osteotomy[51]. The common redirectional osteotomies include Salter, periacetabular and triple pelvic osteotomy.

Salter osteotomy

Salter osteotomy is a classic method of pelvic osteotomy, which belongs to the osteotomies that change the direction of the acetabulum. It was first proposed by Salter in 1961[52]. The osteotomy line of Salter is from the anterior inferior iliac spine to the great ischial notch, and the entire acetabulum is turned forward and outward with the pubic symphysis as the fulcrum. It changes the overall orientation of the acetabulum to increase the inclusiveness of the acetabulum to the femoral head, and the shape and volume of the acetabulum remain unchanged[3]. Therefore, Salter osteotomy is suitable for the following[52,53]: (1) Children aged 18 mo to 6 years with unossified pubic symphysis; (2) anterolateral acetabular defect as the main defect; and (3) AI is basically normal. Salter osteotomy requires internal fixation support, so the wedge-shaped bone removed from the ilium is placed into the fracture line and fixed with Kirschner wire to increase stability of the acetabulum after osteotomy. In the Salter

procedure, the rotation angle and distance of the distal iliac bone are not only the difficulties of the operation, but also the key to its effectiveness. Previous studies have shown that Salter osteotomy changes the acetabular center with the movement of the distal bone mass, and the AI decreases yearly. At 3–4 years after the operation, the AI is stable to about 15°, the CEA increases yearly, and returns to the normal range for about 5 years, and the postoperative obturator area is significantly reduced[54].

Periacetabular osteotomy

Periacetabular osteotomy, also known as GANZ osteotomy, is suitable for patients with hip pain and when the femoral head is located in the center of the acetabulum, and the degree of hip deformity and arthritis is low. It was first proposed by Ganz in 1983[55]. The periacetabular osteotomy procedure is mainly to amputate the pubic bone, ischium and ilium, and under the condition of maintaining the continuity of the pelvis, rotate the acetabulum to make the acetabulum cover the femoral head to the best extent[56]. Because periacetabular osteotomy does not destroy the acetabular blood supply and the pelvic ring, it can improve the biomechanical relationship between the acetabulum and femoral head, reduce the probability of postoperative acetabular necrosis, and avoid the occurrence of hip arthritis [45]. Andrew *et al*[57] found that among athletes with symptomatic hip dysplasia who received periacetabular osteotomy, all acetabular parameters were improved, and the return to exercise rate of competitive athletes was > 70%. Periacetabular osteotomy allows the acetabulum to be relocated in multiple directions to correct the deficiency of the anterior coverage of the femoral head, so even severe acetabular deformities can be satisfactorily corrected by accurate rotation and internal displacement of the acetabular center. Because periacetabular osteotomy maintains the integrity of the posterior column of the acetabulum, better initial stability is obtained[55,58]. Through long-term follow-up, researchers have found that in the patients treated with periacetabular osteotomy, the fracture healed well, the lateral coverage of the femoral head, AI angle and Sharp angle were significantly improved, the cartilage area of the acetabular weight-bearing area was increased, and the gait and hip joint function were significantly improved.

Triple pelvic osteotomy

Triple pelvic osteotomy, which includes osteotomy of the ilium, pubis and ischium around the acetabulum, is a complete redirected osteotomy, which solves the problems of limited movement of bone mass and lateralization of the hip joint after osteotomy[59,60]. This complete redirected osteotomy increases the range of motion of the acetabulum by cutting off the pubic bone, ischium and ilium, so that the rotated acetabulum can completely contain the femoral head and achieve concentric reduction of the hip joint. At present, there are three common triple pelvic osteotomy procedures, which are LeCoeur, Steel and Tonis[61]. By amputating the ilium and the superior and inferior branches of the pubis near the symphysis pubis, the LeCoeur procedure limits the rotation of the acetabulum because the position of the amputated pubis and ischium is far from the acetabulum[11].Steel osteotomy cuts the ischial bone at the ischial tubercle through the posterior approach, and the pubic bone and ilium through the anterior approach. Because the osteotomy is close to the acetabulum, the range of acetabular adjustment is better than that of LeCoeur. The position of the Tonnis osteotomy is closer to the acetabulum than the Steel osteotomy is, so the acetabular rotation is greater[62]. Like other redirected osteotomies, triple pelvic osteotomy is a rotational osteotomy that does not change the size and shape of the acetabulum [63]. The premise of this operation is that the structure of the hip joint is intact, which is mainly suitable for older children with more severe acetabular dysplasia, and it is an unstable osteotomy that requires solid internal and external fixation[59,64]. Triple pelvic osteotomy can improve the CEA, lateral coverage of the femoral head, and stress distribution of acetabular cartilage, and can effectively correct acetabular deformities.

RESHAPING OSTEOTOMIES

Compared with pelvic redirectional osteotomies, pelvic reshaping osteotomies are incomplete, which increases the coverage of the acetabulum and femoral head by bending acetabular vertices[65]. Therefore, this kind of operation is also called acetabuloplasty. Because it is an incomplete osteotomy, the position of the bone mass after operation is stable and usually does not require internal fixation. There are three common methods of reshaping osteotomies, namely, Pemberton, Dega and SanDiego. Researchers[49] compared the effects of these three osteotomies on acetabular morphology using 3D-printed models, and found that Pemberton and Dega increased the upper and anterior coverage of the acetabulum, resulting in retroversion of the acetabulum, while SanDiego increased the posterior coverage of the acetabulum, resulting in acetabular anteversion.

Pembertonpelvic osteotomy

Pemberton pelvic osteotomy is a periarticular osteotomy, also known as Pemberton acetabuloplasty, which was first proposed by Pemberton in 1968[66,67]. Pemberton pelvic osteotomy has a wide range of adaptation, and can be used in children under 12 years old, but because it affects development of the

pelvis and pubic symphysis, caution is needed in children under 6 years old. Pemberton pelvic osteotomy takes the Y-type cartilage around the acetabulum as the rotation fulcrum and controls the shape of the acetabulum by adjusting the position of the bone cortex on the posterior side of the ilium. It increases the coverage of the anterior edge of the acetabulum, and significantly increases the coverage of the outer upper edge and posterior edge of the acetabulum[68]. Pemberton pelvic osteotomy can adjust acetabular direction, correct acetabular deformity and increase acetabular depth according to the degree of acetabular defect. Therefore, it can reduce AI, increase the coverage of acetabulum and femoral head, stabilize the hip joint, and reduce deformity of the acetabulum[69,70]. Because the Pemberton procedure can reduce AI, it is suitable for cases where the acetabulum needs to be corrected by > 15° and the acetabulum is shallow and steep.

Degapelvic osteotomy

Dega osteotomy is one of the commonly used osteotomies in the treatment of DDH. It was first proposed and applied in clinic Dega in 1958[71,72]. The Dega procedure is a type of acetabuloplasty to change the shape and inclination of the acetabulum, mainly to increase the lateral coverage of the acetabulum, which can change the volume of the acetabulum without damaging the Y-type cartilage [73]. Dega operation uses the iliac bone of incomplete osteotomy above the Y-type cartilage as a hinge to change the direction and inclination of the acetabulum. Its advantage is that the position of iliac osteotomy can be adjusted according to the location of the acetabular defect, so that acetabular defects in different parts can be corrected[74]. A retrospective analysis[75] showed that AI decreased significantly in patients who underwent Dega acetabuloplasty, and postoperative Sharp angle was also improved, which can improve AI and inclusiveness of the femoral head.

San Diego pelvic osteotomy

SanDiego osteotomy is a modified Dega osteotomy to improve lateral and posterior acetabular coverage [11,76]. The SanDiego operation is an incomplete osteotomy. The medial iliac bone cortex is intact except for the anterior and posterior sides, and the ischial and pubic corticesare also continuous[51]. In iliac osteotomy, the wedge-shaped bone can be used to stretch the osteotomy surface, so this kind of monocortical osteotomy enables doctors to change the shape of the acetabulum by changing the size and position of the bone graft, thus solving the problem of insufficient acetabular coverage[76]. Because San Diego osteotomy mainly increases coverage of the acetabulum, the shape of the acetabulum tilts forward after osteotomy, the volume of the acetabulum decreases, and the depth of the acetabulum increases.

SALVAGE PELVIC OSTEOTOMIES

If DDH is untreated or inadequately treated, it aggravates the deformity of the hip joint, which eventually develops into a nonfunctional joint with pain symptoms[77]. At that time, the change in the bony structure of the hip joint is more serious, the shaping ability of the bone decreases, the shape of the femoral head and acetabulum are difficult to reduce by simple methods, and in severe cases, cartilage injury of the hip joint occurs[78]. At that time, surgeons should pay attention to recovery of hip joint function and perform salvage surgery, so as to delay the progress of arthritis and reduce the probability of osteonecrosis of the femoral head. The common salvage pelvic osteotomies are Chiari and Shelf.

Chiari pelvic osteotomy

Chiari osteotomy, also known as intrapelvic osteotomy, was first proposed and applied by Chiari *et al* [79] in 1974. Chiari osteotomy changes the weight-bearing line of the hip joint and increases the weight-bearing area by moving the position of iliac osteotomy. It is a type of joint capsule plasty, which belongs to single-plane osteotomy[80]. Therefore, Chiari operation is suitable for older children with abnormal acetabular–femoral head index, non concentric reduction of the femoral head, acetabular deformity and lack of plastic potential[81,82]. The Chiari procedure cuts the ilium from front to back from the area between the acetabulum and the anterior inferior iliac spine along the ischial notch, and then the bone mass of the distal end of the ilium is moved inward and upward. In this process, it is necessary to ensure the coverage of the acetabulum to the femoral head and avoid the impact between the femoral head and ilium[51,78].The coverage of the acetabulum depends on the width of the ilium. In order to achieve satisfactory coverage of the lateral acetabulum, it is usually necessary to move the distal bone completely inward to the width of the ilium. If there is insufficient containment of the anterior side of the femoral head, iliac alar osteotomy can be performed, then coverage on the anterior side of the femoral head was improved. The Chiari procedure distributes the weight-bearing area of the acetabulum by expanding the inclusion of the acetabulum to the femoral head, but the damaged acetabular cartilage and glenoid labrum may still be located in the weight-bearing area after salvage surgery. Therefore, although this operation can better restore the acetabular–femoral head index, it cannot solve the defect in front of the acetabulum, and shortens the transverse diameter of the pelvis, resulting in unsatisfactory surgical results[83].

Table 1 Summation of previous studies with their case number and conclusions

Ref.	Pelvic osteotomies	Number of cases/hip	Conclusion
Sawamura *et al* [52]	Salter osteotomy	42/50	Showed favorable outcomes with satisfactory at skeletal maturity
Scott *et al*[53]		58/78	Improve acetabular morphology, reduced the incidence of advanced osteoarthritis and the probability of THA
Tan *et al*[55]	PAO	?/225	Lead to good deformity correction for both acetabular retroversion and hip dysplasia
Ali *et al*[56]		314/?	All acetabular parameters were observed to be improved
Dornacher *et al* [63]	TPO	176/206	Acetabular parameters recovered well, intraoperative fluoroscopy increased the accuracy of the operation
Lyu *et al*[64]		43/48	Improve parameters of the acetabulum, makes the complex operation safer and more effective
Bhatti *et al*[67]	PPO	60/82	The hips with Pemberton's acetabuloplasty exhibited better acetabular coverage and progressive development of hips as compared to Salter's osteotomy
Czubak *et al* [71]	Dega osteotomy	45/52	It is a safe and adequate operation to restore the acetabulum to normal or close to normal
Badrinath *et al* [76]	San Diego osteotomy	?/45	It is a safe and effective alternative to treat acetabular dysplasia in patients with typical DDH and can solve specific acetabular defects
Ito *et al*[82]	Chiari pelvic osteotomy	31/32	Improve acetabular index, relieve pain and reduce hip replacement rate
Dammerer *et al* [81]		12/12	Improve the acetabular coverage of the hip joint and suitable for some specific older children
Yoo *et al*[84]	Shelf pelvic osteotomy	14/14	Improve the depth and coverage of acetabulum and can stimulate the growth of acetabulum
Benad *et al*[85]		56/61	Relieve pain symptoms, improve joint function and delay THA in patients

PAO: Periacetabular osteotomy; TPO: Triple pelvic osteotomy; PPO: Pemberton pelvic osteotomy; THA: Total hip arthroplasty; DDH: Developmental dysplasia of the hip.

Shelf pelvic osteotomy

Shelf osteotomy, also known as acetabular extension, is mainly suitable for older children with femoral head and acetabular mismatch and hip dislocation. The anterior, posterior and lateral weight-bearing surface of the acetabulum is enlarged by osteotomy of the ilium and bone grafting at the fracture line, so the acetabular coverage of the femoral head is increased[11]. Shelf operation is a salvage operation, which is suitable for older children who have failed nonoperative treatment of DDH[84]. Shelf acetabuloplasty has a favorable, stimulatory effect on acetabular growth[85]. The operation does not change the direction or biomechanical structure of the acetabulum, but increases the volume, so it can improve stability of the hip joint. After Shelf osteotomy, the central marginal angle of the hip joint increases, the coverage of the acetabulum to the femoral head increases, and the acetabular shaping is improved[86].

CONCLUSION

Pelvic osteotomy is an important method for surgical treatment of DDH. There are three common types of pelvic osteotomy: redirectional, reshaping and salvage. The choice of pelvic osteotomy depends on the patient's age, acetabular development and disease severity. No operation is the best, and no operation is suitable for all cases. It is particularly important for pediatric orthopedic surgeons to choose the osteotomy with which they are most familiar and which is most suitable for patients. Different methods of pelvic osteotomy have different effects on acetabular morphology, and the acetabular morphology is closely related to prognosis (Table 1). It is still one of the most challenging problems for pediatric orthopedic surgeons to master the principles of various pelvic osteotomies and to understand the morphological changes in the acetabulum after pelvic osteotomy. At present, the evaluation of acetabular morphology after pelvic osteotomy mainly depends on ordinary X-ray or 3D CT reconstruction, but the measurement of acetabular morphology is not accurate because of the non-replicability of different patients and the individual differences of observers. In the future, the acetabular morphology of different pelvic osteotomy methods will be measured by 3D printing, and the morphological changes in the acetabulum before and after surgery will be accurately measured by real proportional anatomical models, so as to provide a basis for optimizing the surgical plan and improving the osteotomy method.

FOOTNOTES

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MINIREVIEWS

Background, techniques, applications, current trends, and future directions of minimally invasive endoscopic spine surgery: A review of literature

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Abstract

Across many of the surgical specialties, the use of minimally invasive techniques that utilize indirect visualization has been increasingly replacing traditional techniques which utilize direct visualization. Arthroscopic surgery of the appendicular skeleton has evolved dramatically and become an integral part of musculoskeletal surgery over the last several decades, allowing surgeons to achieve similar or better outcomes, while reducing cost and recovery time. However, to date, the axial skeleton, with its close proximity to critical neural and vascular structures, has not adopted endoscopic techniques at as rapid of a rate. Over the past decade, increased patient demand for less invasive spine surgery combined with surgeon desire to meet these demands has driven significant evolution and innovation in endoscopic spine surgery. In addition, there has been an enormous advancement in technologies that assist in navigation and automation that help surgeons circumvent limitations of direct visualization inherent to less invasive techniques. There are currently a multitude of endoscopic techniques and approaches that can be utilized in the treatment of spine disorders, many of which are evolving rapidly. Here we present a review of the field of endoscopic spine surgery, including the background, techniques, applications, current trends, and future directions, to help providers gain a better understanding of this growing modality in spine surgery.

Key Words: Endoscopic; Spine Surgery; Applications; Minimally invasive surgery; Endoscopy; Spine

Core Tip: Endoscopy is a rapidly evolving minimally invasive technique in the field of spine surgery. This review aims to summarize the history, current techniques, and discuss the benefits, limitations, and future directions of this minimally invasive technique.

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INTRODUCTION

Minimally invasive surgery (MIS) with integration of endoscopic techniques has continued to expand its application across various surgical specialties due to its applications of smaller surgical corridors and cannulas[1]. Modern endoscopic approaches allow surgeons to reduce incision size, decrease blood loss, and report less postoperative pain, however, a significant learning curve associated with its adoption does exist[2-6]. Currently, most endoscopic procedures are performed within either an existing 3-dimensional (3D) cavity or the enlargement of a potential space, including endoscopy of the gastrointestinal tract, nasal sinuses, cerebral ventricles, and thoraco-abdominal compartments. However, spinal endoscopy involves a different approach as surgical manipulation within confined spaces is performed. Endoscopic spine surgery has been developed as a MIS technique for decompression in patients with lumbar disc herniation and lumbar stenosis, as decompression by lumbar spinal fusion is the gold standard treatment for a variety of lumbar degenerative diseases[7,8]. Reports as early as 2008 describe the first use of endoscopic technology in fusion surgeries, specifically for transforaminal lumbar interbody fusion (TLIF) procedures[9], as previous approaches reported limitations. The first TLIF approach was described as an open technique in 1998 by Harms *et al*[10]. This was a unilateral approach to the disc space through the ipsilateral facet joint, enabling the placement of an interbody spacer to achieve indirect decompression of impinged nerve roots[11]. With technical refinements and the development of a tubular retractor, the first MIS TLIF was performed and reported as a combination of less tissue disruption and shorter recovery time resulting in reduced postoperative pain, improved clinical outcomes, and lower costs[9-12]. However, recent research has identified potential limitations in the use of MIS TLIF procedures, as it has been suggested that the retraction of muscles during surgery may lead to muscle degeneration and long-term weakness.[8]. Although, MIS endoscopy in spine is a novel technique that may distinguish itself from other approaches, it is still in its nascency and several limitations are important to recognize such as: the steep learning curve when transitioning from traditional open surgery to endoscopic techniques[13], limited field of view and lack of resolution, thus making identification of anatomic structures difficult[1,14], and disorientation due to indirect visualization, resulting in the surgeon being unable to accommodate orientation and perspective[1]. It has been proposed that the implementation of advanced optical systems and the refinement of surgical instruments could effectively mitigate the aforementioned challenges[15]. As endoscopic spine surgery becomes increasingly prevalent, it is critical to understand the applications, progression and continued safety and efficacy of endoscopy in minimally invasive spine surgery. This review addresses previous and current techniques of endoscopic applications in MIS, specifically TLIF procedures, and discusses benefits, limitations, and future perspectives.

History of endoscopic spine surgery

The use of endoscopes in spine surgery dates back to the early 20th century, when they were first utilized for diagnostic purposes (Table 1). In 1931, Burman used arthroscopic tools to perform "myeloscopies" in cadavers which allowed direct visualization of the spinal cord and nerve roots[16]. In 1936, Stern developed a tool called the "spinascope", which was used by Pool in 1938 to visualize nerve roots of the cauda equina and their accompanying blood vessels in patients using an incision "not over 2.5 mm"[17,18]. The breakthrough of fiber optic technology revolutionized the field of endoscopy during the 1970s. Prior to the 1970s, endoscopes were limited by their ability to transmit light and image quality was poor. The use of fiber optic cables in endoscopes allowed for the transmission of bright, high-quality images and enabled surgeons to visualize the inside of the body in greater detail. It also made it possible to design smaller and more flexible endoscopes, which made it easier for surgeons to access and maneuver within small and confined spaces in the body, such as the spinal canal. The foundation for endoscopic spine surgery was formed by the evolution of a needle–based technique called percutaneous endoscopic discectomy in the 1970s. In 1973, Kambin demonstrated a technique for percutaneous nonvisualized indirect spinal canal decompression—percutaneous nucleotomy-through a posterolateral approach using a Craig cannula[19]. Two years later, Hijikata ran an independent study

Table 1 Chronological timeline showing the technical and procedural advancements of endoscopic spine surgery

Decades	Events
1930's	1931: Burman's "myeloscopies" in cadavers, successfully visualized the spinal cord and the nerve roots
	1936: Stern's development of new instrumentation, termed "spinascope"
	1938: Pool's myeloscopies through incisions "not over 2.5 mm", visualized the nerve roots in great detail
1940's-1950's	Technological advancements in optical lens systems and the development of fiber-optics
1960's	1963: Smith's injection of chymopapain intradiscally called "chemonucleolysis", led to "intradiscal decompression"
1970's	1973: Kambin's and Gellmann's feasibility study of mechanical nuclear debulking by inserting Craig cannula *via* posterolateral approach
	1975: Hijikata preformed first percutaneous nucleotomy (posterolateral approach, < 2.6 mm)
	1977-1978: Gazi and Caspar introduced microsurgical techniques
1980's	1982: Harms and Rolinger introduced transforaminal lumbar interbody fusions
	1983: Forst's and Hausman's introduction of arthroscopy into intervertebral disc space
	1986: Kambin further developed percutaneous discectomy
	1988: Kambin;s first endoscopy view of herniated nucleus pulposus
	1989: Schreiber, Suezawa, and Leu were the first preformed percutaneous nucleotomy under visual control and endoscope (discoscopy)
1990's	1990: Kambin created, "Kambin Triangle", a percutaneous technique
	1990: Spine surgeons started doing minimally invasive spine surgery by magnification loupe or under microscope
	1991: Kambin and Sampson developed cannula (10 mm-23 mm) for interlaminar and transforaminal endoscopy
	1996: (Foraminoscopy) Matthew's preformed a more lateral mass route and prefomed foraminal epidural endoscopic surgery
	1997: Yeung had designed YESS endoscope and developed technique of "inside out" technique
	1998: (Foraminoascopy) Ditsworth's preformed endoscopic transforaminal procedure
	1998: Harms described the first TLIF approach as an open technique
	1998: Destandau and Foley developed tubular retractor system and endoscopy aided spine surgery through interlaminar approach
2000's	2003: Hoogland introduced the outside- in technique using transforaminal approach
	2005-2006: Rutten and Choi extended indications and developed interlaminar endoscopic discectomy
2010's	2013: Choi presented work flow to avoid risk of exiting root injury, a step forward in endoscopic spinal surgery

TLIF: Transforaminal lumbar interbody fusion.

which demonstrated the same technique using a 2.6-mm cannula[20]. The evolution of this technique was characterzied by the addition of the endoscope.

During the 1980's, advancements in technology and techniques became more prominent as the introduction of TLIF was introduced by Harms and Rolinger, which was a lateral approach to the disc space, and reduced the amount of thecal sac and nerve root retraction[21]. Furthermore, this technique afforded a less invasive alternative to traditional posterior lumbar interbody fusion. That following year, Forst and Hausman were the first to introduce the endoscope into the intervertebral disc space [22]. Over time, Kambin published the first endoscopic view of the nucleus pulposus in 1988 and it was followed by Schreiber and Suezawa in 1989, who were the first to perform a percutaneous nucleotomy using endoscopy[23-25]. In the 1990's, advancements were made in spine endoscopy techniques and technology based on two different approaches, the extraforaminal and interlaminar approaches. A deeper understanding of the "Kambin Triangle" allowed for the expansion of endoscopic spine surgery beyond the limits of percutaneous nucleotomy. Kambin's triangle provided a pathway for the use of larger instruments and channels near foraminal pathology without risking injury to the exiting nerve [19-26]. The concept of a safe zone between the exiting and traversing nerve roots in the foramen allowed endoscopic spine surgery to extend into the foramen. In 1993, Mayer and Brock introduced the use of an angled lens scope to improve visualization of annular pathology[26]. In the mid 1990's, the introduction of multichannel endoscopes with larger working channels were then introduced by Tsou *et al*[27] and were later developed and studied in the years to come.

Furthermore, the YESS endoscope was first designed for the "inside-out" technique by Yeung in 1997, and foraminoscopy was first developed which was described by Mathews in 1996 and Ditsworth in 1998 [29-31]. In the same year, Harms *et al*[10] described the first TLIF approach as an open technique, which

was a unilateral approach to the disc space through the ipsilateral facet joint, enabling the placement of an interbody spacer to achieve indirect decompression of impinged nerve roots. During that same year, Kambin and Zhou[31] described workflows for decompressing the lumbar nerve root through anulectomy and relieving lateral recess stenosis. After the turn of the new millennium, further developments and techniques in endoscopic spine surgery were further refined and unveiled. Hoogland introduced the "outside-in" technique using a transforaminal approach in 2003[32]. Two years later, Schubert and Hoogland then described a method for transforaminal endoscopic removal of a sequestered disc fragment using reamers which enlarged the foraminal window by removing the ventral portion of the superior articular process[33]. In 2007, Ruetten *et al*[34] facilitated the direct endoscopic decompression of foraminal pathology, based on the introduction of multichannel endoscopes with larger working channels by Tsou *et al*[27] in 1997 and several clinical studies including those by Yeung and Tsou in 2002.

More recently, studies have further examined techniques and workflow to avoid risk of exiting root injuries. In 2013, Choi *et al*[36] reported a workflow to avoid such injury such as, measuring the distance from the exiting root to the facet at the lower disc level based on preoperative magnetic resonance imaging scans. Alternative surgical methods, such as microdiscectomy or conventional open discectomy, should be considered if the distance is too small. With current advancements in technology and refinement in techniques, risk of injury and potential barriers are underway of being well studied and understood.

Techniques in endoscopic spine surgery

There are various endoscopic techniques that can be used to treat spine disorders. These techniques involve using a camera to indirectly view the surgical area (Figure 1), with the camera being inserted into the body through a channel called a working channel (Figures 1 and 2). The size and number of working channels are used to classify different types of spinal endoscopy. The capabilities and benefits of these techniques depend on the size and number of working channels, with a trade-off between having larger or more channels, which can allow for the use of multiple instruments but may cause more tissue disruption, and having smaller or fewer channels, which may cause less tissue disruption but limit the use of multiple instruments. The three most common techniques are full endoscopy, microendoscopy, and biportal endoscopy (Table 2). Full endoscopy involves the use of a single working channel, which holds the endoscope and one surgical instrument in the same tubular device (Figure 2). The working channel only allows for the use of one instrument at a time, so the operator must change the instrument if they want to use a different one. The small size of the working channel means that the camera and the instrument must be moved together, with some modifications allowing for limited independent movement of the instrument's distal end. To create space around the surgical area during full endoscopy, an aqueous environment is typically used to separate tissues. One advantage of this technique is that it causes less collateral tissue damage compared to other techniques. However, the single working channel limits the ability to use multiple instruments concurrently and independently control the camera and instrument movements, which can be limiting during spine procedures. In order to retract tissue during surgery, some full endoscopy techniques use beveled working channels that allow the surgeon to use the working channel as a retractor. The size of the working channel can also limit the ability to implant devices.

Microendoscopy involves the use of a single, larger working channel that allows for the concurrent use of multiple instruments and independent control of the endoscope. In this category of techniques, a rigid endoscope (microendoscope) is attached to a tubular retractor that includes tissue dilators to reduce the need for muscle retraction. The most common system in this category is the METRx tube assembly. This increased flexibility allows the surgeon to use multiple instruments simultaneously and have both hands free. The larger working channel size also allows for the use of a wider range of tools and the implantation of devices such as interbody cages and bone graft. The main disadvantage of microendoscopy is that it may cause more tissue disruption due to the larger portal size, though the clinical impact of this is not well understood. Another disadvantage is that it is currently performed in a dry environment, without the use of an aqueous field to aid in tissue separation and visualization.

Biportal endoscopy involves the use of two working channels: one for the endoscope and one for instruments. This approach is similar to arthroscopy techniques used in other arthroscopic procedures and allows for independent control of the scope and instruments, as well as greater freedom of instrument positioning. Biportal endoscopy may be more familiar to surgeons who have experience with other peripheral joint arthroscopy techniques, as many of the principles are similar. Like full endoscopy, biportal procedures use an aqueous environment to create a space around the surgical site. The main disadvantages of biportal endoscopy are the need for multiple access portals, which can cause more tissue disruption, and the limited ability to implant devices. Additionally, the lack of a contained joint space and the need to exchange and co-locate instruments through multiple portals can make the procedure technically more challenging.

Surgical approaches in endoscopic spine surgery

There are two primary approaches most commonly used for endoscopic spine surgery: The postero-lateral (or interlaminar) approach and the extraforaminal (or transforaminal) approach. The

Table 2 Pros and cons of full endoscopy, microendoscopy, and biportal endoscopy

Technique	Pros	Cons
Full endoscopy	Least amount of tissue damage out of the three	Cannot move camera and tool independently
Microendoscopy	Space for more tools, space for implanting devices	Large portal size
		Dry environment only
Biportal endoscopy	Independence of tools	Most tissue damage out of the three
		Locating tools more
	Familiarly with other arthroscopic techniques	Challenging

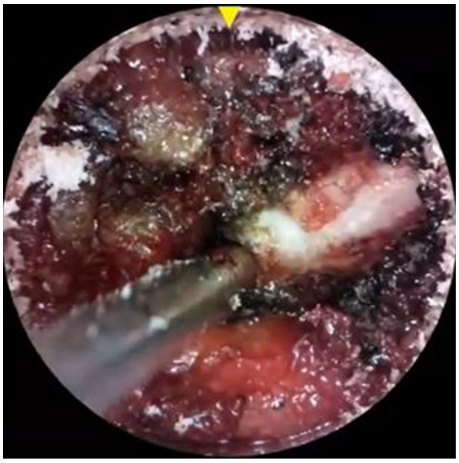

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Figure 1 Direct endoscopic view from tubular/retractor-based camera that provides a two-dimensional image on a screen with digital zoom.

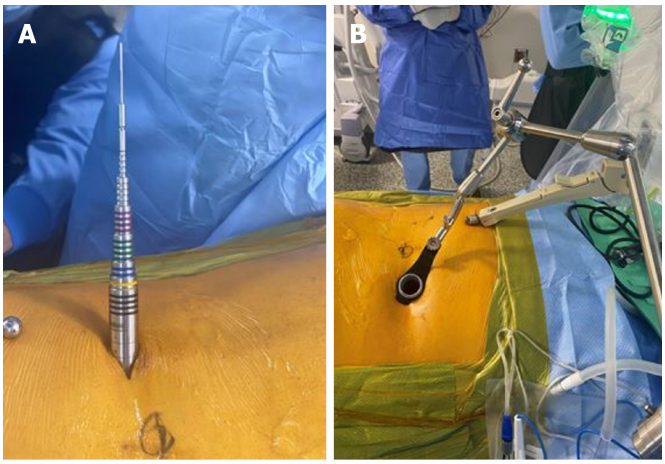

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Figure 2 Minimally invasive surgery endoscopic technique. A: Endoscopic cannula inserted in posterior lumbar region; B: Tubular/retractor-based setup where the camera can be inserted into the body through a channel called a working channel.

interlaminar approach involves making a paramedian incision to access the lamina and interlaminar space, allowing the surgeon to directly reach the spinal structures within the central canal and lateral recesses. This technique is similar to open microscopic lumbar/thoracic decompression, which is familiar to many spine surgeons. The decompression process in this technique is also similar to that of open microscopic decompression. This approach is suitable for a wide range of spinal disorders, as many of these conditions involve neural compression in the central and/or lateral recess zones. The transforaminal approach is a posterior-lateral percutaneous approach to the disc or epidural space through the foraminal window that aims to preserve normal musculoskeletal structures. The transfo-

raminal approach involves making a far lateral incision for cannula set up to allow instruments to access the transforaminal and lateral foraminal zones in an area known as Kambin's triangle (Figure 2). This approach provides direct access to the foramen and is often used for isolated, unilateral foraminal conditions or neural compression in the lateral recess or central canal due to ventral disc pathology (Figure 3). One key benefit of this approach is that it can provide direct access to the area of concern without requiring a large skin incision, extensive muscle retraction, unnecessary bone removal, or general anesthesia. However, the transforaminal approach has the disadvantage of being limited in its ability to address many types of lateral recess or central stenosis caused by dorsal pathology.

Uptick in studies on endoscopic spine surgery

In the last few years, investigation into endoscopic spine surgical techniques has erupted with over 250 related publications on the technique in 2020 compared to less than 50 in 2012[37]. The evolution of different techniques within endoscopic spine surgery such as full endoscopy, microendoscopy, and biportal endoscopy has contributed to this tremendous growth, with recent publications exploring efficacy in numerous procedures through the cervical, thoracic, and lumbar spines. Lumbar disc herniation is one of the most common spinal pathologies and numerous randomized controlled trials (RCTs) have shown similar patient pain scores and functional outcomes with microdiscectomy, the gold standard procedure, and endoscopic surgery for lumbar disc herniation[38-40]. A prominent, early clinical trial, by Ruetten *et al*[41] demonstrated similar pain and disability ratings between 178 patients randomly assigned to either endoscopic discectomy or microdiscectomy for lumbar disc herniation. Endoscopic approaches for TLIF have not been extensively studied because endoscopic techniques generally lessen collateral tissue damage and minimize the need for fusion. Moreover, the size of interbody cages used in fusions are usually too large for the endoscopic access channel, thus more expandable cages are being developed for use[37]. Kim *et al*[42] Examined 87 patients who underwent biportal endoscopic TLIF or MIS TLIF and found significantly lower visual analog scale (VAS) scores in the endoscopic group at two months but no differences in fusion or pain scores at later time points. Furthermore, a case series by Kamson *et al*[43] *d*emonstrated significant improvement in VAS scores and patient satisfaction in 85 patients who were elected for an endoscopic TLIF. Due to the lack of RCTs (likely due to prior lack of expandable interbody cages), more research is needed to deem endoscopic techniques effective for TLIF procedures. Endoscopic surgery has also been examined in the context of several other common spinal pathologies and procedures including lumbar spinal stenosis, posterior cervical discectomy and foraminotomy, and spondylolisthesis[44-46]. Many of these studies have found endoscopic techniques to be equivalent to open surgery and other MIS techniques with inconsistent benefits of shorter operative times and hospital length of stay[43,45,46].

Current trends in usage

Although literature examining endoscopic spine surgery has increased globally, the technique is still much more commonly utilized in Asia and Europe compared to the United States[47,50]. A recent study evaluating geographical usage trends in endoscopic spine surgery found that 70.3% of Asian surgeons and 55.2% of non-Asian surgeons utilized endoscopic techniques (P = 0.015). Additionally, Asian surgeons used endoscopic decompression techniques which required extensive training twice as much as non-Asian surgeons[50]. The basis of the significant difference in volume of endoscopic procedures between Asia and the United States/Europe is multifaceted. In a recent minireview, Yoon and Wang supported the statement above and discussed the reasons for the low usage rate of endoscopic spine surgery in the United States: (1) A lack of United States billing codes for endoscopic spine surgery; (2) Poor surgeon reimbursement for endoscopic procedures; (3) A lack of profit/interest for medical device companies; and (4) Philosophical differences in goals for spine surgery[47]. In the United States, it is clear financial motivation from surgeons and medical device companies is towards fusion procedures and not endoscopic techniques[37,47]. Because endoscopic procedures minimize the need for fusion, medical device companies will get less revenue (due to less plates, interbody cages, and screws sold to hospitals), and surgeons will be compensated less making United States adoption extremely challenging.

Another reason for less usage of endoscopic techniques for spinal surgery in the United States is due to a limited number of training and educational programs on the topic. In the United States, there are no formal training programs/fellowships with endoscopic techniques for spinal surgeons[47]. There are occasional cadaver workshops for interested surgeons in the United States, however Kim *et al*[48] found that these workshops simply introduce the instrumentation and basic technique. The workshops do not offer practical guidelines such as diagnostic workup, surgical indications, and specific procedural steps for management of different spinal pathologies with the endoscopic technique. Due to the training/educational behaviors and steep learning curve related to endoscopic techniques in spine surgery, even highly motivated surgeons in the United States face several challenges when attempting to familiarize and implement endoscopic spine techniques into their repertoire. Overall, financial, educational, and training barriers contribute to the limited utilization of endoscopic spine techniques in the United States.

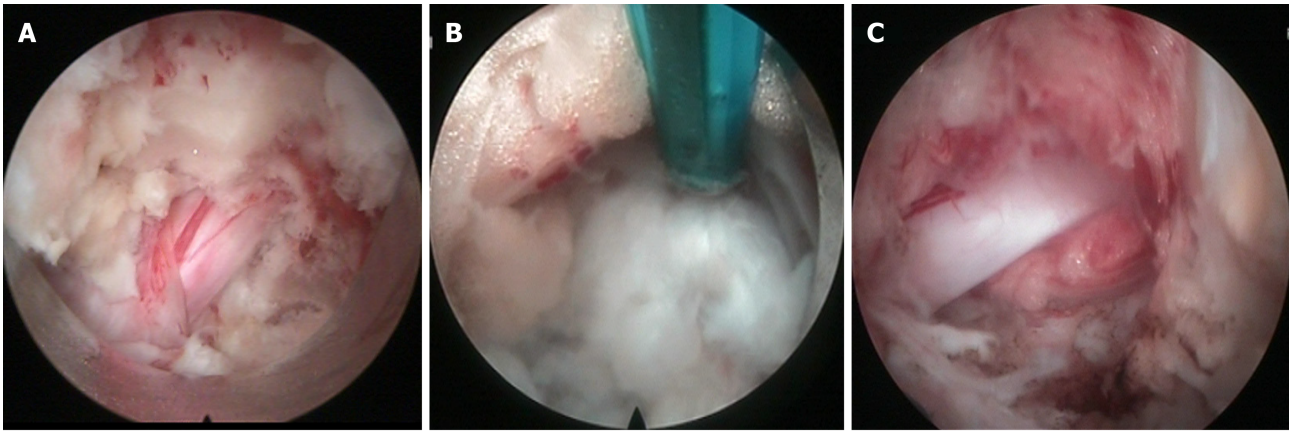

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Figure 3 Direct two-dimensional endoscopic view (top of image as anatomically medial, bottom as lateral, left as cranial, and right as caudal) with dura mater exposed. A: Disc has compressed nerve ventrally; B: Disc irrigated, exposed, and removed to alleviate nerve compression; and C: Nerve has been decompressed.

LIMITATIONS

Although the development of enhanced lighting and visualization techniques are critical to the progression and safety of endoscopic approaches in spine surgery, particularly minimally invasive spine surgery, there are barriers to adoption that do exist. Firstly, most surgeons will experience a steep learning curve when transitioning from traditional open surgery to endoscopic techniques[13]. Secondly, the limited field of view and lack of resolution makes identification of anatomic structures difficult to view. Lastly, disorientation from indirect visualization may result in the surgeon being unable to accommodate orientation and perspective[1]. The transition from traditional open surgery to minimally invasive endoscopic surgery is associated with a steep learning curve. The air-tight and tubular approach requires surgeon manipulation and attention shift from the surgical field to indirect use of two-dimensional monitor viewing, in addition to careful hand–eye coordination[13]. Furthermore, Hirano *et al*[14] described the endoscopic surgical approach to be the opposite of open posterior lumbar decompressions, as microsurgery is done from the outside in, whereas posterior lumbar decompressions are done from the inside out. However, further development of endoscopic instruments may help improve the safety of endoscopic TLIF and reduce the learning curve[4]. In addition, it has been reported that novel surgeons may obtain hands-on training with cadaver simulation when adopting endoscopic surgery for practice[13,50-52].

Aside from the steep learning curve, another common challenge of MIS endoscopic technique is the limited field of view and lack of resolution, therefore making identification of anatomic structures difficult. As anatomical landmarks are absent, there is the possiblity of inadequate exposure during surgery with insufficient decompression, inaccurate placement of cages, and an increased risk of pedicle screw malpositioning[14]. Furthermore, multiple fluoroscopies are required to ensure accurate pedicle screw placement, which may increase the radiation exposure to patients and medical staff[9,14]. Basil *et al*[1] reported anatomical disorientation is due to the optical angle of the endoscopic generally being between 0° to 30° depending on the spinal level at which the endoscope is used. Thus, endoscopes with larger optical angles can lead to greater surgical disorientation because the human eye is accustomed to a 0° optical angle when viewing the world[1,53]. s As the next stages of developments in surgical optical systems occur visualization will improve, helpingmitigate such challenges.

CONCLUSION

Like many other surgical subspecialties in recent years, spine surgery has migrated towards minimally invasive techniques, allowing surgeons to achieve the same goals as they do with open surgery, but with decreased collateral tissue damage and better patient outcomes[13]. Many studies have illustrated adequate functional restoration and decompression of the spine with surgeons utilizing endoscopic techniques[42-47]. Regarding surgical results, the current literature suggests endoscopic techniques are in line with other MIS techniques but not clearly superior. Therefore, more long-term, RCTs comparing endoscopic techniques with other MIS spine techniques are needed to demonstrate additional benefits in the usage of endoscopic techniques. If these studies demonstrate superiority with endoscopic techniques compared to other MIS techniques, then the barriers for adoption of endoscopic techniques in the United States such as medical device company financial motivations and lack of training centers

for endoscopic spine surgery may be overcome. Medical device companies in the United States make a large portion of their money in spine surgery from selling hospitals interbody cages, pedicle screws, and rods used during fusion procedures. Historically, endoscopic spine surgery has achieved decompression while minimizing the need for fusion, thus creating an impediment for adoption in the United States. However, recent technological advancements such as biportal endoscopic surgery and expandable interbody cages have popularized endoscopic TLIF procedures. This may be an avenue to allow medical device companies to profit from selling their instrumentation while enabling better patient outcomes with endoscopic techniques. In summary, due to the migration towards minimally invasive techniques, and the ongoing focus on patient-centered care in spine surgery, it is likely endoscopic techniques will integrate even further into the United States and offer an additional MIS technique for patients and surgeons.

FOOTNOTES

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ORIGINAL ARTICLE

Basic Study

Bridge plating in the setting of radiocarpal instability: Does distal fixation to the second or third metacarpal matter? A cadaveric study

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Abstract

BACKGROUND

Radiocarpal dislocations are rare but potentially devastating injuries. Poorer outcomes are associated with inadequate or lost reduction, such as ulnar translocation, but no consensus exists on the ideal fixation technique. Dorsal bridge plate fixation has been described for various settings in the treatment of complex distal radius fractures and can be fixed distally to the second or third metacarpal, but its application for radiocarpal dislocations has not been established.

AIM

To determine whether distal fixation to the second or third metacarpal matters.

METHODS
Using a cadaveric radiocarpal dislocation model, the effect of distal fixation was studied in two stages: (1) A pilot study that investigated the effect of distal fixation alone; and (2) a more refined study that investigated the effect of described techniques for distal and proximal fixation. Radiographs were measured in various parameters to determine the quality of the reduction achieved.

RESULTS
The pilot study found that focusing on distal fixation alone without changing proximal fixation results in ulnar translocation and volar subluxation when fixing distally to the second metacarpal compared with the third. The second iteration demonstrated that anatomic alignment in coronal and sagittal planes could be achieved with each technique.

CONCLUSION
In a cadaveric radiocarpal dislocation model, anatomic alignment can be maintained with bridge plate fixation to the second metacarpal or the third metacarpal if the described technique is followed. When considering dorsal bridge plate fixation for radiocarpal dislocations, the surgeon is encouraged to understand the nuances of different fixation techniques and how implant design features may influence proximal placement.

Key Words: Wrist; Instability; Bridge plate; Dorsal spanning plate; Radiocarpal dislocation model; Cadaveric study

Core Tip: Radiocarpal dislocations are rare but potentially devastating injuries. Poorer outcomes are associated with inadequate or lost reduction, such as ulnar translocation, but no consensus exists on the ideal fixation technique. Dorsal bridge plate fixation has been described for various settings in the treatment of complex distal radius fractures and can be fixed distally to the second or third metacarpal, but its application for radiocarpal dislocations has not been established. In a cadaveric radiocarpal dislocation model, anatomic alignment can be maintained with bridge plate fixation to the second metacarpal or the third metacarpal if the described technique is followed. When considering dorsal bridge plate fixation for radiocarpal dislocations, the surgeon is encouraged to understand the nuances of different fixation techniques and how implant design features may influence proximal placement.

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INTRODUCTION

Radiocarpal dislocations are uncommon injuries, representing 0.2% of all dislocations[1] with the largest clinical series to date reporting only 27 cases[2]. They occur most frequently after high energy trauma, such as motor vehicle accidents or falls from height. Men in their fourth decade are at highest risk[3,4]. The proposed mechanism of injury is flexion or extension of the radiocarpal joint in combination with a rotational component[2].

Two classifications have been proposed, distinguishing between pure dislocations and those with associated fractures. The Dumontier[2] classification emphasizes the difference between pure radiocarpal dislocations, including those with an avulsion of the tip of the radial styloid (group 1), and those with an associated fracture of the styloid involving more than one third of the scaphoid fossa (group 2). Moneim *et al*[5] describes two types: Type I consists of a pure volar or dorsal dislocation, and type II describes a more complex injury, involving intracarpal fractures, dislocations and more severe ligamentous disruption.

Current published treatment options include pin fixation and external fixation, soft tissue reconstruction, and decompression of neurovascular structures when indicated[2-4]. The most common predictors for a poor outcome include pure ligamentous injuries (Dumontier Group 1 and Moneim Type I), persistent instability and non-anatomic reduction[2]. Primary or secondary ulnar shifting of the

carpus after initial reduction has been reported as a frequent finding associated with poor range of motion and function, especially in Dumontier Group 1 radiocarpal dislocations[2,6] (pure ligamentous injuries). Anatomic reduction and stable fixation, then, are of paramount importance.

The use of dorsal bridge plate fixation for complex distal radius fractures has continued to gain traction in recent years. Relying in part on ligamentotaxis, bridge plate fixation has been advocated for high-energy distal radius fractures[7], those with intraarticular and/or metadiaphyseal comminution[8,9], multiply injured patients with lower extremity trauma who require immediate platform weight-bearing[10], the elderly[11], as well as those in extremis[12,13]. Bridge plate fixation has also been described for lower energy fractures in patients who have a baseline reliance on upper extremity weight bearing assist devices[14,15].

Two major techniques have been described and advocated[8,9,16,17], each with its advantages and disadvantages. Fixation to the third metacarpal may better centralize the distal fragment and carpus with respect to the radius and have certain biomechanical advantages[18] but may also place the extensor tendons at risk[19]. Fixation to the second metacarpal, however, may improve radial height and inclination in certain distal radius fractures and avoid tendon or nerve entrapment[19].

Bridge plate fixation for radiocarpal instability has received some attention recently. Wahl *et al*[20] reported good outcomes with the use of this technique in their retrospective review of 13 patients, using fixation to the third metacarpal in all their cases[20]. Azad *et al*[21] recently shared their results of a cadaveric study and suggested that fixation to the third metacarpal may result in more anatomic alignment. The senior authors of our study (RC Srinivasan and JM Saucedo), however, have routinely used both techniques (distal fixation to the second or third metacarpals) in treating complex distal radius fractures and radiocarpal dislocations, and both techniques appear capable of achieving anatomic reduction and satisfactory clinical results.

Given the rarity of radiocarpal dislocations in the community and in the literature, there appears to be little consensus on which fixation method allows for more anatomic reduction and stable fixation in the setting of radiocarpal instability. To help answer this question, we designed a study to compare distal fixation to the second metacarpal *vs* the third metacarpal in a cadaveric radiocarpal dislocation model. We hypothesized that in a cadaveric model for radiocarpal instability, distal fixation to the third metacarpal and the second metacarpal can equally achieve anatomic alignment.

MATERIALS AND METHODS

Pilot study: Focusing on distal fixation alone

Ten matched trans-humeral cadaveric arms were obtained, whose ages ranged from 25 to 65 years old (mean 48). Four were men and one female. None had a history of previous injury or surgery. Each was examined grossly and radiographically to confirm the absence of anatomic deformity.

Cadaveric models were prepared through a standard dorsal approach to the radiocarpal joint. Under traction and through a dorsal incision over the radiocarpal joint, the dorsal and volar radiocarpal ligaments were transected until both dorsal and volar dislocation could be achieved with manipulation alone (defined by 100% translation of the carpus with respect to the radius on a standard lateral X-ray view) (Figure 1).

Each specimen was matched to itself to minimize confounding variables such as subtle differences in morphology. Each specimen had the plate fixed first to the radial shaft with a single screw through the fourth dorsal compartment. Then, all of the right-side specimens (group A) had the bridge plate fixed first to the second metacarpal. Once alignment was confirmed on fluoroscopy, an additional screw was placed distally and proximally. The plate was then removed from the second metacarpal and then fixed similarly to the third metacarpal with standardized X-rays obtained before and after each intervention. Group B included all of the left-sided specimens and underwent similar treatment except that distal fixation was made to the third metacarpal before the second.

The plate that was used is characterized by a widened center with a cluster of locking screw holes to facilitate fixation of fractures near the articular surface, as its primary design was meant to treat complex distal radius fractures.

Second iteration: Comparison of two described fixation techniques

Based on the results of the pilot study, a second study iteration was designed to more accurately reflect and evaluate the techniques as they were originally described. Two fixation techniques were studied: Distal fixation to the third metacarpal with the plate passed proximally through the floor of the fourth dorsal compartment (3M)[8] and distal fixation to the second metacarpal with the plate passed proximally through the second dorsal compartment (2M)[16]. Because the large cluster of screw holes in the previously used plate (the wide plate, WP) would not permit passage through the second dorsal compartment, a narrow plate (NP) design was used to facilitate passage through the second dorsal compartment.

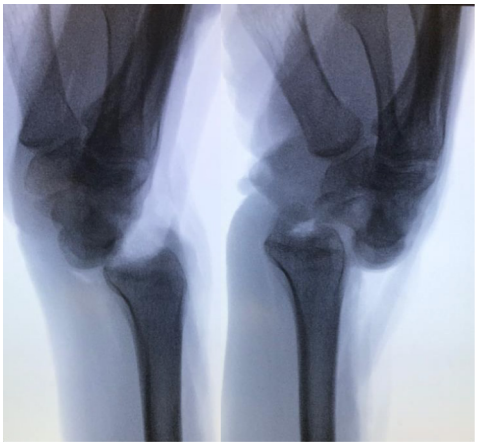

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Figure 1 Lateral fluoroscopic view demonstrating complete radiocarpal instability following transection of dorsal and volar radiocarpal ligaments.

Twelve fresh frozen cadaveric arms were obtained. The age of the specimens ranged from 37 to 85 (average 65.7 years old) and half of the specimens were male. Each was examined grossly and radiographically to confirm the absence of anatomic deformity. Each cadaver radiocarpal dislocation model was prepared in the manner described above.

For the 3M method, the WP is fixed to the third metacarpal distally and proximally to the radial shaft through the fourth dorsal compartment[17]. Our previous incision used to render the wrist unstable was used to expose the third and fourth dorsal compartments. The extensor pollicis longus was transposed, and the floor of the fourth dorsal compartment was elevated. A third incision over the dorsal shaft of the radius was made, and the WP was passed in retrograde fashion. While holding the radiocarpal joint reduced, the plate was secured under fluoroscopic guidance to the radius midshaft with 3.5 locking screws, and to the center of the third metacarpal with 2.7 locking screws. Fixation was obtained first with a single screw proximally and distally. Once reduction of the radiocarpal joint was confirmed by C-arm, a second screw was placed proximally and distally.

For the 2M method, the NP is fixed to the second metacarpal distally and proximally to the radial shaft through the second dorsal compartment[16]. The plate typically sits more radial on the proximal shaft than is seen with the 3M method. An incision was made over the second metacarpal, and the interval between the extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB) tendon insertions was developed. A second incision was made proximal to the muscle bellies of the abductor pollicis longus and extensor pollicis brevis. The interval between the ECRL and ECRB was developed and the radial diaphysis exposed. The NP was passed from distal to proximal. While holding the radiocarpal joint reduced, the plate was secured to the second metacarpal with 2.7 mm screws and then to the radial diaphysis with 3.2 mm screws. Fixation was obtained first with a single screw proximally and distally. Once reduction of the radiocarpal joint was confirmed by C-arm, a second screw was placed proximally and distally.

The cadavers and the WP were provided through a research grant awarded by Acumed (Hillsborough, Oregon). The NP was provided on loan by TriMed (Valencia, California). Plates and screws were returned at the conclusion of the study. Surgical indications for bridge plating in the setting of radiocarpal dislocations were not included in the 510k for Acumed or TriMed at the time of this writing.

Radiographic imaging

Radiographic imaging with standardized posterior-anterior (PA) and lateral radiographs were obtained prior to the dislocation procedure and after application of the plates. A true PA view of the distal radioulnar joint was obtained with the beam perpendicular to the distal radioulnar joint (DRUJ) and was defined by clear visualization of the ulnar head and sigmoid notch. Lateral views of the radiocarpal joint were standardized by using a 10 degree lateral tilt to optimize the lunate fossa and defined by overlap of the distal pole of the scaphoid over the pisiform[22].

Specimens in the pilot study were measured before and after each intervention using two indices: Gilula's lunate uncovering technique to measure the quality of radiocarpal reduction in the coronal plane (*i.e.*, the amount of radio-ulnar translation) and the best-fit circle technique for sagittal alignment (*i.e.*, volar-dorsal translation).

Gilula's lunate uncovering has been proposed as the most sensitive method to measure ulnar translation of the carpus[23-25]. It measures the relationship between the total width of the lunate and the portion that is not covered by the radius lunate fossa. This calculation is demonstrated in Figure 2.

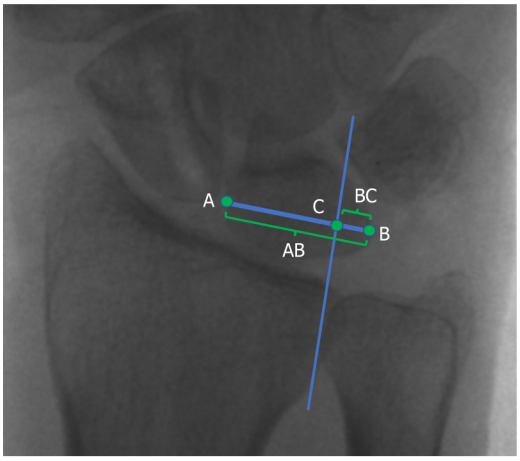

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Figure 2 Gilula's technique for measuring ulnar translocation through lunate uncovering. A line is drawn along the transverse axis of the lunate, from the farthest radial point at the mid-portion of the lunate (point A) to its ulnar-most corner (point B). The long axis of the radius is found and a parallel line at the ulnar corner of the radius is drawn until the A-B line is transected (point C). The distance between B and C is divided by the distance between A and B (G = BC/AC) [23].

Lateral views were evaluated to assess radiocarpal reduction. Fitting a circle to the contour of the distal radius and next to the proximal pole of the lunate should result in concentric articular contours. If that relationship was altered, we considered the radiolunate joint noncongruent[26] and defined each state as either reduced or subluxated (Figure 3). Based on what was learned in the Pilot Study, two additional measurements (Chamay and Bouman) were made in the second iteration to further evaluate coronal alignment[23-25]. They are demonstrated and described in Figure 4.

Respective measurements were made before and after plate placement using OsiriX Lite (Pixmeo SARL, Switzerland).

Statistical analysis

Wollstein *et al*[23] found that the average physiologic lunate overhang with the wrist in neutral deviation ranged from 36% to 44% (radial shaft aligned with the third metacarpal). Lunate overhang greater than 50% was defined as pathologic. A power analysis showed that five patients in each group were needed to find a 6% difference between values with an 80% power and a 95% confidence level.

Pilot study

Comparison of lunate overhang was calculated for the Group A method and Group B method using the nonparametric Mann-Whitney U test, independent sample *t*-test, and parametric paired samples *t*-test. All analyses were done using SPSS (Chicago, IL) and significance assigned as $P < 0.05$.

Comparison of 2M and 3M techniques

The mean, median, range, minimum and maximum were calculated for each of the three scores (Chamay, Gilula, and Bouman) preoperatively and postoperatively for the 2M and 3M plating techniques. The Shapiro Wilk test was used to examine normality of distribution and all scores were found to have a normal distribution. Next, the paired sample *t*-test was used to compare the means of the preoperative and postoperatively scores for all subjects. Similarly, paired sample *t*-tests were used to compare the means of the postoperative scores of the 2M and 3M plating techniques. Lateral views were evaluated and described as either reduced or subluxated.

RESULTS

Pilot study

Lunate overhang (Gilula) was 0.29 ± 0.12 mm preoperatively, 0.78 ± 0.20 mm when fixed distally to the second metacarpal, and 0.44 ± 0.19 mm, when fixed distally to the third metacarpal. Paired samples t-test analysis demonstrated a significant difference ($P = 0.001$) between second and third metacarpal fixation for lunate overhang, with more anatomic alignment associated with third metacarpal plating (Figure 5A).

In addition, we found volar subluxation of the radiocarpal joint in 5 out of 10 specimens (Figure 5B). Each of those cases had the plate applied from the floor of the fourth dorsal compartment to the second metacarpal. None of the specimens that had been plated from the floor of the fourth dorsal

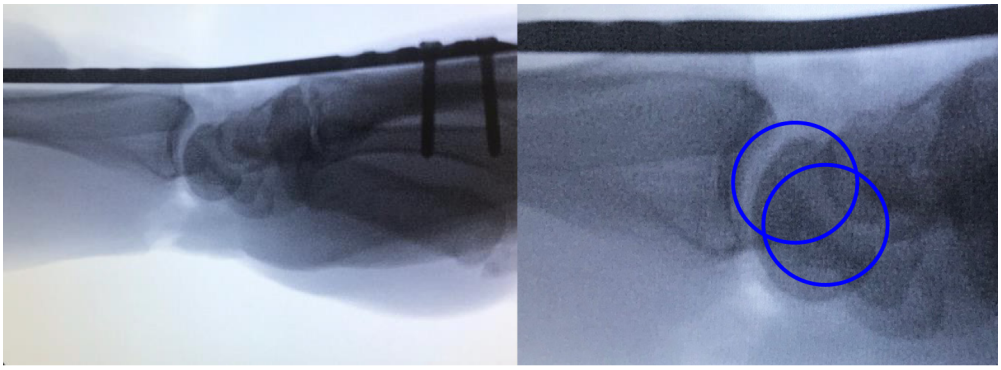

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Figure 3 Concentric circle technique for assessing radiolunate joint alignment on the lateral view. Subluxation or inadequate reduction is demonstrated by the lack of concentricity.

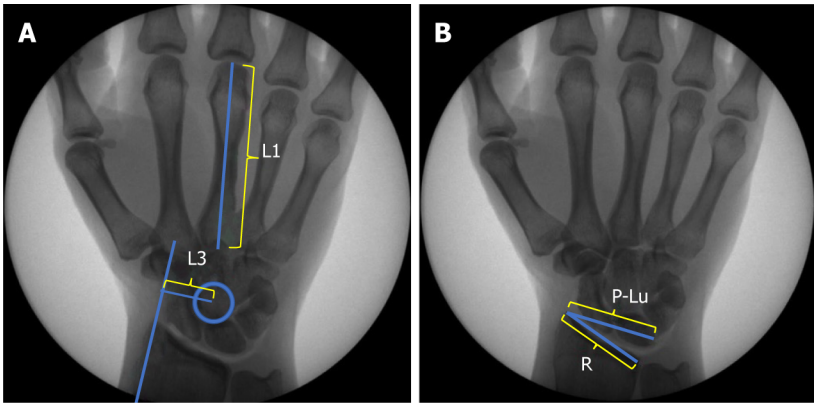

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Figure 4 Chamay and Bouman techniques for measuring ulnar translocation. A: Chamay's index is calculated by dividing the distance between a line parallel to the axis of the radius passing through the radial styloid process and the center of rotation of the capitate (L3) and the length of the long finger metacarpal (L1)[25]; B: Bouman's index is calculated by dividing the length of the distal articular surface of the radius (R) by the distance between the radius styloid process and the proximal ulnar corner of the lunate (P-Lu)[25].

compartment to the third metacarpal had volar subluxation of the lunate.

Comparison of 2M and 3M techniques

The pre-operative Gilula lunate overhang measurement was 0.32 ± 0.33 mm with a postoperative measurement of 0.4 ± 0.51 mm and 0.33 ± 0.49 mm for the 2M and 3M techniques, respectively. The preoperative Chamay measurement was 0.27 ± 0.11 mm. The postoperative Chamay measurement was 0.25 ± 0.07 mm and 0.27 ± 0.15 mm for the 2M and 3M techniques, respectively. The Bouman measurements were 0.98 ± 0.37 mm preoperatively and for the postoperative measurements for the 2M and 3M techniques, they were 1.02 ± 0.75 and 1.00 ± 0.44, respectively (Table 1).

Bridge plating from the second dorsal compartment to the second metacarpal (2M) and from the fourth dorsal compartment to the third metacarpal (3M), resulted in no statistically significant differences in radiocarpal alignment compared to pre-dislocation status, according to the indices of Gilula, Chamay and Bouman, suggesting that each technique could achieve anatomic coronal alignment (Table 2 and Figure 6).

In all specimens (2M and 3M), lateral alignment was found to be anatomic using the best-fit circle technique.

DISCUSSION

While there is no consensus for the best fixation strategy for radiocarpal dislocations, it is generally understood that poorer outcomes are associated with inadequate or lost reduction, such as ulnar translocation. It stands to reason, then that anatomic reduction and stable fixation are essential, though not always sufficient, to obtaining a satisfactory clinical outcome. Bridge plating for distal radius fractures has been well-established through multiple biomechanical and clinical studies[26], but its use

Table 1 Differences in coronal alignment between distal fixation to the second and to the third metacarpal, measured in millimeters

Variable	Mean	Median	Maximum	Minimum	Range
Preoperative Gilula score	0.32	0.34	0.48	0.15	0.33
2M Gilula score	0.4	0.38	0.68	0.17	0.51
3M Gilula score	0.33	0.32	0.59	0.1	0.49
Preoperative Chamay score	0.27	0.28	0.32	0.21	0.11
2M Chamay score	0.28	0.28	0.33	0.26	0.07
3M Chamay score	0.27	0.27	0.34	0.19	0.15
Preoperative Bouman score	0.98	0.95	1.2	0.83	0.37
2M Bouman score	1.02	1.04	1.39	0.64	0.75
3M Bouman score	1.00	0.98	1.23	0.79	0.44

2M: Second metacarpal fixation technique; 3M: Third metacarpal fixation technique.

Table 2 Differences in coronal alignment before and after fixation to the second and third metacarpals (*P* values)

	Chamay	Gilula	Bouman
2M technique	0.199	0.065	0.462
3M technique	0.408	0.846	0.578

2M: Second metacarpal fixation technique; 3M: Third metacarpal fixation technique.

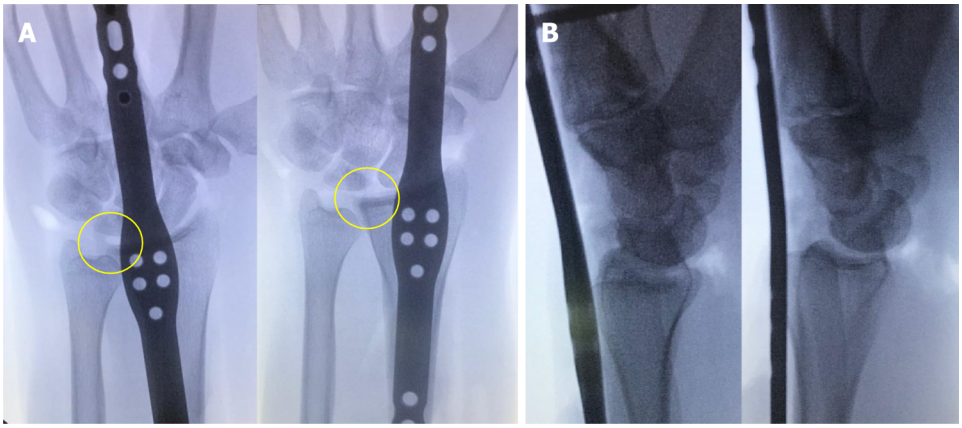

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Figure 5 The effect of focusing on distal fixation alone with proximal bridge plate placement through the fourth dorsal compartment. A: Posterior-anterior view of third metacarpal fixation (left) and second metacarpal fixation (right) demonstrates ulnar translocation of the carpus (even radial translation within the fourth dorsal compartment is insufficient to align the radiocarpal joint); B: Lateral view demonstrates volar subluxation of the radiocarpal joint, which was observed in half of the pilot study specimens with second metacarpal distal fixation (third metacarpal left, second metacarpal right).

in radiocarpal dislocations is less understood.

The present study demonstrates that anatomic alignment is achievable with the two most commonly cited techniques for bridge plate fixation–distal fixation to the second metacarpal through the second dorsal compartment and distal fixation to the third metacarpal through the floor of the fourth dorsal compartment–if the techniques are followed carefully.

In addition to those findings, we believe that the Pilot Study results and subsequent analysis are just as relevant. The initial study exclusively used a plate that includes a cluster of screw holes designed to allow for supplemental periarticular fixation without compromising resistance to fatigability across the wrist joint. This design feature, however, results in a wider section of the plate that does not easily facilitate passage through the second dorsal compartment. In testing the concept of distal fixation to the second metacarpal, proximal fixation was essentially set at a single point, leading to mal-reduction of

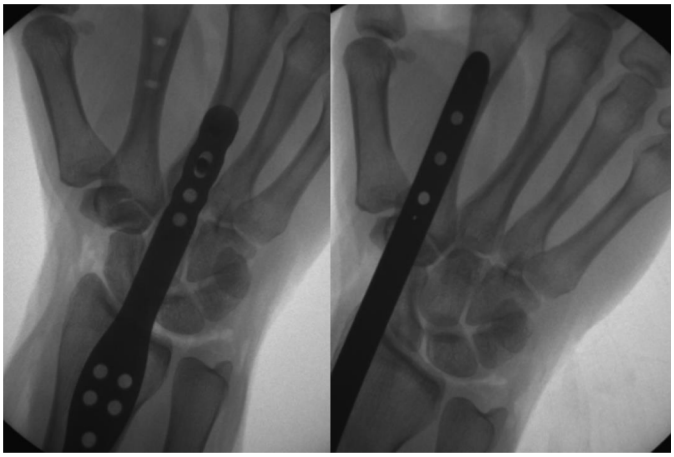

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Figure 6 Anatomic radiocarpal alignment was achieved with each the second metacarpal fixation technique (2M) and third metacarpal fixation technique (3M).

the radiocarpal joint when fixed to the second metacarpal *vs* the third metacarpal, which included ulnar translocation in nearly every specimen and volar subluxation at least 50 percent of the time. This is consistent with the results found by Azad *et al*[21] and may at least in part explain their findings. Another design feature, six degrees of dorsal bend, may have contributed to the volar subluxation, but this was found in only 50 percent of the Pilot Study specimens, so its significance is unclear.

The results of the pilot study were carefully studied and led the authors to realize that the second metacarpal fixation model did not accurately reflect the technique as it was originally described[16]. The 2M technique is known for its fixation to the second metacarpal, but it requires passage through the second dorsal compartment and more radial placement proximally on the radial shaft between the ECRB and ECRL tendons in order to maintain alignment. Fixation to the third metacarpal generally assumes passage through the floor of the fourth dorsal compartment and proximal fixation to the more central aspect of the radial shaft[8,17].

Comparing our methods to those of Azad *et al*[21] reveals that our models and techniques may have differed in significant ways and may explain the different results. Their model appears to have removed the extensor retinaculum in addition to the "dorsal radiocarpal capsuloligamentous structures." Though they do not specify that the retinaculum was removed, the clinical photo in their article seems to suggest that this structure (and landmark) has been removed, which might obscure proper proximal placement of the plate when performing the 2M technique to the second extensor compartment. In addition, the authors do not specify the nuances of proximal positioning of the plate on the radius, which may introduce the opportunity for coronal and even sagittal malreduction, as we found in our pilot study.

There are advantages and disadvantages to each approach, and advocates have several studies to cite in support of their preferred technique, such as a potential protective advantage against tendon entrapment for the 2M technique[19] or a potential biomechanical advantage for the 3M technique[18].

Based on their collective experience and the results of this study, however, the senior authors encourage surgeons to be comfortable with both techniques, as each may offer different advantages and disadvantages in different scenarios. A larger patient with a heavier arm, for example, may fare better with a larger plate placed along the central axis of the radiocarpal joint and fixed to the third metacarpal. Similarly, in the setting of an unstable fracture pattern that requires multiple fragment-specific implants and supplemental bridge plate fixation, the surgeon may find it easier to pass the plate through the second dorsal compartment to the second metacarpal. And finally, anatomic variations among patients may at times require small changes in technique and bridge plate application.

Modification of the 3M technique in which we attempted to fix the wider plate to the second metacarpal from the floor of the fourth dorsal compartment consistently resulted in less anatomic reduction of the radiocarpal joint in our cadaveric model with observed ulnar translocation, relative supination of the carpus and volar subluxation, even when trying to translate the plate radially within the fourth dorsal compartment (Figure 5A). Such a finding may not be readily observed in the setting of a distal radius fracture in which the ligaments are intact, but our cadaveric model suggests that this modification of the 3M technique may result in non-anatomic alignment and would not be advised.

When choosing to bridge plate a distal radius fracture or radiocarpal dislocation, the treating surgeon is encouraged to carefully follow the technique as it is described by its proponents and understand the design features of their implant and the implications they may have for their chosen technique. Likewise, the surgeon must recognize that anatomic reduction is ultimately the surgeon's responsibility and should maintain a critical eye for coronal and sagittal alignment, making adjustments as needed to match their patients' normal anatomy. We suggest that obtaining preoperative contralateral images may

help with this assessment, in addition to the various parameters that were used in this study (*i.e.*, Gilula's lunate uncovering and best-fit circles).

Limitations of this study include the use of an unvalidated cadaveric model of radiocarpal instability. Our model represents a completely unstable joint where the radiocarpal joint capsule and the ligaments have been transected completely. Though this may or may not accurately reflect the true nature of a radiocarpal dislocation *in vivo*, our model represents an extreme version of instability and demonstrates that in the setting of complete instability, both the 2M and 3M techniques appear to permit anatomic reduction. However, it is possible that *in vivo*, one technique may more easily facilitate anatomic reduction than the other, perhaps lending some credence to the findings of Azad *et al*[21], but without a consistent validated radiocarpal dislocation model or clinical studies, we cannot answer that question at this time.

Another potential limitation of this study is that the biomechanical strength of each technique was not tested. Therefore, we cannot comment on whether one technique is better than the other with regards to the stability of the construct; however, the aim of this study was to determine whether anatomic alignment could be achieved regardless of distal fixation, not biomechanical advantage. Compared to intramedullary wires and external fixator placement, bridge plating offers the advantage of maintaining an anatomic reduction throughout the postoperative course given that fixation is more robust and closer to the joint axis. While it has been well studied in biomechanical models of distal radius fractures[26], there is not enough data exploring its use in the setting of radiocarpal dislocations[20,21]. Biomechanical strength may either be extrapolated from the study by Alluri *et al*[18] or may represent an area of future research.

Further studies will be needed to advance in the understanding of the intricacies of these rare but devastating injuries. The creation of a validated cadaveric model would indeed enable us to compare the biomechanical advantages of one technique over another, as well as to test dorsal spanning plating *vs* other options such as external fixation or the use of Kirschner wires. Ultimately, *in vivo* studies will be necessary to evaluate the outcome in a real scenario.

CONCLUSION

In our cadaveric radiocarpal dislocation model, we found that bridge plating with distal fixation to the third metacarpal may facilitate more anatomic alignment if fixation to the radius through the fourth dorsal compartment is required. However, anatomic alignment and stable fixation can also be achieved with distal fixation to the second metacarpal through the floor of the second dorsal compartment if the technique is followed appropriately. When considering dorsal bridge plate fixation for radiocarpal dislocations, the surgeon is encouraged to understand the nuances of different fixation techniques and how implant design features may influence placement.

ARTICLE HIGHLIGHTS

Research background

Dorsal bridge plate fixation has been described for various settings in the treatment of complex distal radius fractures and can be fixed distally to the second or third metacarpal, but its application for radiocarpal dislocations has not been established.

Research motivation

To determine whether distal fixation to the second or third metacarpal matters.

Research objectives

Using a cadaveric radiocarpal dislocation model, the effect of distal fixation was studied.

Research methods

Two stages were considered: (1) a pilot study that investigated the effect of distal fixation alone; and (2) a more refined study that investigated the effect of described techniques for distal and proximal fixation. Radiographs were measured in various parameters to determine the quality of the reduction achieved.

Research results

The pilot study found that focusing on distal fixation alone without changing proximal fixation results in ulnar translocation and volar subluxation when fixing distally to the second metacarpal compared with the third. The second iteration demonstrated that anatomic alignment in coronal and sagittal planes could be achieved with each technique.

Research conclusions

Anatomic alignment can be maintained with bridge plate fixation to the second metacarpal or the third metacarpal if the described technique is followed. When considering dorsal bridge plate fixation for radiocarpal dislocations, the surgeon is encouraged to understand the nuances of different fixation techniques and how implant design features may influence proximal placement.

Research perspectives

Further studies will be needed to advance in the understanding of the intricacies of these rare but devastating injuries. The creation of a validated cadaveric model would indeed enable us to compare the biomechanical advantages of one technique over another, as well as to test dorsal spanning plating *vs* other options such as external fixation or the use of Kirschner wires. Ultimately, *in vivo* studies will be necessary to evaluate the outcome in a real scenario.

FOOTNOTES

Author contributions: Tabeayo E, Rodriguez-Merchan EC, and Srinivasan RC designed the research; Tabeayo E, Saucedo JM and Rockwood J performed the research; Karamanos E analyzed the data; Tabeayo E, Shah AR and Karamanos E wrote the paper.

Conflict-of-interest statement: Tabeayo E, Saucedo JM and Rockwood J performed the research. The cadavers and the wide plate were provided to them through a research grant awarded by Acumed (Hillsborough, Oregon). The narrow plate was provided to them on loan by TriMed (Valencia, California). Plates and screws were returned at the conclusion of the study. Karamanos E, Rodriguez-Merchan EC, Shah AR, and Srinivasan RC have no conflict of interest.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Clinical outcomes of cemented distal femur replacements with all-polyethylene tibial components for oncologic indications

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Abstract

BACKGROUND

Endoprosthetic distal femoral replacement (DFR) is a well-established salvage procedure following resection of malignant tumors within the distal femur. Use of an all-polyethylene tibial (APT) component is cost-effective and avoids failure due to locking-mechanism issues and backside wear, but limits modularity and the option for late liner exchange. Due to a paucity of literature we sought to answer three questions: (1) What are the most common modes of implant failure for patients undergoing cemented DFR with APT for oncologic indications? (2) What is the survivorship, rate of all-cause reoperation, and rate of revision for aseptic loosening of these implants? And (3) Is there a difference in implant survivorship or patient demographics between cemented DFRs with APT performed as a primary reconstruction *vs* those performed as a revision procedure?

AIM

To assess outcomes of cemented DFRs with APT components used for oncologic indications.

METHODS

After Institutional Review Board approval, a retrospective review of consecutive patients who underwent DFR between December 2000 to September 2020 was performed using a single-institutional database. Inclusion criteria consisted of all patients who underwent DFR with a GMRS® (Global Modular Replacement System, Stryker, Kalamazoo, MI, United States) cemented distal femoral endoprosthesis and APT component for an oncologic indication. Patients

undergoing DFR for non-oncologic indications and patients with metal-backed tibial components were excluded. Implant failure was recorded using Henderson's classification and survivorship was reported using a competing risks analysis.

RESULTS

55 DFRs (55 patients) with an average age of 50.9 ± 20.7 years and average body mass index of 29.7 ± 8.3 kg/m^2 were followed for 38.8 ± 54.9 mo (range 0.2-208.4). Of these, 60.0% were female and 52.7% were white. The majority of DFRs with APT in this cohort were indicated for oncologic diagnoses of osteogenic sarcoma (n = 22, 40.0%), giant cell tumor (n = 9, 16.4%), and metastatic carcinoma (n = 8, 14.6%). DFR with APT implantation was performed as a primary procedure in 29 patients (52.7%) and a revision procedure in 26 patients (47.3%). Overall, twenty patients (36.4%) experienced a postoperative complication requiring reoperation. The primary modes of implant failure included Henderson Type 1 (soft tissue failure, n = 6, 10.9%), Type 2 (aseptic loosening, n = 5, 9.1%), and Type 4 (infection, n = 6, 10.9%). There were no significant differences in patient demographics or rates of postoperative complications between the primary procedure and revision procedure subgroups. In total, 12 patients (21.8%) required a revision while 20 patients (36.4%) required a reoperation, resulting in three-year cumulative incidences of 24.0% (95%CI 9.9%-41.4%) and 47.2% (95%CI 27.5%-64.5%), respectively.

CONCLUSION

This study demonstrates modest short-term survivorship following cemented DFR with APT components for oncologic indications. Soft tissue failure and endoprosthetic infection were the most common postoperative complications in our cohort.

Key Words: Distal femoral replacement; Modular; Revision; Dislocation; Oncologic

Core Tip: The current study demonstrates modest short-term survivorship following cemented distal femoral replacement with all-polyethylene tibial components for oncologic indications. Approximately one third of patients experienced a postoperative complication. The most common modes of implant failure were soft tissue failure and endoprosthetic infection.

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INTRODUCTION

Background

Endoprosthetic reconstruction of the distal femur has been used as a limb-salvage procedure to treat oncologic processes of the distal femur for nearly five decades[1], and is currently considered standard of practice for this indication. Improvements in design, such as a rotating hinge mechanism and ongrowth collars adjacent to the femoral cut surface, have improved survivorship with regards to aseptic loosening, and are now included in most modern systems[2-4]. However, implant design and research regarding fixation has focused primarily on the femoral side[5-7].

Rationale

Metal-backed and all-polyethylene tibial components are available, both of which can be fixed to the bone with fully cemented, hybrid, or in some cases cementless fashion. However, there is a paucity of literature examining the survivorship of distal femoral replacements (DFRs) with respect to the type of tibial component or fixation used[8,9]. Furthermore, the majority of available studies fail to describe the type of tibial component or fixation used[10,11]. Therefore, the purpose of this study is to assess outcomes of cemented DFRs with all-polyethylene tibia (APT) components used for oncologic indications.

Specifically, we sought to answer the following research questions: (1) What are the most common modes of implant failure for patients undergoing cemented DFR with APT for oncologic indications? (2) What is the survivorship, rate of all-cause reoperation, and rate of revision for aseptic loosening of these implants? and (3) Is there a difference in implant survivorship or patient demographics between cemented DFRs with APT performed as a primary reconstruction *vs* those performed as a revision procedure?

MATERIALS AND METHODS

Study design and participants

After Institutional Review Board approval (IRB HS-20-00396), a retrospective review of consecutive patients who underwent DFR between December 2000 to September 2020 was performed using a single-institutional database. The DFR was performed either as the primary treatment for the disease in question, or as a revision of a previous failed surgery (indications included recurrence, fracture, *etc*.). We then defined reoperation as any subsequent procedure, including manipulation under anesthesia, that was performed after placement of the DFR. Revision of the DFR was defined as a subsequent procedure which specifically required exchange or removal of femoral or tibial components. Inclusion criteria consisted of all patients who underwent DFR with a GMRS® (Global Modular Replacement System, Stryker, Kalamazoo, MI, United States) cemented distal femoral endoprosthesis and APT component for an oncologic indication. Patients were excluded if undergoing DFR for non-oncologic indications or if a different implant design was used. Patients were then stratified into two groups based on whether the index procedure was a primary reconstruction or a revision of a previous DFR. Patients who had undergone previous incisional biopsies or arthroscopic procedures without reconstruction on the operative limb prior to DFR implantation were classified in the primary reconstruction cohort.

Thorough review of patient medical records and operative reports was performed to obtain patient demographic information including comorbidities, age at the time of surgery, sex, race/ethnicity, body mass index (BMI), and American Society of Anesthesiologists score. Operative reports were reviewed to obtain surgical variables including the indication for surgery, a comprehensive surgical history of the operative limb, surgical approach, implants utilized, and operative time. The primary outcome was implant survivorship, with all-cause reoperation and revision total knee arthroplasty as endpoints. Given the primary purpose of the present study was to characterize early complications and implant longevity in the setting of limb-salvage, functional and patient-reported outcome measures were not collected.

Implant design

The Stryker GMRS® (Global Modular Replacement System, Stryker, Kalamazoo, MI, United States) was utilized for all cases in this series. This system is designed to assist in the reconstruction of large segmental and osteoarticular defects about the knee joint, particularly in the setting of tumors, previously failed arthroplasty, and traumatic injury. In this system, the standard distal femoral components can be paired with either a modular rotating-hinge tibial baseplate or APT component, the latter of which was used selectively in the present cohort (Figure 1). Multiple cemented stem options are available, including straight, curved, and long curved geometries, both with and without extra-cortical porous-coated intercalated body sections. This construct can be further customized with the use of extension pieces, available in over a dozen sizes, for the optimization of leg length.

Surgical technique

Medial and lateral parapatellar approaches were utilized based upon previous biopsy incisions and location of the neoplasm. Following oncologic resection, the femur and tibia were prepared using conventional jigs and reamers, and the femur was reamed in a sequential manner to accommodate the appropriate stem diameter and length. Trial implants were inserted to assess appropriate range of motion, limb length, and patellar tracking prior to insertion of the final implant. Polymethylmethacrylate cement was used for fixation in all cases.

Clinical follow-up

Each patient's clinical course was followed in detail to characterize postoperative complications and the need for reoperations or revision surgery. Given the complex patient demographics, we decided to not have a minimum follow-up in order to capture all patients who underwent this reconstruction. No follow-up was chosen over the conventional two-year minimum to capture early postoperative complications in this high-risk cohort of patients undergoing limb-salvage procedures, especially those with metastatic disease or prior failed reconstruction. Following the index procedure, any procedure on the affected limb that did not involve removal or alteration of the endoprosthesis was classified as a reoperation. Revision procedures were defined as any surgery involving removal or replacement of any prosthetic component. Implant failure was categorized based on the Henderson classification of failure

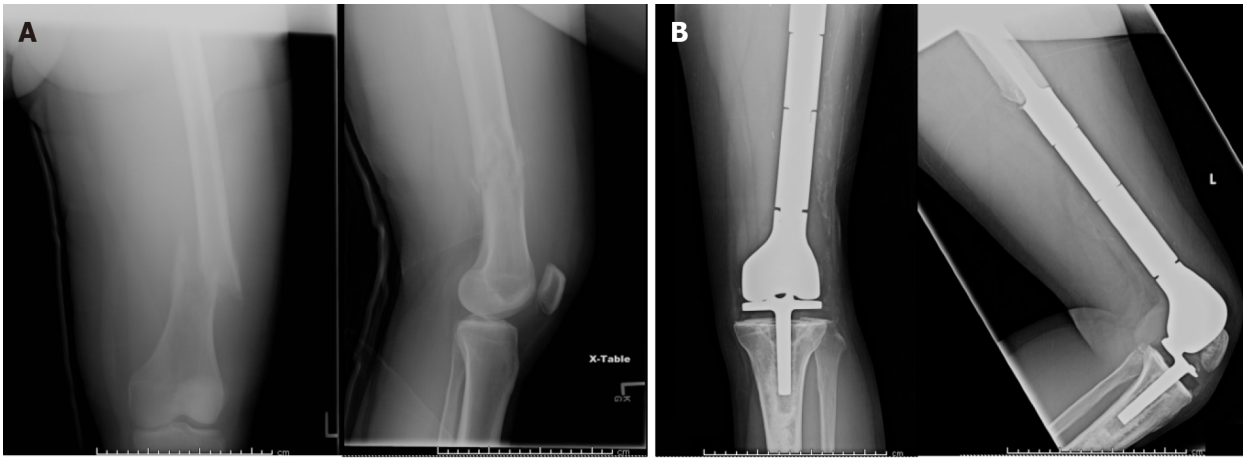

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Figure 1 Radiographs of a 28-year-old male patient demonstrating a pathologic fracture of the distal third of the left femoral diaphysis. A: Preoperative anteroposterior and lateral radiographs prior to reconstruction; B: Following left distal femoral replacement with use of an all-polyethylene tibial component.

of limb salvage after reconstructive surgery for bone tumors[12].

Patient demographics and operative variables

In total, 92 patients were identified during the study period and screened for inclusion. Eleven patients (12.0%) with a metal-backed tibial baseplate and 26 patients (28.3%) who underwent DFR for a non-oncologic indication were excluded, leaving 55 patients (59.8%) who were included in the final analysis. The mean age of the cohort was 50.9 ± 20.7 years (range, 16-88 years) and mean BMI was 29.7 ± 8.3 kg/m^2 (range, 16.4-52.9). The average follow-up of the study cohort was 38.8 ± 54.9 mo (range 0.2-208.4 mo), with a total of 21 patients (38.2%) possessing a minimum follow-up of 2 years (Table 1).

DFR with APT implantation was performed as a primary procedure in 29 patients (52.7%) and a revision procedure in 26 patients (47.3%), with a median operative time of 178 minutes across the entire cohort. For the 26 patients who underwent DFR with APT implantation as a revision procedure, the average number of previous surgeries on the affected limb was 2.0 ± 1.3 (range 1-5) (Table 2). The primary procedures for the revision were as follows: distal femoral replacement[12], open reduction internal fixation for pathologic fracture[6], Cryoablation +/- curettage[6], and soft tissue resection[2] (Table 3). The majority of DFRs with APT in this cohort were indicated for oncologic diagnoses of osteogenic sarcoma (n = 22, 40.0%), giant cell tumor (n = 9, 16.4%), and metastatic carcinoma (n = 8, 14.6%) (Table 2).

Statistical analysis

Statistical analyses were performed using SPSS version 26 (IBM, Armonk, New York, United States). Patient demographics, operative variables, and postoperative complications are presented as means or percentages with standard deviations or ranges where appropriate. Univariate analyses were performed to compare differences between groups using the Mann-Whitney-*U* test for continuous variables and Chi-square test for categorical variables or Fisher's exact test where appropriate. Competing risk analyses were performed to evaluate the cumulative incidence of all-cause reoperation, need for revision surgery, and patient death. Competing risk analysis was conducted using the survival[13,14] and cmprsk[15] function within R (R Core Team, 2021 packages)[16]. Figure 2 and Figure 3 were produced using the package ggplot2[17,18].

RESULTS

Modes of implant failure (Henderson classification)

In total, 20 patients (36.4%) experienced a postoperative complication requiring reoperation (Figure 4). The indications for the 26 reoperations were the following: Mechanical failure[11], non-union of prior pathological fracture[7], tumor progression[3], definitive management of a prior open reduction internal fixation for a pathologic fracture[2], local recurrence[1], infection[1], and soft tissue failure[1] (Table 4). Of these 20 cases requiring reoperation, 7 patients (12.7%) required only one reoperation, 2 patients (3.6%) required 2 reoperations, 4 patients (7.3%) required 3 reoperations, and 7 patients (12.7%) required 4+ reoperations. The primary modes of implant failure in this cohort according to Henderson's classification included Type 1 (soft tissue failure, n = 6, 10.9%), Type 2 (aseptic loosening, n = 5, 9.1%), and

Table 1 Patient demographics of the study cohort, including age, gender, race/ethnicity, American Society of Anesthesiologists score, body mass index, and length of follow-up, *n* (%)

Demographic variable	Value
Age (mean ± SD)	50.9 ± 20.7 yr
Gender	
Male	22 (40.0)
Female	33 (60.0)
Race/Ethnicity	
White	29 (52.7)
Hispanic or Latino	9 (16.4)
Black	4 (7.3)
Asian	5 (9.1)
Other	8 (14.5)
ASA score	
1	10 (18.2)
2	21 (38.2)
3	21 (38.2)
4	3 (5.5)
Body mass index (mean ± SD)	29.7 ± 8.3 kg/m^2
Follow-up (mean ± SD)	38.8 ± 54.9 mo

ASA: American Society of Anesthesiologists.

Type 4 (infection, n = 6, 10.9%) (Table 2). Of the 6 patients with a soft tissue failure, 3 were due to arthrofibrosis, 2 due to extensor mechanism failures, and one was due to wound dehiscence. Regarding the patients who failed due to infection, none of the individuals were on chemotherapy when infection was identified. Finally, local recurrence of the primary bone tumor occurred in one patient who was diagnosed with a "neoplasm of unspecified behavior" and was managed with radical resection at 13.2 mo (Henderson Type 5).

Of the five patients who required reoperation for soft tissue failure (Henderson Type 1), two patients experienced arthrofibrosis requiring manipulation under anesthesia with lysis of adhesions at 3.3 and 4.0 mo postoperatively, two patients required extensor mechanism repair for postoperative falls at 14.5 and 19.7 mo postoperatively, and one patient required multiple flaps for soft tissue reconstruction at 6.8 mo postoperatively. All six patients who underwent reoperation for infection (Henderson Type 4) were managed with serial irrigation and debridement procedures (mean 2.2 procedures, range 1-5), with two patients requiring antibiotic spacer placement and three patients undergoing soft tissue reconstruction at the time of reoperation. None of these patients required amputation.

Additionally, two patients required revision surgery for corrosion and metal wear debris at 32.5 mo and 99.5 mo postoperatively (Type 3). Two cases were complicated by deep peroneal nerve palsy, which were managed nonoperatively with ankle-foot orthoses. There were no identified cases for which periprosthetic fracture was the primary indication for revision surgery with the use of these constructs.

Competing risks analysis

Competing risks analysis depicting the need for any revision operation (requiring exchange of either the femoral or tibial component), any reoperation, and patient death were plotted (Figure 3). In total, 12 patients (21.8%) required a revision, resulting in one- and three-year cumulative incidence of 14.6% (95%CI 5.7%-27.4%) and 24.0% (95%CI 9.9%-41.4%), respectively, with all-cause revision as the endpoint. Additionally, 20 patients (36.4%) required reoperation, resulting in one- and three-year cumulative incidences of 26.1% (95%CI 14.2%-39.7%) and 47.2% (95%CI 27.5%-64.5%), respectively, with all-cause reoperation as the endpoint. At final follow-up, one patient (1.8%) had died, with cause of death unrelated to the DFR procedure. No information regarding the date of death was available for this patient.

In total, 10 of the 12 patients (83.3%) who underwent revision surgery required revision of the APT component. Of these 10 patients, three (30.0%) were revised due to aseptic loosening at an average of

Table 2 Operative variables of the study cohort, including procedure type (primary *vs* revision), surgical indications, mode of failure according to the Henderson Classification, and number of previous knee surgeries on the operative knee, *n* (%)

Operative variable	Value
Procedure type	
Primary	29 (52.7)
Revision	26 (47.3)
Surgical indications	
Osteogenic sarcoma	22 (40.0)
Giant cell tumor	9 (16.4)
Metastatic carcinoma	8 (14.6)
Soft-tissue sarcoma[a]	4 (7.3)
Chondrosarcoma	
High-grade	3 (5.5)
Low-grade	2 (3.6)
Synovial chondromatosis	2 (3.6)
Multiple myeloma	2 (3.6)
Non-Hodgkin's lymphoma	1 (1.8)
Pigmented villonodular synovitis	1 (1.8)
Neoplasm of unspecified behavior	1 (1.8)
Primary mode of failure, henderson classification	
Type 1 (soft-tissue failure)	6 (10.9)
Type 2 (aseptic loosening)	5 (9.1)
Type 3 (structural failure)[b]	2 (3.6)
Type 4 (periprosthetic infection)	6 (10.9)
Type 5 (tumor progression)	1 (1.8)
Number of previous surgeries (mean ± SD)	1.1 ± 1.3 surgeries

[a]Soft-tissue sarcomas included malignant fibrous histiocytoma, pleomorphic fibrosarcoma, and myxofibrosarcoma.
[b]Both cases of henderson type 3 failure were due to trunnionosis; there were no periprosthetic fractures observed in this cohort.

Table 3 Primary procedures for individuals requiring a revision distal femoral replacement

Primary procedure in the revision cohort (N = 26)	
Category	Number of patients
Distal femoral replacement	12
Open reduction internal fixation for pathologic fracture	6
Curettage +/- cryoablation	6
Soft tissue resection	2

80.4 mo postoperatively, six (60.0%) were revised due to periprosthetic joint infection at an average of 44.8 mo, and one (10.0%) was revised due to periprosthetic fracture requiring placement of medial and lateral titanium plates at 9.6 mo. A second competing risks analysis depicting the incidence of all-cause revision of the APT component and APT component failure secondary to periprosthetic joint infection (PJI) was plotted (Figure 3). This analysis demonstrated one- and three-year cumulative incidences of 18.2% (95%CI 2.5%-45.5%) and 47.0% (95%CI 15.1%-74.0%), respectively, with all-cause revision of the APT component as the endpoint. When failure of the APT secondary to PJI was used as the endpoint, the one- and three-year cumulative incidences were 10.0% (95%CI 0.5%-37.4%) and 44.0% (95%CI 6.3%-59.3%), respectively.

Table 4 Indication groupings for individuals requiring revision distal femoral replacement

Reason for revision	
Category	Number of patients
Mechanical failure	11
Nonunion of prior pathological fracture	7
Tumor Progression	3
Definitive management of a prior open reduction internal fixation for a pathological fracture	2
Local recurrence	1
Infection	1
Soft tissue failure	1

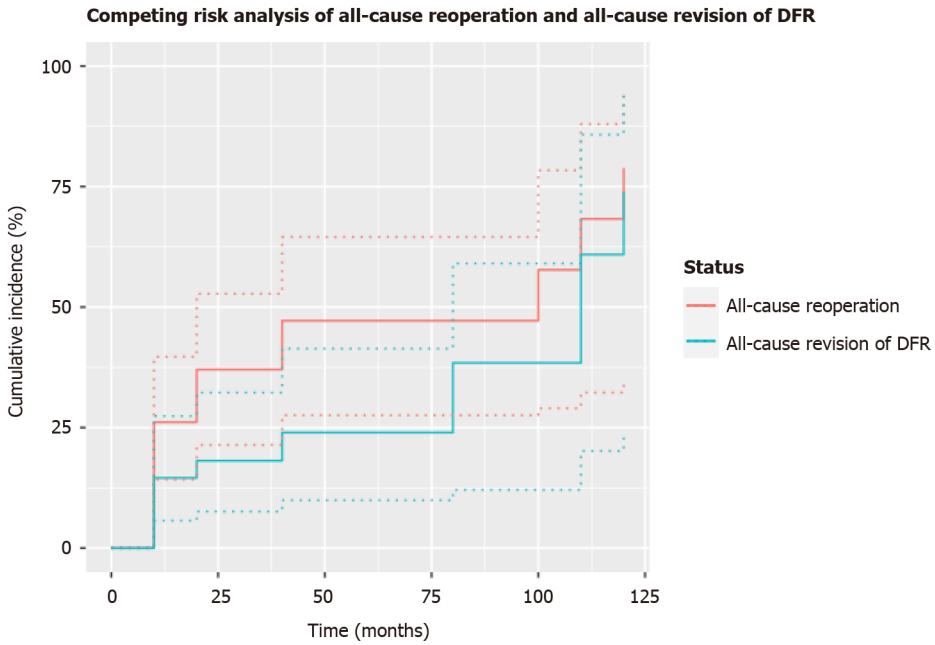

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Figure 2 Competing risk analysis for cemented distal femoral replacement with all-polyethylene tibial component constructs for oncologic indications with all-cause revision (femoral or tibial component) and all-cause reoperation as the primary endpoints. One- and three-year cumulative incidences were 14.6% (95%CI 5.7%-27.4%) and 24.0% (95%CI 9.9%-41.4%), respectively, with all-cause revision as the endpoint. One- and three-year cumulative incidences were 26.1% (95%CI 14.2%-39.7%) and 47.2% (95%CI 27.5%-64.5%), respectively, with all-cause reoperation as the endpoint. DFR: Distal femoral replacement.

Univariate analysis

No significant differences in patient demographics or reoperation rates were identified between patients for whom the index procedure was a primary reconstruction ("primary DFR") and patients for whom DFR was performed as a revision procedure ("revision DFR"). Both cohorts had similar lengths of clinical follow-up (42.7 ± 61.4 *vs* 34.5 ± 47.5 mo, $P = 0.946$) (Table 5).

DISCUSSION

Endoprosthetic reconstruction is standard-of-care for oncologic processes of the distal femur, as greater than 90% of patients can be treated with limb salvage. While this procedure is effective in restoring mobility and salvaging the limb, it has a well-known complication and survival profile[19]. Aside from septic failure, aseptic loosening has been the leading cause of failure historically, and improvements have been focused on fixation of the femoral component[5,10]. However, relatively little attention has been paid to the tibial component. Unlike the femoral component, tibial components are available in both metal and all-polyethylene, and fixation of the tibial component can be achieved in a variety of ways, including cemented, cementless, and hybrid fixation. Despite the increased utilization of DFR

Table 5 Univariate analysis comparing demographic characteristics and reoperation rates between the primary distal femoral replacement and revision distal femoral replacement subgroups, *n* (%)

	Primary DFR (*n* = 29)	Revision DFR (*n* = 26)	*P* value
Age (mean ± SD)	49.7 ± 20.6 yr	52.2 ± 21.1 yr	0.649
Gender			0.44
Male	13 (44.8)	9 (34.6)	
Female	16 (55.2)	17 (65.4)	
Body mass index (mean ± SD)	29.5 ± 8.5 kg/m^2	30.0 ± 8.4 kg/m^2	0.567
Follow-up (mean ± SD)	42.7 ± 61.4 mo	34.5 ± 47.5 mo	0.946
Complication requiring reoperation?	11 (37.9)	9 (34.6)	0.799
Total reoperations required (mean ± SD)	1.4 ± 2.6	1.0 ± 1.8	0.624

DFR: Distal femoral replacement.

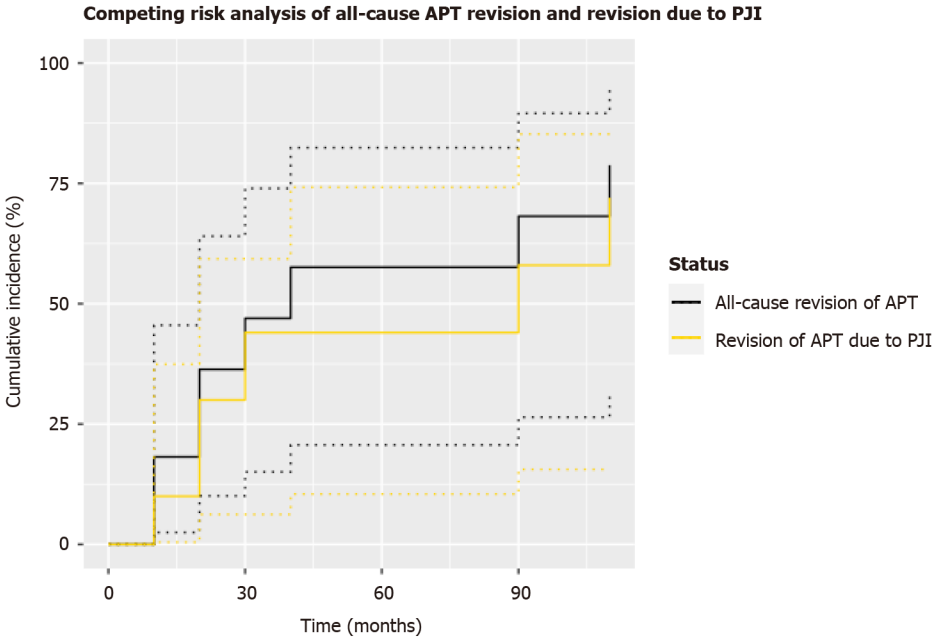

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Figure 3 Competing risk analysis for cemented distal femoral replacement with all-polyethylene tibial components for oncologic indications with all-cause revision of the all-polyethylene tibial component (APT) and revision of the APT due to periprosthetic joint infection as the primary endpoints. One- and three-year cumulative incidences were 18.2% (95%CI 2.5%-45.5%) and 47.0% (95%CI 15.1%-74.0%), respectively, with all-cause revision of the APT as the endpoint. One- and three-year cumulative incidences were 10.0% (95%CI 0.5%-37.4%) and 44.0% (95%CI 6.3%-59.3%), respectively, with revision of APT due to periprosthetic joint infection as the endpoint. APT: All-polyethylene tibial; PJI: Periprosthetic joint infection.

with APTs over time, previous studies have paid little attention to the outcomes of tibial components until recently[6,9,20]. Bukowski *et al*[20] showed that DFRs with APT have a significantly lower incidence of tibial revision at 10 years (1.1% *vs* 12.5%, HR = 0.18, *P* = 0.03) and no difference in infection-free survival (*P* = 0.72) when compared to the traditional DFR with a metal backed tibia.

APTs are monoblock cemented components that offer cost-effectiveness and surgical efficiency when compared to metal-backed tibial components[21,22]. They avoid failure due to locking-mechanism issues and backside wear, but limit modularity and the option for late liner exchange. While we theorized that APTs would suffer from some of the same failure mechanisms as metal backed tibial components, such as periprosthetic joint infection and late polyethylene wear, it is unclear whether they exhibit novel modes of failure, or whether they are more resistant to certain types of failure, such as aseptic loosening, than metal-backed components. The purpose of this study was to examine a large cohort of DFR with APT performed for oncologic indications, with specific focus on failure rate and mechanisms of the APT.

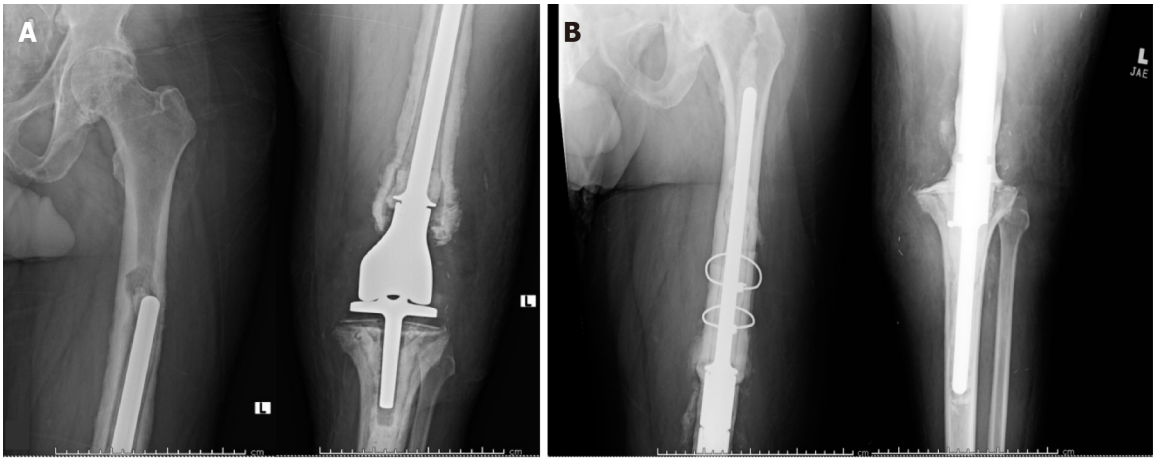

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Figure 4 Radiographs of a 58-year-old male patient showing increased lucency surrounding the proximal femoral stem with abutment of the lateral cortex. A: Anteroposterior radiographs of the loosened distal femoral replacement; B: Interval explantation of the prior distal femoral replacement and placement of an intercalary cemented modular antibiotic spacer.

The most common modes of implant failure in this cohort were soft tissue (Type I) (10.9%) and deep infection (Type IV) (10.9%), followed by aseptic loosening (Type II) (9.1%). Aseptic loosening was evenly split between the femoral and tibial components. There were two revisions for corrosion and metal debris (Type III), and one case of tumor recurrence (Type V). The rate of infection is comparable to previous large series. Sharma demonstrated a 7.8% infection rate (Type IV), 6.5% local recurrence rate (Type V), and no aseptic loosening with line-to-line cemented femoral stems using the same implant system[23]. Henderson demonstrated 1.3% soft tissue failure (Type I), 6.4% aseptic loosening (Type II), 6.3% structural failure (Type III), and 8.3% infection (Type IV) in their cohort's subset of distal femur replacements[12]. Our soft tissue failure rate was significantly higher, for unclear reasons. Given the referral nature of our practice, the present cohort may be inherently at greater risk for soft tissue failure due to a higher proportion of ethnic minorities from underserved areas with greater comorbid burden, many of whom require prior insurance authorization resulting in delayed time to definitive treatment. However, rates of infection, aseptic loosening, and structural failure were similar. Pala demonstrated a 26.6% overall failure rate for DFRs in their study, including 6% soft tissue failure (Type I), 5% aseptic loosening (Type II), and 9% infection (Type IV)[24]. Our series of DFR with APT for oncologic indications appears to have similar modes and rates of failure as previously published studies. We demonstrated a higher rate of soft tissue failure, the reason for which is unclear. However, it is unlikely to be due to the APT, as the rotating tibial component and axel for the APT is approximately 2.5 cm longer for the APT than the metal-backed tibia, conferring a much larger jump distance prior to dislocation, i.e. soft tissue failure leading to instability[25].

Our study demonstrated a 24% revision rate and 47% all-cause reoperation rate at 3 years. This is consistent with large reports of modern distal femoral replacements[9]. The rate of aseptic loosening was 9.1%, which was seen on both the femoral and tibial side. This appears to be consistent with previous reports for femoral-sided aseptic loosening[12,24]. However, few reports have specifically examined the tibial component, so it is unclear how this rate of aseptic loosening of the tibial component (3/55) compares with other historical groups. One recent study suggests that these components achieve durable fixation, with no cases of aseptic loosening and a small number (6) sustaining mechanical failure of the tibial component out of 125 patients[8]. This speaks to the advantage of line-to-line cement technique on the femur, and durable fixation of the APT, with predictable long-term failure like our study. They also observed one patient with polyethylene granuloma over the APT. Finally, they noted an infection rate (Type IV failure) of 10%, nearly identical to our study, and reported a 15% reoperation rate at 1 year and 30% reoperation rate at 5 years.

Finally, we found no significant differences in terms of preoperative demographics or post-operative complications in patients who received DFR with APT as a primary or revision procedure for their oncologic process. The revision cohort had 2.0 ± 1.3 (range 1-5) previous operations prior to DFR. It is surprising that the group performed as a revision procedure did not have a higher complication or reoperation rate, despite having been operated on previously. However, this finding is supported by several previous investigations. The reoperation rate of 38% in the revision DFR cohort is similar to published reports of DFR used for non-oncologic revision total knee arthroplasty, as the Mayo clinic series demonstrated a 46.3% percent all-cause reoperation rate at 10 years for non-oncologic DFR[26]. A similar reoperation rate was found by Staats and colleagues in a cohort of both oncologic and non-oncologic DFRs (36.4% at 2 years), and they were unable to detect a difference in the cumulative incidence of revision surgery in patients with oncologic *vs* non-oncologic disease[27]. Other studies have

found no difference between primary and revision DFRs as well[28,29], indicating that previous oncologic procedures in the same field do not significantly affect outcomes after DFR.

This study has several limitations. It is a single institution, retrospective study in which statistical power is limited due to sample size. Also, given the heterogeneity of oncologic disease, specific indications, treatments, and surgical techniques could not be standardized. However, the risk of unintentional selection bias in the present study is mitigated by the composition of the current cohort, which represents a consecutive series of DFR with APT performed for oncologic indications by a single surgeon at our institution. The APT was used consistently as the primary construct of the treating surgeon in this consecutive series of patients - therefore, we can only make historical comparisons to other studies, and cannot directly compare these patients with a cohort of metal-backed tibial components performed in the same patient population. These types of studies are difficult to accomplish in orthopaedic oncology due to the heterogeneous patient population and rare diseases treated. Nevertheless, the present study provides valuable insight into the survivorship and common modes of implant failure for the DFR with APT construct utilized this high-risk patient population, and there is value in reporting these case series so that they may be analyzed in aggregate with other published reports.

CONCLUSION

Despite the inherent risk of complications and reoperations associated with oncologic surgery, DFR with APT is a reliable reconstructive option for oncologic defects of the distal femur. APTs are efficient, cost-effective, and more likely to avoid failure mechanisms related to modularity. Failures of DFR with APT, like other DFRs, are mostly related to infection, soft tissue failures, and late aseptic loosening. While we observed several cases of aseptic loosening of the tibial component, we did not observe fractures of the APT, which has been reported previously. In concordance with previous studies, we did not observe a difference in complication rates or failures between DFR with APT performed for primary and revision indications. Further studies, including cohort or randomized trials, are needed to determine the optimal tibial component for oncologic DFR.

ARTICLE HIGHLIGHTS

Research background

Future prospective studies with larger sample sizes and longer term followup are necessary to determine the optimal construct for oncologic distal femoral replacement (DFR). Comparative studies investigating the differences in clinical, functional, and patient-reported outcomes between the use of metal-backed *vs* all-polyethylene tibial components and cemented *vs* cementless fixation will provide further insight into the specific failure mechanisms associated with each construct.

Research motivation

This study proposes that DFR with all-polyethylene tibial (APT) is a reliable reconstruction option for oncologic defects of the distal femur.

Research objectives

DFR with APT implantation was performed as a primary procedure in 29 patients (52.7%) and a revision procedure in 26 patients (47.3%). Overall, twenty patients (36.4%) experienced a postoperative complication requiring reoperation. In total, 12 patients (21.8%) required a revision while 20 patients (36.4%) required a reoperation, resulting in three-year cumulative incidences of 24.0% (95%CI 9.9%-41.4%) and 47.2% (95%CI 27.5%-64.5%), respectively.

Research methods

A retrospective review of consecutive patients who underwent DFR with a GMRS® (Global Modular Replacement System, Stryker, Kalamazoo, MI, United States) cemented distal femoral endoprosthesis and APT component for an oncologic indication was performed using a single-institutional database. Univariate analyses were performed to compare differences between those who had a DFR performed either as the primary treatment for the disease in question *vs* those who had a DFR as a revision of a previous failed surgery (indications included recurrence, fracture, *etc*.). Competing risk analyses were performed to evaluate the cumulative incidence of all-cause reoperation, need for revision surgery, and patient death.

Research results

This study was designed to answer the following research questions: (1) What are the most common

modes of implant failure for patients undergoing cemented DFR with APT for oncologic indications? (2) What is the survivorship, rate of all-cause reoperation, and rate of revision for aseptic loosening of these implants? and (3) Is there a difference in implant survivorship or patient demographics between cemented DFRs with APT performed as a primary reconstruction *vs* those performed as a revision procedure?

Research conclusions

Prior studies investigating the outcomes of endoprosthetic distal femoral replacement have largely failed to describe the type of tibial component or fixation used. Unlike the femoral component, tibial components are available in both metal-backed and all-polyethylene designs, and fixation may be achieved *via* cemented, cementless, or hybrid fixation. Future research investigating the effect of tibial component design and fixation on clinical outcomes is critical to determining the optimal construct for oncologic DFR.

Research perspectives

Endoprosthetic reconstruction of the distal femur has been used as a limb-salvage procedure to treat oncologic processes of the distal femur for nearly five decades, and is currently considered standard of practice for this indication. However, there is a paucity of literature examining the survivorship of DFRs with respect to the type of tibial component utilized. The purpose of this study was to report on the clinical outcomes of patients undergoing cemented DFR with all-polyethylene tibial components for oncologic indications.

FOOTNOTES

Author contributions: Christ AB, Menendez LR, and Heckmann ND generated the idea, provided guidance throughout, were heavily involved in copy-editing, and oversaw execution of the project; Chung BC, Urness M, Mayer L, and Gettleman BS were responsible for data collection, literature review, statistical analysis, and drafting the manuscript; All authors listed read and approved the final manuscript.

Institutional review board statement: Proposal #HS-20-00396 indicates that this study is determined to be IRB exempt.

Informed consent statement: The study is IRB-exempt at our institution because we did not employ the use of humans and the use of their protected health information for this study was deemed minimal risk. Thus, an Informed Consent form is not applicable for this study.

Conflict-of-interest statement: One of the authors (N.D.H.) is a paid consultant for Intellijoint Surgical and MicroPort Orthopedics, has stock options from Intellijoint Surgical, and is a committee member of AAOS and AJRR. One of the authors (L.R.M.) is a paid consultant for Onkos Surgical and receives IP royalties from TeDan Surgical. Each author certifies that he has no commercial associations that might pose a conflict of interest in connection with the submitted article. One of the authors (A.B.C) is a board member for AAOS, Musculoskeletal Tumor Society, Orthopaedic Society. (A.B.C) is also a paid consultant for Smith and Nephew, Intellijoint Surgical, and Enovis.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Acute hospital-community hospital care bundle for elderly orthopedic surgery patients: A propensity score-matched economic analysis

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Abstract

BACKGROUND

While Singapore attains good health outcomes, Singapore's healthcare system is confronted with bed shortages and prolonged stays for elderly people recovering from surgery in acute hospitals. An Acute Hospital-Community Hospital (AH-CH) care bundle has been developed to assist patients in postoperative rehabilitation. The core concept is to transfer patients out of AHs when clinically recommended and into CHs, where they can receive more beneficial dedicated care to aid in their recovery, while freeing up bed capacities in AHs.

AIM

To analyze the AH length of stay (LOS), costs, and savings associated with the AH-CH care bundle intervention initiated and implemented in elderly patients aged 75 years and above undergoing elective orthopedic surgery.

METHODS
A total of 862 1:1 propensity score-matched patients aged 75 years and above who underwent elective orthopedic surgery in Singapore General Hospital (SGH) before (2017-2018) and after (2019-2021) the care bundle intervention period was analyzed. Outcome measures were AH LOS, CH LOS, hospitalization metrics, postoperative 30-d mortality, and modified Barthel Index (MBI) scores. The costs of AH inpatient hospital stay in the matched cohorts were compared using cost data in Singapore dollars.

RESULTS
Of the 862 matched elderly patients undergoing elective orthopedic surgery before and after the care bundle intervention, the age distribution, sex, American Society of Anesthesiologists classification, Charlson Comorbidity Index, and surgical approach were comparable between both groups. Patients transferred to CHs after the surgery had a shorter median AH LOS (7 d *vs* 9 d, $P < 0.001$). The mean total AH inpatient cost per patient was 14.9% less for the elderly group transferred to CHs (S$24497.3 *vs* S$28772.8, $P < 0.001$). The overall AH U-turn rates for elderly patients within the care bundle were low, with a 0% mortality rate following orthopedic surgery. When elderly patients were discharged from CHs, their MBI scores increased significantly (50.9 *vs* 71.9, $P < 0.001$).

CONCLUSION
The AH-CH care bundle initiated and implemented in the Department of Orthopedic Surgery appears to be effective and cost-saving for SGH. Our results indicate that transitioning care between acute and community hospitals using this care bundle effectively reduces AH LOS in elderly patients receiving orthopedic surgery. Collaboration between acute and community care providers can assist in closing the care delivery gap and enhancing service quality.

Key Words: Care bundle; Community hospital; Orthopedic surgery; Cost-effectiveness; Care transition; Intervention

Core Tip: This study evaluated the cost-effectiveness of an intervention that bundled Acute Hospital-Community Hospital (AH-CH) care. The AH-CH care bundle intervention effectively reduced AH length of stay (LOS) and costs for elderly patients aged 75 and above undergoing elective orthopedic surgery in Singapore General Hospital. Our findings indicate that systematically transitioning care between AH and CH using this care bundle reduces AH LOS and achieves cost savings. This intervention increases public hospital bed capacity and reduces inpatient hospitalization costs.

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INTRODUCTION

Singapore is one of the world's fastest-aging countries, with a total population of 5.7 million people[1]. According to the forecasts of demographic statistics[1], the proportion of people aged 65 and beyond is anticipated to quadruple from 8% in 2005 to 20% in 2030 and 38% by 2050[2]. This demographic transition puts Singapore's healthcare system under strain, as an aging population presents a mix of issues. For instance, an aging population increases the demand for joint replacement surgery, particularly among those aged 65 years and above[3]. Orthopedic surgery is sometimes associated with increased mortality and morbidity in the elderly patient population compared to the general population [4-7].

Additionally, the risk of hospitalization for those aged 65 years and above is higher and is associated with a longer length of stay (LOS) in acute hospitals (AHs)[8], resulting in an increased socioeconomic burden. In Singapore, age-adjusted per capita bed days in AHs have been gradually increasing since 2006, primarily due to an increase in admissions[9]. The proportion of patients aged 65 years and older admitted to public healthcare institutions has climbed from 28.6% in 2006 to 39.0% in 2020[9]. The

requirement for postoperative rehabilitation and continuing care following discharge from AHs is also projected to increase as the elderly require a more extended recovery period. Therefore, any interventions that may be utilized to lower inpatient stay costs and shorten LOS in AHs benefit Singapore's public healthcare providers.

Several care bundles or interventions have been adopted to improve patient care and decrease AH LOS in a general population undergoing surgery[10-12]. Most of them are interdisciplinary in nature and focus on optimizing all aspects of the patient's perioperative management while also encouraging the patient to participate actively in their own recovery and rehabilitation. Similarly, Singapore's Ministry of Health (MOH) has developed an AH-CH care bundle to improve the quality of care and provide ongoing postoperative care to assist patients in rehabilitating and reintegrating into their communities[13]. The core concept of this care bundle is to transfer patients out of AHs at the point when clinically necessary and into CHs, where they can receive more beneficial dedicated postoperative care to aid in their recovery while freeing up scarcer capacity in AHs. The AH-CH care bundle aims to recognize CH as an integral aspect of inpatient care by treating the AH and CH stay as a single episode. The workstream of this care bundle collaborates closely with inpatient teams at AHs to facilitate discharge planning and a smooth transfer to CHs.

This study aimed to evaluate the potential benefits and analyze the AH inpatient hospitalization costs and savings associated with this AH-CH care bundle in elderly patients undergoing orthopedic surgery in Singapore General Hospital (SGH).

MATERIALS AND METHODS

This study was approved by our institutional review board (IRB No. 2022/2178) and reported following Consolidated Health Economic Evaluation Reporting Standards (CHEERS 2022) guidelines[14]. It was a retrospective single-center analysis of outcomes for elderly patients ≥ 75 years admitted to the orthopedic surgery department in SGH between two study periods: 2017-2018 (before the bundled-care period) *vs* 2019-2021 (after the bundled-care period). The inclusion criteria were all elderly patients aged 75 and above undergoing elective major orthopedic surgery between 2017 and 2021. Data was collected from our electronic health intelligence system and finance database. Patients who underwent emergency surgery were excluded from the evaluation.

Propensity score matching was performed to balance the comparison of elderly patients receiving orthopedic surgery in a 1:1 ratio before and after the care bundle periods based on age, sex, American Society of Anesthesiologists classification, Charlson Comorbidity Index (CCI), and surgical approach. The matched cohorts were examined for discharge deposition, AH LOS, and postoperative 30-d mortality. The CCI was calculated based on a patient's diagnosis using the 10th revision of the International Statistical Classification of Disease and Related Health Problems (ICD-10) codes. Patients within the care bundle were further analyzed for CH LOS, total AH-CH LOS, referral waiting time from AH to CH, U-turn rates, and Modified Barthel Index (MBI) scores, which employs a 100-point rating scale that evaluates a patient's capacity to execute ten distinct activities of daily living[15].

Costs were derived from inpatient billing data and indicated the total cost of the inpatient stay per case prior to the subsidy. Cost data were adjusted to 2021 Singapore dollars to account for healthcare inflation (approximately 1.02%-1.08% over the study period; Monetary Authority of Singapore, https://www.mas.gov.sg/). Cost breakdown was calculated and compared between the two matched cohorts.

Statistical analyses were performed in R Statistical Software (version 4.2.1). Continuous variables were reported as median (range) or mean ± SD. Categorical variables were reported as frequency (percentage). The Wilcoxon-Mann-Whitney test was used to analyze continuous variables, and χ^2 or Fisher's exact tests were used to analyze categorical variables. Cost data were presented as mean ± SD following CHEERS guidelines[14]. Statistical significance was set at a P value < 0.05.

RESULTS

Following the AH-CH care bundle intervention, we have developed a rapid transfer pathway from AH to CH for elderly patients undergoing orthopedic surgery (Figure 1). Briefly, once patients have completed surgery at the AH site, they are screened for fast-track transfer to CH sites by nursing professionals from the orthopedic surgery department. Patients who consent to be treated in CH facilities are entitled to financial counseling for an estimated cost of their entire AH-CH stay. Afterward, surgeons initiate CH referral letters, and patients are transported and admitted to CH sites. We analyzed 862 elderly patients in total who underwent elective orthopedic surgery before and after the AH-CH care bundle intervention.

Patient demographics, clinical and surgical characteristics, and hospitalization metrics between the two matched cohorts are shown in Table 1. There was no significant difference in patient demographics, baseline characteristics, and discharge deposition. Elderly patients within the care bundle transferred to CHs after the surgery had a shorter median AH LOS of 7 d (range: 1-44; mean 8.83) compared to 9 d

Table 1 Comparison of patient demographics, clinical characteristics, and hospitalization metrics between elderly patients who underwent elective orthopedic surgery before and after the care bundle intervention

Variable	Before care bundle period (2017-2018)	After care bundle period (2019-2021)	*P* value
	n (%)	*n* (%)	
Matched patients	431	431	
Age (yr), median (range)	79 (75-97)	80 (75-99)	0.184
Gender			
Male	111 (25.8)	123 (28.5)	0.400
Female	320 (74.2)	308 (71.5)	
ASA classification			
1	3 (0.7)	8 (1.9)	0.074
2	336 (78.0)	311 (72.2)	
3	92 (21.3)	112 (26.0)	
4	0	0	
CCI			
0	3 (0.7)	8 (1.9)	0.200
1	12 (2.8)	21 (4.9)	
2	316 (73.3)	292 (67.7)	
3	16 (3.7)	18 (4.2)	
≥ 4	84 (19.5)	92 (21.3)	
Surgical approach			
Open	346 (80.3)	337 (78.2)	0.502
MIS	85 (19.7)	94 (21.8)	
AH LOS (d)			
Median (range)	9 (7-73)	7 (1-44)	< 0.001
Mean (SD)	12.5 (13.8)	8.83 (7.02)	< 0.001
Discharged home	431 (100)	431 (100)	-
Postoperative mortality	0	0	-

Continuous variables were presented as median (range) or mean ± SD; categorical variables were presented as *n* (%). ASA: American Society of Anesthesiologists classification; CCI: Charlson Comorbidity Index; MIS: Minimally Invasive Surgery; AH: Acute hospital; LOS: Length of stay.

(range: 7-73; mean 12.5) in patients before the care bundle period ($P < 0.001$). The mortality rate for all included patients was 0% following orthopedic surgery.

The AH inpatient stay of both groups is shown in Table 2. Elderly patients within the care bundle group had a significantly lower mean total AH inpatient hospitalization cost of S$24497.3 per patient, 14.9% lower than patients before the care bundle period of S$28772.8 per patient ($P < 0.001$). The detailed cost breakdown analysis revealed that the care bundle group had much lower costs for ward accommodation (S$5924.4 *vs* S$8748.8, $P < 0.001$), daily medical treatment (S$2932.4 *vs* S$3980.9, $P < 0.001$), nursing care (S$1379.9 *vs* S$1574.3, $P = 0.040$), investigation (S$1847.1 *vs* S$2173.2, $P = 0.003$), and rehabilitation (S$634.0 *vs* S$905.0, $P < 0.001$) services. There was no significant difference in the costs of surgery procedure, pharmacy, and consumables between the two groups.

The CH hospitalization metrics are shown in Table 3. Our first CH was officially opened in August 2018, followed by the second in January 2019. There was no CH data available prior to the implementation of the AH-CH care bundle. The median CH LOS was 23 d, 24 d, and 22 d within the care bundle group from 2019 to 2021. The median total AH-CH LOS was reduced from 35 d in 2019 to 33 d in 2021. The overall referral time from AH to CH after surgery was around 3 d to 5 d. A U-turn occurs when a patient is readmitted to AH within 8 h of being transferred to CH. The overall U-turn was almost 0, with only one case in 2021 readmitted to AH. MBI scores of elderly patients were significantly increased at the time of being discharged from CHs. The average MBI score for all elderly

Table 2 Comparison of inpatient hospitalization costs between elderly patients receiving elective orthopedic surgery before and after the care bundle intervention

AH hospitalization cost (S$)	Before care bundle period (*n* = 431)	After care bundle period (*n* = 431)	% Difference	*P* value
Total inpatient cost per case	28772.8 (28581.6)	24497.3 (15281.8)	14.9% decrease	< 0.001
Cost breakdown				
Surgery procedure	4861.8 (2076.2)	4594.6 (1847.1)	5.5% decrease	0.561
Ward accommodation	8748.8 (15164.3)	5924.4 (6277.9)	32.3% decrease	< 0.001
Daily medical treatment	3980.9 (4875.8)	2932.4 (2371.8)	26.3% decrease	< 0.001
Nursing	1574.3 (1715.5)	1379.9 (959.5)	12.4% decrease	0.040
Investigation	2173.2 (2086.3)	1847.1 (1828.1)	15.0% decrease	0.003
Rehabilitation	905.0 (1474.5)	634.0 (490.7)	29.9% decrease	< 0.001
Pharmacy	479.6 (1149.3)	414.8 (988.2)	13.5% decrease	0.369
Consumables	2231.4 (1883.8)	2412.2 (1631.4)	8.1% increase	0.132

Cost data were presented as mean ± SD in 2021 Singapore dollars (S$), adjusted for inflation. 1 Singapore dollar (S$) = 0.722 United States dollar (US$).

Table 3 Community hospitalization metrics in elderly patients undergoing elective orthopedic surgery within the care bundle intervention

Item	2019	2020	2021
Total case	135	170	126
CH LOS (d) (median, range)	23 (4-98)	24 (2-175)	22 (2-87)
Total AH-CH LOS (d) (median, range)	35 (8-122)	33 (5-184)	33 (9-114)
Referral time from AH to CH (d) (median, range)	4 (1-20)	5 (1-14)	3 (1-12)
U-turn from CH to AH within 8 h (%)	0	0	1 (0.79)
MBI score (median, range)			
Admission	58 (11-98)	47 (5-94)	37 (10-97)
Discharge	74 (14-100)	65 (12-100)	68 (13-99)

Continuous variables were presented as median (range); categorical variables were presented as *n* (%). CH: Community hospital; LOS: Length of stay; AH: Acute hospital; MBI: Modified Barthel Index.

patients within the care bundle group improved significantly from 50.9 (SD: 23.9) at admission to 71.9 (SD: 23.4) at discharge ($P < 0.001$).

DISCUSSION

This study demonstrates that the AH-CH care bundle intervention can directly reduce AH LOS in elderly patients undergoing orthopedic surgery. Regaining movement and strength cannot occur quickly enough for an elderly patient recovering after orthopedic surgery. Physical and occupational therapy are the most effective strategies for resuming normal activities as quickly as possible[16]. Postoperative rehabilitation assists elderly patients in learning to perform their exercise appropriately, monitor their performance, and identify potential problems that the clinician should be aware of. However, rehabilitation and physiotherapy are typically time-consuming, and AH LOS is a quality indicator used by healthcare systems to assess the efficiency of their hospital operation. Reduced AH LOS increases bed turnover, enabling AHs to meet the demand for acute admission and interhospital transfers with an available capacity[17,18]. In Singapore, it has been observed a growth in AH admissions that was disproportionate to the growth of the general population. The mean AH LOS for elderly patients increased from 7.8 d in 2010 to 8.2 d in 2013[19]. As a result, Singapore is implementing system-level strategies to provide excellent care and a safe discharge while preventing prolonged AH

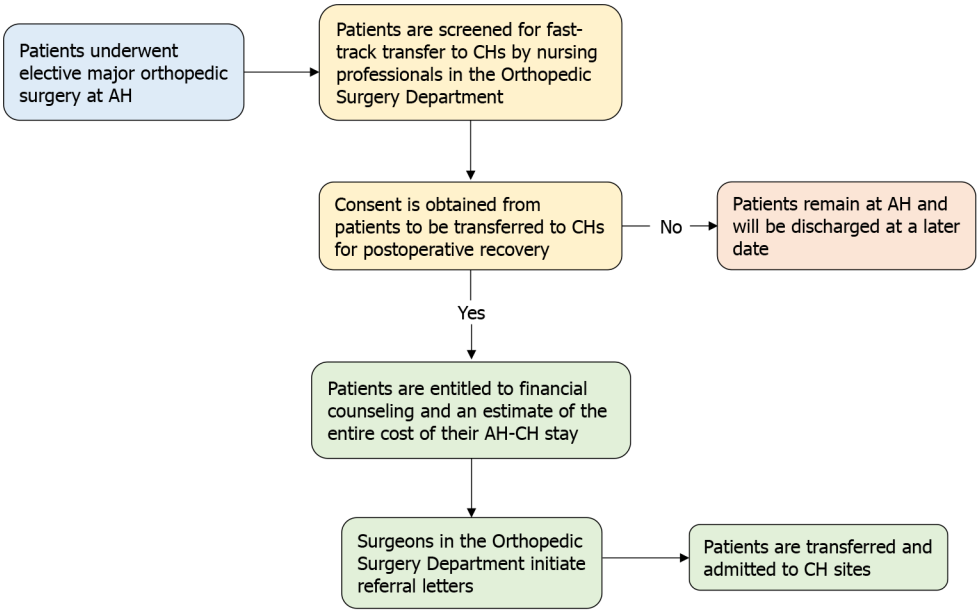

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Figure 1 Fast transfer pathway from acute hospital to community hospitals for elective elderly orthopedic patients. Once patients have completed surgery at the acute hospital (AH) site, they are screened for fast-track transfer to community hospital (CH) sites by nursing professionals from the orthopedic surgery department. Patients who agree to be treated in CH facilities are entitled to financial counseling and an estimate of the total cost of their AH-CH stay. Afterward, surgeons initiate CH referral letters, and patients are transported and admitted to CH sites. AH: Acute hospital; CH: Community hospital.

stays. Our results identified potential benefits of this care bundle in shortening median AH LOS by two days in elderly patients undergoing orthopedic surgery, without sacrificing postoperative complications, readmissions, and mortality.

The total costs of AH inpatient stay were consequently reduced. Cost savings were achieved from cost buckets associated with prolonged AH LOS. Applying the observed decrease in AH LOS to our elderly patient cohort would have resulted in an estimated bed day savings of S$184440.0 between 2019 and 2021 (200 beds reserved for the orthopedic surgery department with an estimated bed day cost of S$461.1). Furthermore, the reduced LOS would improve AH's capacity due to cost savings. As a result, there would be substantial advantages for both patients and the hospital because the increased capacity may boost utilization and cut down on waiting lists.

Compared to AH LOS, a CH stay might last from a few days to a few weeks, depending on the patient's condition. CH services are designed to enhance patient functional impairment statuses and maximize their physical capacities in preparation for discharge home or continuation of treatment at other community-based step-down care facilities. The benefits of admission to CHs for rehabilitation care include the following: (1) A good chance for patients, particularly elderly patients, to improve physical functions; (2) patients can participate in at least two hours of therapy daily; and (3) patients and caregiver can participate in rehabilitation and discharge planning. Patients undergoing orthopedic surgery in this care bundle had a median CH LOS of 22-24 d. One constraint of this study was the limited bed capacity of our two newly-constructed CHs, which resulted in a slower bed turnover rate. The median duration between AH site referral and CH site acceptance was observed to be approximately 3-5 d. To fulfill the demand for intermediate residential care, Singapore's MOH is expanding its network of CHs that will be co-located with their cluster-run AHs to complement acute care services and assist patient care continuums.

Our results demonstrated that CH is critical in providing rehabilitation and continuing care to assist elderly patients in rehabilitation. When elderly patients were discharged from CHs, their MBI scores increased significantly. The second constraint was that we were unable to get MBI scores for the matched cohort before the care bundle period. As such, we were unable to compare MBI scores between matched elderly patients discharged directly from AH and those transferred to CHs for further rehabilitation. Even if patients are discharged immediately from AH following orthopedic surgery, many of them will most likely require weekly postoperative rehabilitation at AH. In comparison, support from CH care professionals is another factor related to positive results for patients referred to CHs for postoperative rehabilitation. CH care teams will work with patients, particularly the elderly, to establish daily, achievable goals for participating in a function-specific exercise to regain strength. This is of great benefit to both patients and healthcare providers.

This study has a few limitations. First, the AH-CH care bundle is designed for a specific patient population and may not be applicable to other populations or healthcare settings. Second, the exclusion of emergency surgery patients may limit the generalizability of the study's findings to a broader patient

population. Third, this care bundle may not capture the unique characteristics and complexities of each specific orthopedic surgery procedure. However, there are a few perspectives on our findings. The AH-CH care bundle is a promising approach to improving the quality and efficiency of care for elderly patients undergoing elective orthopedic surgery. It provides a standardized and evidence-based practice, which may lead to enhanced patient outcomes and reduced costs, as well as promote a multidisciplinary approach to improve communication and collaboration between healthcare providers.

CONCLUSION

Our results show that transitioning care between acute and community hospitals *via* the AH-CH care bundle effectively reduces AH LOS in elderly patients undergoing orthopedic surgery. A well-designed postoperative rehabilitation program at CH sites can help prevent complications that may have a lasting effect on the quality of life.

ARTICLE HIGHLIGHTS

Research background

Singapore's healthcare system has faced bed shortages and extended stays for elderly patients recovering from surgery in acute hospitals.

Research motivation

An Acute Hospital-Community Hospital (AH-CH) care bundle was created to transfer patients to CHs where they can receive specialized care and free up beds in AHs.

Research objectives

To evaluate the impact of the AH-CH care bundle on AH length of stay (LOS), costs, and savings for elderly patients aged 75 years and above who underwent elective orthopedic surgery.

Research methods

The study examined a cohort of 862 patients aged 75 years and above undergoing elective orthopedic surgery at Singapore General Hospital before (2017-2018) and after (2019-2021) the implementation of the AH-CH care bundle intervention. Patients were matched 1:1 based on their propensity scores and compared for AH LOS, CH LOS, hospitalization metrics, postoperative 30-d mortality, modified Barthel Index (MBI) scores, and costs.

Research results

Elderly patients transferred to CHs had a significantly shorter median AH LOS (7 d *vs* 9 d, $P < 0.001$), and the mean total AH inpatient cost per patient was 14.9% less for the elderly group transferred to CHs (S$24497.3 *vs* S$28772.8, $P < 0.001$). The overall AH U-turn rates for patients within the care bundle were low, with no mortality rate following orthopedic surgery. When elderly patients were discharged from CHs, their MBI scores improved significantly.

Research conclusions

The AH-CH care bundle was found to be effective and cost-saving for elderly patients undergoing elective orthopedic surgery.

Research perspectives

Collaboration between acute and community care providers can help to improve clinical service quality and achieve cost savings.

FOOTNOTES

Author contributions: Au MKH, Ang KA, Tan AHC, and Tan EJKW conceived and planned the study; Tan IEH and Chok AY supervised the study and wrote the manuscript; Chok AY and Zhao Y performed the analysis and interpreted the results; Chen YH, Soh MHT, and Foo CH collected and verified data; Koo CH and Aw JJ participated in the review of the manuscript; Chok AY, Tan EJKW, and Au MKH provided critical revisions for final approval; all authors have read and approved the final version of the manuscript.

Institutional review board statement: This study was approved by Singapore Health Services (SingHealth) Institutional Review Board (approval No. 2022/2178).

Informed consent statement: Due to the study's retrospective design using de-identified data, written informed consent collection was waived by SingHealth Centralised Institutional Review Board.

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ORIGINAL ARTICLE

Retrospective Study

Knowledge and attitudes of orthopedic surgeons regarding prosthesis joint infection

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Abstract

BACKGROUND

Periprosthetic joint infection (PJI) is a critical complication after joint arthroplasty and is accompanied by increasing rates of morbidity and mortality. Several studies have aimed at preventing PJI.

AIM

To research the knowledge level and attitudes of orthopedic surgeons, who play a key role in both preventing and managing PJI.

METHODS

We conducted a web-based survey to evaluate orthopedic surgeons' knowledge level and attitudes regarding PJI. The Likert scale survey utilized consisted of 30 questions which were prepared based on the "Proceedings of the International Consensus on Periprosthetic Joint Infection".

RESULTS

A total of 264 surgeons participated in the survey. Their average age was 44.8, and 173 participants (65.5%) had more than 10 years of experience. No statistically significant relationship was found between the PJI knowledge of the surgeons and their years of experience. However, participants who worked in training and research hospitals demonstrated higher levels of knowledge than the ones in the state hospitals. It was also noticed that surgeons' knowledge concerning the duration of antibiotic therapy and urinary infections was not consistent with their

attitudes.

CONCLUSION
Even though orthopedic surgeons have adequate knowledge about preventing and managing PJI, their attitudes might contradict their knowledge. Future studies are required to examine the causes and solutions of the contradictions between orthopedic surgeons' knowledge and attitudes.

Key Words: Antibiotic prophylaxis; Periprosthetic joint infection; Prevention; Total joint replacement; Turkey

Core Tip: In this study, researching the knowledge level and attitudes of orthopedic surgeons, who play a key role in both preventing and managing prosthesis joint infections, has been aimed.

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INTRODUCTION

Total joint replacement is the most frequently applied procedure in orthopedic surgery, and the prevalence of this surgery is increasing gradually. However, the number of periprosthetic joint infection (PJI) cases is also increasing in parallel with arthroplasties[1]. PJI is a critical complication after joint arthroplasty operations and is accompanied by higher rates of morbidity and mortality. Apart from increasing the cost of health services, the treatment of PJI is complicated, and patients generally need to undergo more than one major operation and receive antibiotic treatment to annihilate the infection. There have been several studies aimed at preventing PJI[2,3].

Gram-positive bacteria are the most seen pathogens in infected orthopedic prostheses, and 75% of the infections are caused by *Staphylococcus aureus* (*S. aureus*). The most frequently used antibiotics in total joint replacement (TJR) are cephalosporins and semi-synthetic penicillins. Routine prophylaxis is applied as a multi-cefazolin dose by many authors in clean surgical procedures including elective orthopedic surgeries. Most early postoperative infections are the result of intraoperative contamination of the surgical site[3-5].

Guidelines about preventing PJI are published by the International Consensus Meeting, World Health Organization (WHO), and the Center for Disease Control and Prevention, and these guidelines are updated regularly in parallel with the current practices and progression[6]. However, orthopedic surgeons' compliance with these principles might differ depending on their knowledge level, experience, and working conditions. In this research, the examination of the knowledge and attitudes of orthopedic surgeons in Turkey about preventing PJI has been aimed by means of a survey study.

MATERIALS AND METHODS

This study was performed between January and March 2019. An online survey was conducted with orthopedic surgeons who were registered in the Turkish Society of Orthopedics and Traumatology in 2019 and who still performed hip arthroplasty. For this purpose, a total of 30 questions were prepared with the intent of providing an evaluation regarding orthopedic surgeons' knowledge about and attitudes towards PJI after joint prostheses. The questions were prepared based on the "Proceedings of the International Consensus on Periprosthetic Joint Infection"[7].

The survey consisted of questions that inquired about surgeons' demographical data, work experiences, features of the institution where they worked at the time of the study, annual arthroplasty numbers, and pre-surgical, intra-surgical, and post-surgical knowledge levels as well as attitudes regarding PJI. The demographic data and questions regarding surgeons' operations (attitudes of surgeons) were presented in the first section of the survey. The second section was allocated for the questions concerning how the operations should be done (knowledge). In the survey, the Likert scale was used. The study has been carried out in accordance with the principles of the Declaration of Helsinki.

Statistical analysis

The data collected were analyzed using the software IBM SPSS version 22.0 (IBM Corp., Armonk, NY, United States). In order to statistically evaluate the data, descriptive statistics and analysis of variance (ANOVA) were utilized. The significance level was defined as $P < 0.05$.

RESULTS

The total number of surgeons who participated in the survey was 264. Their average age was 44.8 ± 8.7, 173 participants (65.5%) had more than 10 years of experience, and 162 participants (61.4%) performed more than 50 TJR operations in a year (Tables 1 and 2). Whereas most of the participants were working in private hospitals (37.5%) at the time of the study, the number of participants who were working in a state hospital was smaller (24.6%) (Table 3).

Participants' answers to the questions that examined their attitudes towards PJI are presented in Table 4. Of the participants, 48.5% stated that they gave 2 g of cefazolin to every patient for surgical prophylaxis in arthroplasty operations. While 28.4% of them stated that they gave 1 g to every patient, 20.8% of them adjusted the dosage according to the patient's weight (Table 5).

Only one out of the total 264 participants stated that he/she did not change gloves during operation (0.4%). Whereas 20.5% of the participants said that they changed gloves once during an arthroplasty operation, 53% of them changed gloves twice, and 26.5% of them changed gloves three or more than three times. Of the participants, 54.9% noted that they changed their gloves when they were disintegrated, yet the rest reported that they did not change gloves. While 54.2% of the participants stated that they changed their gloves after contact with cement, the rest said that they did not change. Regarding the frequency, 38.6% of the participants stated that they changed their gloves every 1 h, while 9.5% changed their gloves every 90 min. More than half (59.5%) of the participants noted that they performed irrigation and debridement to the persistent drainage that continues more than 1 wk after the prosthesis operation, while the rest stated that they did not perform these. Just over a half (51.5%) of the participants pointed out that they administered antibiotic treatment, whereas the rest did not. Of the participants, 50.8% remarked that they discontinued anticoagulants, whereas the rest continued to administer anticoagulants.

While all participants finished the first section of the survey, 192 of them (73%) completed the second section. Participants' answers to the questions that examined their knowledge level in the second section are demonstrated in Table 6.

As a result of the ANOVA, it was determined that the knowledge levels of the participants did not differ in terms of their working period as an orthopedics and traumatology specialist ($P = 0.483$) (Table 7).

In addition, the results of the ANOVA revealed that the knowledge levels of participants did not differ in terms of the number of performed operations per year ($P = 0.675$).

When the average knowledge levels of the participants were examined according to the hospital types, it was seen that the knowledge level of those who worked in training and research hospitals (4.0403) was higher than the ones who worked in state hospitals (3.6580). The ANOVA also revealed that the knowledge levels of participants differed in terms of the type of hospital they currently worked in ($P = 0.030$). In the post-hoc multi comparison test that was done to discriminate between which hospital types this difference occurred, it was determined that there was a significant difference in the knowledge levels between those who worked in training and research hospitals and the ones who worked in state hospitals (Table 8).

DISCUSSION

The most important outcome of this study is the finding that the knowledge levels of the doctors who participated in the study are not congruent with their operations. While the most popular answer is that antibiotic therapy should not be continued longer than 24 h in mega-prosthesis operations, those who have stated that they give antibiotic treatment longer than 24 h construct the most crowded group. In recent survey studies, it has been reported that most orthopedic surgeons in Turkey do not follow antibiotic prophylaxis for TJR and administer antibiotic treatment longer than 24 h. This recent study has shown that orthopedic surgeons in Turkey have a good level of PJI knowledge, and antibiotics are used longer than 24 h in operations, which is in line with literature findings[6,8]. In addition, it has been reported in studies that 58% of the surgeons in Canada and 30% of the surgeons in Italy prefer antibiotic treatment that lasts longer than 24 h[9,10]. However, there is proof that antibiotic prophylaxis that is longer than 24 h is unnecessary and probably increases bacteria resistance[11]. We think that further studies are needed to determine why orthopedic surgeons in Turkey prefer antibiotic treatment that lasts longer than 24 h and to search for solutions to this issue. Another example of knowledge and attitude contradiction in this study is about urinary tract infections. While the most popular answer is 'urine tests should be ordered,' the majority of the participants have stated that they never order urine

Table 1 Number of years as an orthopedic and traumatology specialist

	Frequency	%
< 5	37	14.0
5-10 yr	54	20.5
10-20 yr	104	39.4
> 20 yr	69	26.1
Total	264	100.0

Table 2 Average number of arthroplasty operations per year

	Frequency	%
< 50	102	38.6
50-100	85	32.2
100-200	50	18.9
> 200	27	10.2
Total	264	100.0

Table 3 Hospital type

	Frequency	%
State hospital	65	24.6
University hospital	53	20.1
Training and research hospital	47	17.8
Private hospital	99	37.5
Total	264	100.0

tests in clinical practice. With that being stated, according to up-to-date literature, while symptomatic urinary tract infection should be diagnosed and treated before PJI, routine tests and treatment are not suggested for asymptomatic bacteriuria since it has been reported that asymptomatic bacteriuria is not a risk factor for PJI. Routine tests and following treatment operations lead to unnecessary treatments[12]. In the survey study by Çimen *et al*[6], 59% of the participants perform a routine test prior to arthroplasty while 12% of them never perform it. Azboy *et al*[8] have found in their survey study that almost every surgeon who performs an arthroplasty operation more than 20 times a month orders routine urinary tests. These contradictory findings about urinary tract infections in our country might indicate that well-attended studies are required and that we do not have standardization in our country.

S. aureus is the agent that mostly causes surgical site infections besides many other infections[13]. The nasal colonization of *S. aureus* is around 25%, and the risk of surgical site infection increases in nasal methicillin-resistant *S. aureus* (MRSA) carriers. In addition to this, no consensus has been arrived at on the issue whether an MRSA scan should be done or not before TJR[10,14]. In this study, it has been noted that the majority of the orthopedic surgeons in Turkey have not performed routine tests.

It has been shown that skin cleaning before TJR surgery decreases the rate of PJI, and guidelines highly recommend skin cleaning before surgery. Chlorhexidine is reported as the most effective agent in this matter[15]. Çimen *et al*[6] have reported that half of the orthopedic surgeons in Turkey do not follow the recommendations related to skin cleansing before surgery. In the current study, while 44% of the participants stated that they never do chlorhexidine bathing, 35% of them maintained that they do it occasionally, and 30% of them always do it.

In a survey study conducted in Canada, it has been reported that most of the participants use 1 g of first-generation cephalosporin before TJR[9]. The literature promotes 2 g of first-generation intravenous cephalosporin dosage, which is higher, regarding antibiotic prophylaxis[16]. Besides, the American National Surgical Infection Prevention Project guideline group has determined that the dosage should be adjusted according to the weight of the patient[11]. Almost half of the participants (48.5%) in this study have stated that they administer 2 g of cefazolin.

Table 4 Participants' answers to the questions that examine attitudes towards periprosthetic joint infection

	Never		Rarely		Occasionally		Frequently		Always	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Do you consult your patients to the dentist before total knee or hip arthroplasty?	94	35.6	61	23.1	61	23.1	21	8	27	10.2
Do you perform urine screening prior to elective arthroplasty of a patient with no symptoms of urinary tract infection?	119	45.1	25	9.5	22	8.3	21	8	77	29.2
Do you delay elective arthroplasty of asymptomatic patients with bacteriuria?	186	70.5	14	5.3	29	11	14	5.3	21	8
Do you screen your patients for nasal MRSA carriage prior to elective arthroplasty?	179	67	28	10.6	20	7.6	9	3.4	28	10.6
Do you recommend chlorhexidine bathing to your patients before elective arthroplasty?	117	44.3	15	5.7	35	13.3	19	7.2	78	29.5
Do you administer surgical prophylaxis in the second stage of the two-stage revision surgery?	10	3.8	0	0	13	4.9	10	3.8	231	87.5
Do you pay attention to the fact that the prophylaxis agent covers the patient's previously isolated prosthetic infection agent?	11	4.2	2	0.8	9	3.4	16	6.1	226	85.6
Do you administer surgical prophylaxis for a mega prosthesis (TM prosthesis) longer than 24 h?	40	15.2	8	3	27	10.2	26	9.8	163	61.7
Do you have your patients wear a mask during arthroplasty surgery?	214	81.1	15	5.7	14	5.3	5	1.9	16	6.1

MRSA: Methicillin-resistant *Staphylococcus aureus*.

Table 5 Prophylaxis agent and dosage used in arthroplasty operations

	Frequency	%
1 g of cefazolin	75	28.4
2 g of cefazolin	128	48.5
I adjust cefazolin according to the patient's weight.	55	20.8
Gentamicin	1	0.4
Other	5	1.9
Total	264	100.0

The knowledge and attitudes of the participants regarding the subject of performing prophylaxis surgery in the second stage of the two-stage revision surgery and the subject of paying attention to the fact that the patient's agent of prophylaxis covers the patient's previously isolated prosthetic infection agent been consistent.

New algorithms are being presented to orthopedists related to complication protection, diagnosis, and treatment in TJR practices at regular intervals[17]. However, different attitudes emerge in applying these algorithms due to factors such as the experiences of orthopedists and the opportunities provided by the hospital they work in, which results in the discussion of these differences in studies[6,8-10]. In the present study, it has been determined that there is a significant knowledge level difference between participants who work in training and research hospitals and those who work in state hospitals, and surgeons who work in training and research hospital have higher knowledge levels. Discussing the guidelines that are created to prevent PJI and the standardized protocols in courses and congresses in detail might be beneficial in raising awareness as well as in generating documents for this field.

There have been some restrictions in this study. Even though the types of institutions are questioned, there has not been data concerning the geographical distribution and the location of the hospitals in Turkey. In addition, although our survey was composed of two sections, 27% of the participants did not complete the second section.

Table 6 Participants' answers to the questions that examine their knowledge

Participants' answers	Never		Rarely		Occasionally		Frequently		Always	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
The patient should consult the dentist before total knee or hip arthroplasty	20	7.6	37	14	63	23.9	15	5.7	57	21.6
A urinary test should be ordered for the patient with dysuria complaint during the preoperative stage of an arthroplasty operation	33	12.5	22	8.3	29	11	13	4.9	95	36
Surgical prophylaxis should be administered in the second stage of a two-stage revision surgery	16	6.1	2	0.8	5	1.9	11	4.2	158	59.8
Prophylaxis agents should involve the factor of previously isolated prosthesis infection	9	3.4	2	0.8	4	1.5	6	2.3	171	64.8
Gloves should be definitely changed after contact with cement	14	5.3	10	3.8	26	9.8	25	9.5	117	44.3
For the diagnosis of prosthesis infection, 3–5 culture samples should be obtained	11	4.2	5	1.9	19	7.2	20	7.6	137	51.9
Irrigation and debridement should be applied to the patient in case of persistent drainage that continues more than 1 week after the total hip and knee arthroplasty operation	19	7.2	21	8.0	51	19.3	16	6.1	85	32.2
Surgical prophylaxis should not be longer than 24 hours for a mega prosthesis	52	19.7	18	6.8	43	16.3	11	4.2	68	25.8
The risk of infection increases as the duration of surgery gets longer	4	1.5	3	1.1	4	1.5	3	1.1	178	67.4

Table 7 Comparison of participants' knowledge level and work experience

	n	Mean	Standard deviation	Standard error
< 5	21	3.7143	0.71277	0.15554
5-10 yr	42	3.8829	0.52707	0.08133
10-20 yr	74	3.9032	0.54305	0.06313
> 20 yr	55	3.7924	0.60175	0.08114
Total	192	3.8464	0.57638	0.04160

Table 8 Comparison of participants' knowledge level and type of hospital they work in

Hospital type (I)	Hospital type (J)	Mean difference (I-J)	Standard error	Significance
State hospital	University hospital	-0.21482	0.12318	0.304
	Training and research hospital	-0.38234[1]	0.13071	0.020
	Private hospital	-0.21535	0.10486	0.172
University hospital	State hospital	0.21482	0.12318	0.304
	Training and research hospital	-0.16752	0.13730	0.615
	Private hospital	-0.00053	0.11296	1.000
Training and research hospital	State hospital	0.38234[1]	0.13071	0.020
	University hospital	0.16752	0.13730	0.615
	Private hospital	0.16699	0.12113	0.514
Private hospital	State hospital	0.21535	0.10486	0.172
	University hospital	0.00053	0.11296	1.000
	Training and research hospital	-0.16699	0.12113	0.514

[1]The mean difference is significant at the 0.05 level.

CONCLUSION

Even though orthopedic surgeons have enough knowledge about preventing and managing PJI, their attitudes might contradict their knowledge. Future studies that examine the causes and solutions of contradictions between orthopedic surgeons' knowledge and attitudes are required.

ARTICLE HIGHLIGHTS

Research background

Periprosthetic joint infection (PJI) is a critical complication after joint arthroplasty and increases morbidity and mortality. There have been several studies aimed at preventing PJI.

Research motivation

The treatment of PJI is difficult, and patients generally need to undergo more than one major operation and receive antibiotic treatment to annihilate the infection. Therefore, PJI also increases the cost of health services.

Research objectives

In this study the examination of knowledge about and attitudes toward preventing PJI of the orthopedic surgeons who work in Turkey has been aimed by means of a survey study. A good understanding of orthopedic surgeons' knowledge and attitudes about preventing PJI may guide new interventions to prevent PJI.

Research methods

A web-based 30-question survey was conducted in order to evaluate orthopedic surgeons' knowledge level about PJI and their attitudes towards it.

Research results

The knowledge and practices of surgeons regarding the duration of antibiotic treatment and urinary tract infections in prosthesis operations are different in Turkey.

Research conclusions

This study has shown that even though orthopedic surgeons have got enough knowledge about preventing and managing PJI, their attitudes might contradict their knowledge.

Research perspectives

The knowledge and attitudes of orthopedic surgeons may be different in practice. Future research that examines the causes and solutions concerning the contradictions between orthopedic surgeons' knowledge and attitudes are needed.

FOOTNOTES

Author contributions: Aytekin MN and Hasanoglu I designed the manuscript and collected the data; Öztürk R performed the data analysis and wrote the manuscript; Tosun N contributed by critically reviewing the manuscript; and all authors have read and approved the manuscript.

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ORIGINAL ARTICLE

Observational Study

Perceived barriers and facilitators of day-case surgery for major foot and ankle procedures? A cross-sectional survey of United Kingdom surgeons

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Abstract

BACKGROUND

Advances in minimally invasive surgery and improved post-operative pain management make it possible to consider performing even major foot/ankle operations as day-case. This could have significant benefits for patients and the health service. However there are theoretical concerns about post-operative complications and patient satisfaction due to pain.

AIM

To scope the current practice of foot and ankle surgeons on day-case surgery for major foot and ankle procedures in the United Kingdom (UK).

METHODS

An online survey (19 questions) was sent to UK foot and ankle surgeons *via* the British Orthopaedic Foot & Ankle Society membership list in August 2021. Major foot and ankle procedures were defined as surgery that is usually performed as an inpatient in majority of centres and day-case as same day discharge, with day

surgery as the intended treatment pathway.

RESULTS

132 people responded to the survey invitation with 80% working in Acute NHS Trusts. Currently 45% of respondents perform less than 100 day-case surgeries per year for these procedures. 78% felt that there was scope to perform more procedures as day-case at their centre. Post-operative pain (34%) and patient satisfaction (10%) was not highly measured within their centres. Lack of adequate physiotherapy input pre/post-operatively (23%) and lack of out of hours support (21%) were the top perceived barriers to performing more major foot and ankle procedures as day-case.

CONCLUSION

There is consensus among UK surgeons to do more major foot/ankle procedures as day-case. Out of hours support and physiotherapy input pre/ post-op were perceived as the main barriers. Despite theoretical concerns about post-operative pain and satisfaction this was only measured by a third of those surveyed. There is a need for nationally agreed protocols to optimise the delivery of and measurement of outcomes in this type of surgery. At a local level, the provision of physiotherapy and out of hours support should be explored at sites where this is a perceived barrier.

Key Words: Day-case; Foot; Ankle; Physiotherapy; Survey

Core Tip: We have identified an appetite to increase the number of major foot and ankle procedures within United Kingdom foot and ankle surgeons who completed our survey. Despite theoretical concerns about post-operative pain and satisfaction this was only measured by a third of those surveyed. Out of hours support and physiotherapy input pre/post-op were perceived as the main barriers to doing day-case surgery in foot and ankle surgery.

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INTRODUCTION

Day-case surgery is defined as surgery performed where the patient is undergoing a planned procedure, where day surgery is the intended management plan and the patient is admitted, operated upon and discharged on the same day[1]. Day-case surgery brings recognised benefits for both patients and the healthcare system in relation to patient quality and experience, reduced bed days and significant financial savings[2]. The British Association of Day Surgery (BADS) is a multidisciplinary professional organisation which promotes day surgery by setting standards for day surgery and has developed national benchmarking for day surgery performance[1]. The Academy of Medical Royal colleges also strongly recommended that patients be given the option of day surgery wherever possible and guidelines have been produced to this effect[3]. This guideline has helped to increase the number of day-case surgeries performed. Their recommendations are aimed at surgeons and anaesthetists to offer updated guidance on changes within day surgery and how they may implement these within their practice. These were to offer guidance on day/short-stay surgery, including: The selection of patients; Social, medical and surgical factors in day-case surgery; Pre-operative preparation; Urgent cases; Management and staffing; Postoperative recovery and discharge.

There are many factors in choosing these surgeries to be inpatient or day-case such as the injury sustained, patient health and social circumstances, hospital bed availability, hospital protocols, surgical team, anaesthesia protocol *etc*[4]. There is disparity across the UK in day-case provision. In terms of orthopaedic procedures, some hip and knee surgeries are commonly performed as day-case and are effective, safe and cost-saving[5-7]. The most recent figures from Model Health System (NHS England) for the proportion of all admissions for trusts that were day-cases for all procedures was 69% (in this quartile July 2022 data based on the latest 3 months of activity with primary total replacements of hips/knees excluded from the total). For orthopaedic surgery this day-case rate was 78% (NHS England Model Health System, July 2022). However there are only 3 procedures listed within the BADS day-case directory of procedures (January 2022[1]) for foot and ankle day-case surgery (bunion operation, open

reduction and fixation of ankle, lengthening/ shortening of tendons). Therefore day-case rates for foot and ankle procedures are low.

Major foot and ankle surgery in the UK is usually carried out as an inpatient due to the complexity of surgery, pain post-surgery requiring opiates and ongoing observations required[8]. Major foot and ankle procedure include ankle and hindfoot fusion, joint replacements and tendon repair[9]. However in many cases, day-case surgery can be highly satisfactory for patients and providers in major foot and ankle cases in adults[9] and children[10]. Day-case foot and ankle surgery is known to be safe for the patient with high satisfaction rates as well as being cost effective for the service[11]. There is recent evidence showing there were little to no differences in complication rates or readmissions following foot/ankle surgeries (total ankle replacements, ankle fractures, total ankle arthroplasty and hindfoot fusions) that were performed as day-case *vs* inpatient[12-17]. However there are no specific guidelines for foot and ankle day-case surgery.

As previously outlined, there is evidence to suggest there are benefits to performing foot and ankle surgeries as day-case over inpatient procedures as well as guidance on performing surgeries as day-case. However there is a gap within the literature around what are the perceived barriers and facilitators to performing major foot and ankle surgeries as day-case and no specific guidelines for foot and ankle day-case surgery. The aim of this survey therefore was to scope the current practice of UK foot and ankle surgeons in terms of perceived barriers and facilitators to performing day-case surgery for major foot/ankle procedures.

MATERIALS AND METHODS

A cross-sectional survey (Table 1) consisting of 19 questions was created using the online platform SurveyMonkey. The questionnaire was designed following a qualitative synthesis of published literature. The questions were broken into 3 separate categories to evaluate: current practices and protocols, pre-operative and post-operative management and what are the perceived barriers and facilitators of performing major foot and ankle surgeries as day-case.

The study was reviewed and approved by the British Orthopaedic Foot and Ankle Society (BOFAS) Scientific Committee who also deemed the proposed statistical methods as appropriate. The questionnaire was sent to the membership of BOFAS *via* an administrator. It was sent to 605 recipients of whom 482 were full BOFAS members. A total of 365 recipients opened the email and 152 started the survey. For the purpose of this survey a major foot and ankle procedure was defined as surgery that is usually performed as an inpatient (*e.g.* ankle fusion, reconstruction). Day-case surgery was defined as patients that were discharged on the same day, with day surgery as the intended treatment pathway. There were two rounds of communication *via* email, the survey was then closed and data extracted into Microsoft Excel. The available data was analysed (as proportions/percentages) and free-text responses were tabulated for word clouds to be generated.

RESULTS

The survey design allowed multiple responses to some of the questions and this was taken into account in the final analysis.

Population

Out of 132 respondents, 120 were foot and ankle surgeons and 12 were trauma and orthopaedic consultants. The majority (80%) worked in acute NHS care trusts and a proportion (28%) had additional work within private or district healthcare. 20% worked in just private or district general hospitals. 11% of those working in private practice only, 29% work in district general hospitals and 7% work in both private practice and district general hospitals.

Current practices and protocols

Table 2 outlines the responses for current practices and protocols. The most responses when asked approximately how many major foot and ankle surgeries are performed in their centre in 1 calendar year was less than 100 (45%) and 200-500 (22%) with an average of 31.5% being performed as day-case. 78% of all respondents think there is a potential for more major foot and ankle surgeries to be performed as day-case in their centres. From the total respondents 48% said they did follow a protocol, 90% following their local protocol and 10% following generic national guidance.

The most common type of anaesthetic used was a combination of general and regional anaesthetic (81%) the second highest was specific blocks *e.g.* popliteal, ankle *etc.* (76%). 64% of respondents put both a combination of regional and general as well as specific blocks. 64% of respondents do not routinely discharge patients with opiate/controlled drugs post-surgery.

Table 1 Survey sent to British Orthopaedic Foot and Ankle Society membership list in August 2021

Question 1
What is your occupation?
Open-response
Question 2
In what setting do you work? Select all that apply
Acute NHS Trust -specialist foot and ankle unit
Acute NHS Trust – non specialist foot and ankle unit
District General Hospital
Community care
Private practice
Question 3
Please estimate the number of major foot and ankle procedures that your primary centre performs in 1 calendar year
Less than 20
20-50
50-75
75-100
100-200
200-500
500-1000
Over 1000
Don't know
Question 4
Please estimate what percentage of these major ankle and hindfoot procedures are performed as day case procedures
Open response
Question 5
Do you think there is potential for more of these cases to be done as day case in your own unit?
Yes
No
Question 6
Do you follow a protocol for day case procedures?
Yes- national
Yes- local
No
Unsure
Question 7
If you follow a national protocol for day case surgery, please state which one
Open-response
Question 8
Which type of anaesthesia do you offer for day case procedures? Tick all that apply
Don't know
Regional
General

Combination of GA and regional

Specific blocks

Question 9

If you use blocks, please state which

Open-response

Question 10

Do you routinely discharge day case patients with opiate/controlled drugs such as oxycodone/oromorph?

Yes

No

Unsure

Question 11

What post-op analgesia do you offer for day case procedures? Tick all that apply

Don't know

Amitriptyline

Gabapentin

Ibuprofen

Paracetamol

Codeine

Other: Please state

Question 12

Are all patients seen by physiotherapy pre-op for walking aid/ weight bearing instruction and education?

Yes

No

Unsure

Question 13

Are all patients seen by physiotherapist post-op (before discharge) for walking aid instruction and education?

Yes

No

Unsure

Question 14

Is a post-op phone call/email/text message made to the patient?

Yes

No

Unsure

Question 15

If yes who provides this contact?

Open-Response

Question 16

Which outcome measures are recorded for day-case patients? Tick all that apply

pain levels using Visual Analogue Score (VAS)

patient satisfaction, please state which measure

complication rate and type

MOX-FQ

EQ-5D
Other (please specify)
Question 17
What are the barriers for day case surgery for major foot and ankle procedures in your unit?
No provision of physiotherapist out of hours
No anaesthetist to perform peripheral nerve blocks
Lack of managerial support
Out of hours support/ point of contact for patients not available
Never done it before
No physiotherapy input at pre-assessment
Other: Please state
Question 18
Which complications have you witnessed or heard about in major foot and ankle procedures done as a day case? Tick all that apply
Wound healing problems
Wound infection
Breakthrough pain
Patient dissatisfaction
Unplanned readmission
Need for further surgery
Delayed/non-union
Other, please state
Question 19
When and how are patients first re-evaluated after discharge? Tick all that apply for
24 h face to face
24 h telephone call
1 wk face to face
1 wk telephone call
2 wk face to face
2 wk telephone call
6 wk face to face
6 wk telephone call
Other: Please state

GA: General Anaesthetic.

Pre and post-operative management

Table 3 shows all responses for pre-operative and post-operative management. Physiotherapy assessment was performed pre-operatively (61%) and post-operatively (70%). The most common post-operative analgesic drugs used are paracetamol (86%) and codeine (84%) or a combination of the two (80%). 42% offer ibuprofen, paracetamol and codeine. The majority of surgeons responded that they did not routinely discharge patients with opiates/controlled drugs such as; oramorph or oxycodone (64%).

Barriers to increasing day-case surgery in major foot and ankle procedures

The top two perceived barriers to performing day-case surgery were lack of physiotherapy input pre/post operatively (23%) and no of out of hours support (21%). Free text responses from respondents were tabulated and created into a word cloud diagram (Figure 1). The main complications respondents have witnessed/heard about in major foot and ankle surgery done as day-case were breakthrough pain (64%) and unplanned readmission (45%). Respondents most commonly reported re-evaluating patients 2

Table 2 Survey results showing current practices of major foot and ankle surgeries within their centre, *n* (%)

Factor	Result
Estimated number of major foot and ankle surgeries performed in 1 calendar year	Less than 100 (*n* = 60) (45)
	100-200 (*n* = 25) (19)
	200-500 (*n* = 29) (22)
	500-1000 (*n* = 9) (7)
	Over 1000 (*n* = 2) (2)
	Unsure (*n* = 7) (5)
Estimated procedures performed as day-case	0-50 (*n* = 99) (75)
	50-100 (*n* = 30) (23)
	Unsure (*n* = 3) (2)
Is there a potential for more to be done as day-case	Yes (*n* = 103) (78)
	No (*n* = 29) (22)
Follow a protocol for day-case	Yes Local (*n* = 57) (43)
	Yes national (*n* = 6) (5)
	No (*n* = 50) (38)
	Unsure (*n* = 19) (14)
Types of Anaesthesia offered for day-case[a]	Regional (*n* = 63) (48)
	General (*n* = 69) (52)
	Combination of regional & general (*n* = 107) (81)
	Specific blocks (*n* = 100) (76)
	Unsure (*n* = 3)
Routinely discharge with controlled drugs	Yes (*n* = 34) (26)
	No (*n* = 85) (64)
	Unsure (*n* = 13) (10)

[a]Percentage is more than 100 as respondents can select more than 1 option.

weeks post operatively, and this being face to face (90%) (Table 4).

DISCUSSION

Main findings

This survey found that there are a small number of major foot and ankle surgeries taking place as day-case within the centres of respondents. The majority of those who responded believed that there was scope to perform more major foot and ankle procedures as day-case. The main perceived barriers for performing more major foot and ankle procedures as day-case were lack of adequate physiotherapy input before or after surgery and lack of out of hours support for patients to contact in an emergency following their surgery. Although lack of physiotherapy input was one of the top perceived barriers, the majority of respondents selected yes to whether patients were seen by physiotherapy pre and post-operatively. This response was in relation to surgeon's current management with no specificity to whether this was inpatient or day-case surgery management.

Previous evidence has suggested that a concern for patients' pain and satisfaction levels post-surgery is a reason for major foot and ankle surgeries to be performed as inpatient over outpatient[8]. This survey found that majority of respondents have heard or witnessed breakthrough pain and unplanned readmissions as the top two complications to day-case surgery, however patients' pain and satisfaction levels was only measured by a third of respondents. The top two highest complications heard/witnessed by respondents agrees with previous evidence however the low response rate to measuring post-operative pain/satisfaction means it is not possible to determine whether these are a barrier to major foot and ankle surgeries being performed as day-case.

Table 3 Survey results showing pre/post-operative management of major foot and ankle surgeries within their centre, *n* (%)

Factor	Result
All patients seen pre-operatively by physiotherapy	Yes (*n* = 80) (61)
	No (*n* = 45) (34)
	Unsure (*n* = 7) (5)
All patients seen post-operatively by physiotherapy	Yes (*n* = 92) (70)
	No (*n* = 28) (21)
	Unsure (*n* = 12) (9)
Post-operative contact made to the patient	Yes (*n* = 20) (15)
	No (*n* = 92) (70)
	Unsure (*n* = 20) (15)
Outcome measures recorded for day-case[a]	VAS (*n* = 45) (34)
	Complication rate & type (*n* = 41) (31)
	Patient satisfaction (*n* = 13) (10)
	MOX-FQ (*n* = 42) (32)
	EQ-5D (*n* = 31) (23)
	Other (*n* = 7) (5)
Types of post-op analgesia offered for day-case[a]	Amitriptyline (*n* = 1) (1)
	Gabapentin (*n* = 5) (4)
	Paracetamol (*n* = 114) (86)
	Ibuprofen (*n* = 64) (48)
	Codeine (*n* = 111) (84)
	Unsure (*n* = 9) (7)
	Other (*n* = 18) (14)
	Paracetamol & codeine (*n* = 105) (80)
	Ibuprofen, codeine & paracetamol (*n* = 55) (42)
	Ibuprofen & paracetamol (*n* = 6) (5)

[a]Percentage is more than 100 as respondents can select more than 1 option.

When observing the outcomes following outpatient total ankle replacements Sadoun and colleagues found that re-admission for acute care did not occur for any patient for haematoma or uncontrolled pain; only 1 patient had delayed wound healing but this did not require any implant revision[18]. The evidence for foot and ankle surgeries such as total ankle replacement and other hind foot procedures is promising and shows that they can be performed safely as day-case. There is, howevera lack of evidence around other major procedures such as ankle fusions being performed as day-case. The safety of outpatient compared with inpatient ankle surgery is comparable and therefore they suggest that outpatient ankle surgeries should be considered for patients that are suitable[19].

Recently, the Get It Right First Time (GIRFT) initiative has been working with British Association of Day Surgery (BADS) to 'address common misconceptions and making the case for expanding and increasing day case surgery, especially at a time when the NHS needs to re-start and catch up with demand for elective surgery following the Covid-19 pandemic'[2]. Part of the work of the GIRFT initiative is to develop a generic day case pathway which can be applied to specific surgical areas. Alongside this, specific best practice pathways, templates and checklists will be produced[2]. Nearly half of the respondents reported that they do follow a protocol for day-case surgeries and this was predominately a local protocol. To our knowledge there are no known national protocols for day-case foot and ankle surgery which could account for the lack of day surgeries taking place within this patient population. This is in contrast to other lower-limb orthopaedics procedures. Therefore by achieving consensus on guidelines and making them more specific for foot and ankle procedures, this may increase the amount of day-case surgeries for foot and ankle. Thereby extending the list of day-case procedures in the BADS directory [1].

Table 4 Results from the survey showing potential barriers to performing major foot and ankle surgeries as day-case within their centre, *n* (%)

Factor	Result
Barriers to performing day-case	No out of hours support (*n* = 28) (21)
	No Physio pre/post-op (*n* = 31) (23)
	No Anaesthetist (*n* = 12) (9)
	Lack of managerial support (*n* = 10) (8)
	Never been done before (*n* = 9) (7)
	Non-response (*n* = 15) (11)
	Unsure (*n* = 23) (17)
	Other (*n* = 7) (5)
Complications heard/witnessed from day-case[a]	Wound healing (*n* = 33) (25)
	Wound Infection (*n* = 23) (17)
	Breakthrough pain (*n* = 84) (64)
	Patient dissatisfaction (*n* = 33) (25)
	Unplanned readmission (*n* = 60) (45)
	Further surgery (*n* = 12) (9)
	Delayed non-union (*n* = 12) (9)
How are patients first re-evaluated after discharge[a]	24 h (Face to face, *n* = 3, 2%) (Telephone, *n* = 14, 11%)
	1 wk (Face to face, *n* = 15, 11%) (Telephone, *n* = 3, 2%)
	2 wk (Face to face, *n* = 119, 90%) (Telephone, *n* = 1, 1%)
	6 wk (Face to face, *n* = 54, 41%) (Telephone, *n* = 2, 2%)
	Other (*n* = 9) (7)

[a]Percentage is more than 100 as respondents can select more than 1 option.

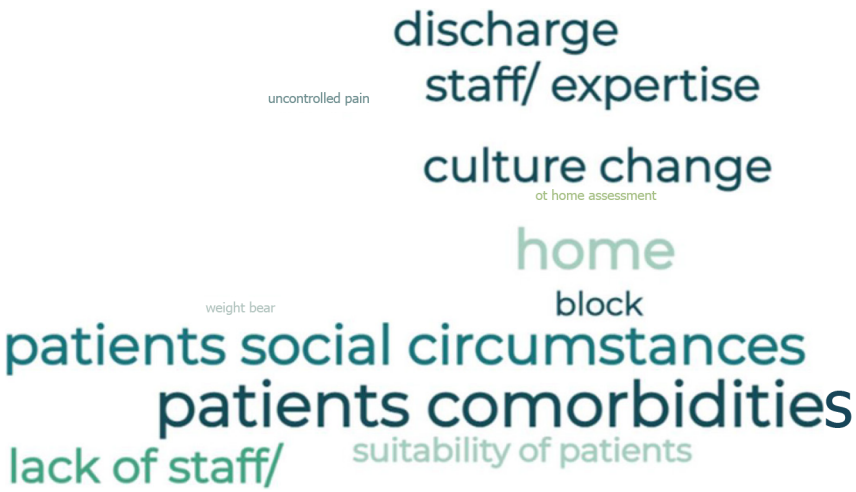

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Figure 1 Word cloud for free text response to barriers to performing major foot and ankle surgeries as day-case.

Limitations

There are limitations within this scoping survey. The survey design in itself relies on accurate self-report by the respondents who may over/underestimate data from their unit. Therefore, the data should be interpreted with caution. The number of responses from the survey was relatively low (37% response rate from those who read the email invitation). This is a fairly typical response rate; however may not be

representative of the BOFAS organisation as a whole. Also the survey was only sent to surgeons; therefore there were no responses from other health professionals who manage this patient group (*e.g.* physiotherapists, plaster technicians). It may be important to capture the views of these professionals in future work. More in depth responses may also be valuable in the form of qualitative interviews/focus groups. For example, it would be useful to know more about in-operative anaesthesia, catherisation and on discharge pain medication.

Future work

Moving forwards to further explore/overcome the facilitators and barriers for performing major foot and ankle surgeries as day-case would include; out of hours support, therapy input pre and post-op, standardising outcome measures, patient education and culture shifts within patient and professionals mind sets. Breakthrough pain and unplanned readmissions were the most prevalent complications heard about/witnessed from day-case surgery in respondents and could therefore influence decisions about performing this type of surgery. Further work to address these risks is warranted. Future work should explore a cost effectiveness analysis of increasing day-case surgery in major foot and ankle procedures.

CONCLUSION

We have identified an appetite to increase the number of major foot and ankle procedures within UK foot and ankle surgeons who completed our survey. Post-operative pain and patient satisfaction was only measured by a third of those surveyed; despite theoretical concerns about these outcomes. Out of hours support and physiotherapy input were perceived as the main barriers to doing day-case surgery in foot and ankle surgery.

ARTICLE HIGHLIGHTS

Research perspectives

There is a need for nationally agreed protocols to optimise the delivery of and measurement of outcomes in this type of surgery. At a local level, the provision of physiotherapy and out of hours support should be explored at sites where this is a perceived barrier.

Research conclusions

There is consensus amongst United Kingdom (UK) surgeons to do more major foot and ankle procedures as day-case. Despite theoretical concerns about post-operative pain and satisfaction this was only measured by a third of those surveyed. Out of hours support and physiotherapy input were perceived as the main barriers.

Research results

A total of 132 respondents completed the survey and 80% worked in Acute NHS Trusts. Currently 45% of respondents perform less than 100 day-case surgeries per year for these procedures. Post-operative pain (34%) and patient satisfaction (10%) was not highly measured within their centres. The top perceived barriers to performing more major foot and ankle procedures as day-case were: Lack of adequate physiotherapy input and lack of out of hours support.

Research methods

Online survey sent to British orthopaedic foot and ankle society members. Quantitative and qualitative data collected.

Research objectives

To scope the current practices of UK foot and ankle surgeons on day-case surgery for major foot and ankle procedures.

Research motivation

Day-case is used in other orthopaedic procedures with benefits of patients and providers.

Research background

There are currently no specific guidelines for day-case surgery in major foot and ankle procedures.

FOOTNOTES

Author contributions: Mangwani J, Townshend D, Clayton R contributed to concept; Berry A, Houchen-Wolloff L, Crane N, Clayton R contributed to data collection; Houchen-Wolloff L, Mangwani J, Clayton R contributed to data analysis; Mangwani J, Houchen-Wolloff L, Townshend D contributed to data interpretation; Berry A, Houchen-Wolloff L, Crane N contributed to writing the manuscript; Mangwani J, Crane N, Townshend D, Clayton R contributed to manuscript critical revision.

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CASE REPORT

Subclinical ankle joint tuberculous arthritis - The role of scintigraphy: A case series

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Abstract

BACKGROUND

Tuberculosis remains a complicated problem. A lack of awareness accompanied by difficulty in diagnosis hinders the management of tuberculosis. Delayed management, particularly in osteoarticular regions, results in unnecessary procedures, including joint-sacrificing surgery.

CASE SUMMARY

Three cases of subclinical ankle joint tuberculosis without clear signs of tuberculosis were presented. The efficacy of technetium-99m-ethambutol scintigraphy in diagnosing early-stage tuberculous arthritis is reported.

CONCLUSION

The reports suggested that scintigraphy is recommended to diagnose subclinical tuberculous arthritis, especially in tuberculosis endemic regions.

Key Words: Ankle; Infectious arthritis; Ethambutol; Scintigraphy; Tuberculosis; Case report

Core Tip: Tuberculosis may present in a subclinical state that hindered the diagnosis and subsequent management. Technetium-99m-ethambutol scintigraphy is a useful noninvasive method to detect early stage of joint tuberculosis in which morphological and laboratory changes are still unclear. By using this method, earlier diagnosis and prompt intervention can be made especially in tuberculosis endemic regions, to avoid unnecessary procedures resulting from disease advancement.

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INTRODUCTION

Tuberculosis remains a currently public health problem worldwide, especially in developing countries. The resurgence of this disease, which began in the mid-1980s after a period of decreasing incidence, has been influenced by poverty, failures in the treatment system, immigration, and, unsurprisingly, the human immunodeficiency virus (HIV) epidemic[1,2]. Tuberculosis affects not only the lungs but also any other organs in the body, which is known as extrapulmonary tuberculosis, including osteoarticular sites. Tuberculosis of the foot and ankle is exceedingly rare, accounting for approximately one percent of all cases of osteoarticular tuberculosis[3-5].

The relative infrequency of foot and ankle tuberculosis may result in a lack of awareness among health care providers, and when combined with the similarity of tuberculosis symptoms with those of other diseases, diagnostic delays often occur[5]. The clinical features of this condition at early stages are nonspecific and may result in inadequate treatment and subsequent damage[4]. Subclinical tuberculosis occurs in asymptomatic, immunocompromised hosts, with loss of effective containment. Therefore, subclinical tuberculosis rapidly progresses if left untreated[6].

The final diagnosis of tuberculosis can be made by histopathological testing and/or microorganism culture. However, these methods are hindered by their long processing time and the difficulty of obtaining adequate specimen tissues. Nuclear medicine modalities, particularly Technetium-99m-Ethambutol scintigraphy, are quick and effective methods to diagnose tuberculosis even at an early stage of the disease[3,7].

This report describes three cases of subclinical ankle joint tuberculosis with diagnostic difficulty that were subsequently diagnosed by scintigraphy. All scintigraphy procedures were carried out in the Department of Nuclear Medicine and Molecular Imaging, Hasan Sadikin Hospital, Bandung, Indonesia. Informed consent for publications was obtained from all patients or family. This case series was recognized and approved by Hasan Sadikin Hospital Institutional Review Board No. LB.02.01/X.6.5/250/2022.

CASE PRESENTATION

Chief complaints

All patients presented a slight pain and swelling on their ankle joints for several months.

History of present illness

Case 1: A 17-year-old female presented with slight pain and swelling of the bilateral ankle. The complaint slowly worsened, starting four months prior to the hospital visit. There was no history of injury near the ankle, swelling in any other body regions, fever, chills, or unexpected weight loss. She had taken analgesics for one month, but the pain and swelling remained.

Case 2: A 22-year-old female was referred to our foot and clinic for a chronic ankle sprain resulting from a low-energy trauma. Initial treatment from a previous hospital included immobilization with a semirigid cast for three weeks followed by protective partial weight bearing, along with anti-inflammatory analgesics. After six weeks, she still complained of pain, swelling, and limited motion.

Case 3: A 36-year-old female presented with slight pain and a swollen right ankle that had lasted for two months. There was no history of injury near the ankle, swelling in any other body regions, fever, chills, or unexpected weight loss. She had been given anti-inflammatory analgesics, but the pain and swelling persisted.

History of past illness

No relevant history of past illness was found in Case 1 and 2. However, Case 3 present a pulmonary tuberculosis that might be related to current symptoms.

Personal and family history

No relevant personal and family history was found in all cases.

Physical examination

Case 1: The patient appeared healthy based on general appearance. Upon physical examination, slight swelling was observed by inspection and palpation (Figure 1A). Pain was induced by direct pressure and joint motion, especially ankle dorsiflexion.

Case 2: The patient presented at the clinic using crutches due to difficulty and pain while walking. Swelling was visible on the whole ankle, including the lateral and medial sides (Figure 1C). Pain was induced with palpation and ankle joint movement.

Case 3: She was undergoing pulmonary tuberculosis treatment and had been administered anti-tuberculosis therapy for four months. On physical examination, slight swelling was observed in the ankle region by inspection and palpation (Figure 1E). She was still able to walk normally.

Laboratory examinations

Case 1: Laboratory blood tests showed normal values, including a white blood cell (WBC) count of 8.6 × 10^9/L, erythrocyte sedimentation rate (ESR) of 9 mm/h, and C-reactive protein (CRP) level of 3 mg/L. Other biochemical parameters were within the normal range, and chest radiography was unremarkable.

Case 2: The WBC count was 11.0 × 10^9/L, ESR was 20 mm/h, and the CRP level was 4.9 mg/L. Other laboratory results were within normal reference values.

Case 3: Laboratory blood tests showed a WBC count of 10.4 × 10^9/L, ESR of 25 mm/h, and CRP level of 7.4 mg/L. Other biochemical parameters were within the normal range.

Imaging examinations

Case 1: Plain ankle radiography was inconclusive, showing no localized bony lesion, osteoporosis, or articular changes (Figure 1B).

Case 2: Ankle radiography showed soft tissue swelling without remarkable bony derangement (Figure 1D).

Case 3: Narrowing joint space was observed on plain ankle radiography (Figure 1F).

FINAL DIAGNOSIS

Referring to positive scintigraphy results (Figure 2), all patients were diagnosed as tuberculous arthritis of ankle joint.

TREATMENT

All patients were subsequently given anti-tuberculosis therapy according to extrapulmonary tuberculosis treatment protocol.

OUTCOME AND FOLLOW-UP

Case 1

After the completion of therapy, the symptoms had improved, and she returned to normal daily activities.

Case 2

The symptoms improved afterward, although the patient still needed physical therapy due to ankle arthrofibrosis.

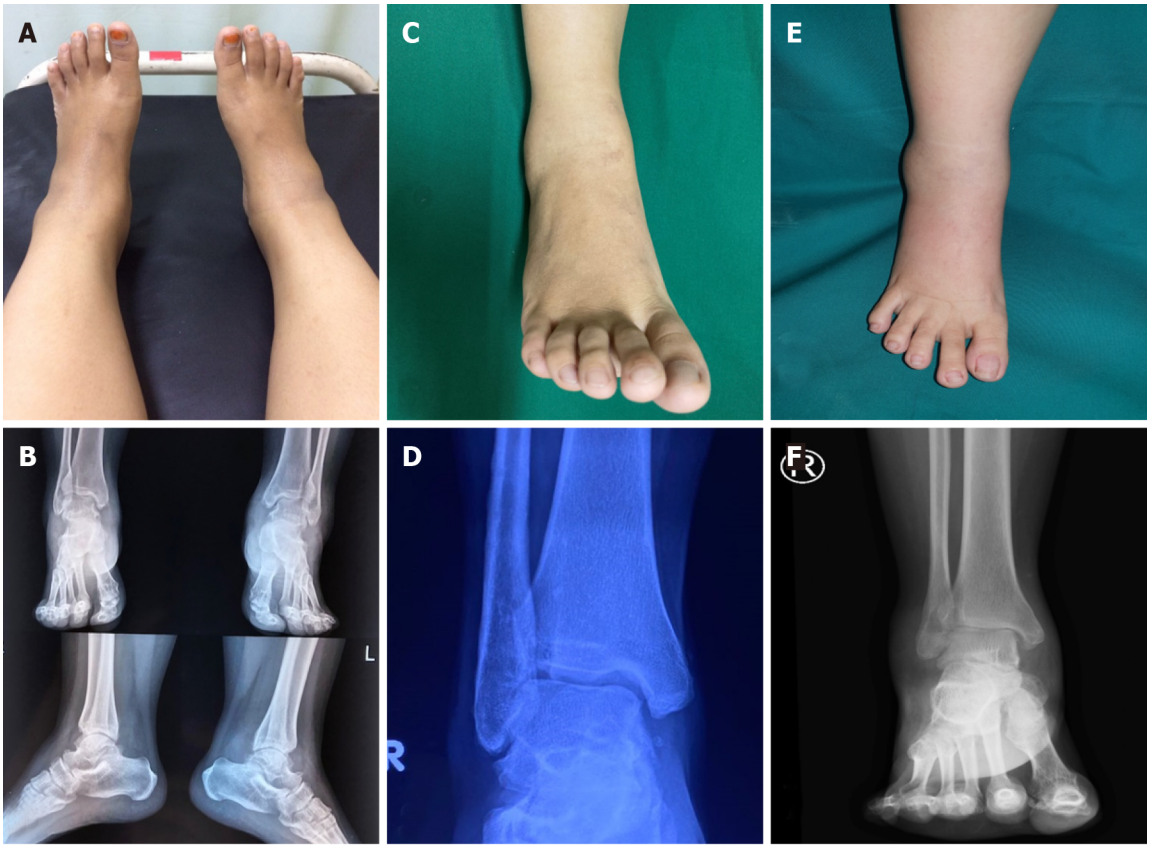

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Figure 1 Clinical and radiological images of case 1, 2, and 3, respectively. A, B: Case 1; C, D: Case 2; E, F: Case 3.

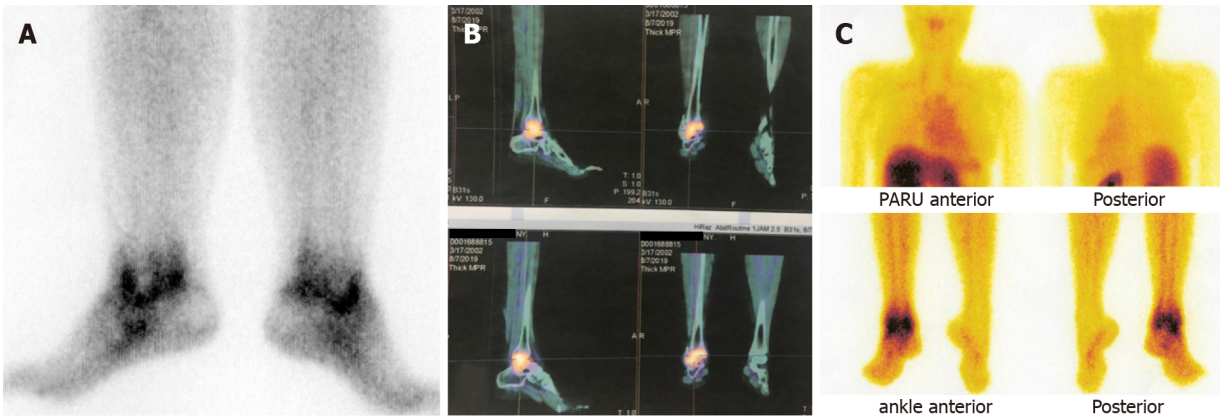

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Figure 2 Scintigraphy images of case 1, 2, and 3, respectively. A: Case 1; B: Case 2; C: Case 3.

Case 3

After the completion of therapy, the symptoms improved, although the swelling did not completely resolve.

DISCUSSION

Subclinical tuberculosis disease is difficult to identify. It may be entirely asymptomatic or may present subtle symptoms that are underreported according to classic tuberculosis symptom screenings. Tuberculous arthritis shows wide variability in clinical symptoms and imaging appearance, ranging from asymptomatic with normal radiographic examination to severe joint pain along with joint destruction. Its slow progression and chronicity cause patients to present with subtle symptoms and

signs, resulting in delayed diagnosis. The identification of people who have asymptomatic tuberculosis is a diagnostic challenge[8,9]. From a public health perspective, the concern is whether these people are infectious or not[10]. The significance from an osteoarticular problem standpoint is that timely intervention will help avoid the sequelae of joint destruction and disability that require joint-sacrificing surgical procedures, such as ankle fusion or arthroplasty.

Clinical features of tuberculosis are nonspecific and may overlap with other conditions, including pyogenic osteomyelitis or arthritis, bone tumors, pigmented villonodular synovitis, avascular necrosis of the talus, and other inflammatory processes[4,11]. However, the diagnosis of mycobacterial arthritis should be entertained when chronic monoarticular arthritis is encountered. The Phemister triad is an eponym that refers to three classic radiological features seen in tuberculous arthropathy: (1) Juxta-articular osteoporosis; (2) peripheral osseous erosions; and (3) gradual narrowing of joint spaces (Figure 3)[12]. A flaky sequestrum in a cavity and/or dystrophic calcification in soft tissue are suggestive of tuberculous pathologies[5]. Specialized investigations, such as computed tomography (CT) or magnetic resonance imaging, may be helpful to assess signals, synovial proliferation, and bone marrow edema. However, radiological findings are still often inconclusive and lack specific findings, especially at an early stage. By the time bony destruction appears, the tuberculosis disease process is severe and capable of contiguous or hematological spread to the sites[13]. Confirmatory tests included the isolation of acid-fast bacilli on specialized culture media and histopathological findings depicting a chronic granulomatous inflammatory process with multinucleated giant cells (Figure 4). A positive Mantoux tuberculin skin test can be obtained in patients with long-standing tuberculosis but is also considered not specific since it can also be obtained in vaccinated populations and in people in endemic areas[5].

Some inflammatory markers, such as those measured in laboratory blood tests, reflect the activity of tuberculosis. In tuberculosis patients, the serum hemoglobin level, red blood cell count, and platelet count are decreased, whereas ESR, CRP, and WBC are increased compared with controls[14]. ESR is an inflammatory marker and reflects the sedimentation of erythrocytes after a period of 60 min. In the acute inflammatory phase, increased serum proteins neutralize red blood cells, resulting in stacking aggregation and subsequent increased ESR[15]. A prior study reported that although an elevated ESR may be expected in tuberculosis patients, one-third of children had a normal ESR at the time of diagnosis[16]. CRP is considered a favorable tool for active tuberculosis screening[17]. CRP is an acute-phase reactant protein that is primarily induced by IL-6 during the acute phase of an inflammatory/infectious process[18]. There are numerous causes for elevated CRP, including acute or nonacute and infectious or noninfectious. Trauma can also cause CRP elevation. However, it is most often associated with infection. The WBC count is increased during infection due to the body's immune defense mechanism that combats invading bacteria, in which the numbers of polymorphonuclear and macrophage cells increase[14]. In these reported cases, all patients' WBC, ESR, and CRP data were within the normal range. Considering the inconsistency of laboratory results for tuberculosis diagnosis, adjunct examination is still needed to establish the diagnosis.

Nuclear medicine scintigraphy is known as a noninvasive diagnostic modality with high sensitivity and specificity for detecting and locating the lesion at an early stage. The metabolic activity of the skeleton can be visualized by bone scan. Nuclear scintigraphy of the bone commonly utilizes the radionuclides technetium-99m or fluoride-18. These molecules are intravenously injected, and then a dual-head SPECT-CT gamma camera is used to capture the decay of photons from the radioisotope at the suspected site[3,19]. Ethambutol is an active specific antibiotic against mycobacterium. Technetium-99m-labeled ethambutol is specifically taken up by *Mycobacterium tuberculosis* and detected under a gamma camera at 1 h and 3 h after the intravenous injection of 370-740 MBq. Technetium-99m-ethambutol remains in tubercular lesions as it is bound to mycolic acid in the cell wall of bacteria but is cleared from nontubercular lesions[7]. The image interpretation was as follows: (1) Normal scan, if there was no pathologically increased uptake other than the normal uptake in the kidney, urinary bladder, liver, and spleen; (2) positive scan, if pathological uptake was observed at the suspected site and gradually increased with time; and (3) negative scan, if pathological uptake was observed at 1 h and gradually decreased (washed out) at the 3-h image[3]. Negative scan implies that the tuberculosis infection is not established, as the strong bond between technetium-99m-ethambuthol and the mycobacteria is not formed. Other radiopharmaceutical agents have also been introduced, such as ciprofloxacin and isoniazid. Technetium-99m-ciprofloxacin can be useful for bacterial infection imaging but cannot differentiate tuberculosis from other bacterial infections, as it acts as a broad-spectrum antibiotic that can be taken up by any living bacteria. Technetium-99m-isoniazid has also been developed but is not widely used clinically[7,20]. This method results in only minimal or no side effects, since the dosage of radiotracer given to the patient is only 2 mg and excreted through the physiological process[3].

The basic principles of tuberculosis control include early detection and well-timed management of the affected patients. There was a clear association between delay of treatment and clinical severity at presentation due to the longer time for disease progression[21]. In general, in septic arthritis, when the infection is not cleared quickly, the potent activation of the immune response with the associated high levels of cytokines and reactive oxygen species leads to joint destruction through glycosaminoglycan loss[22]. The infection process also promotes joint effusion that increases intra-articular pressure,

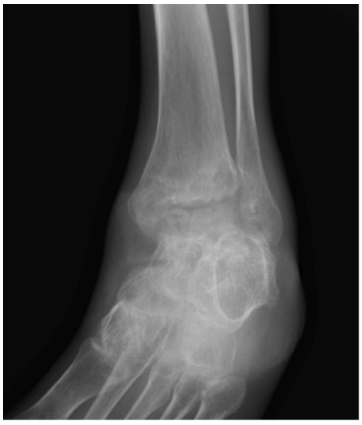

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Figure 3 Radiological image depicting Phemister Triad.

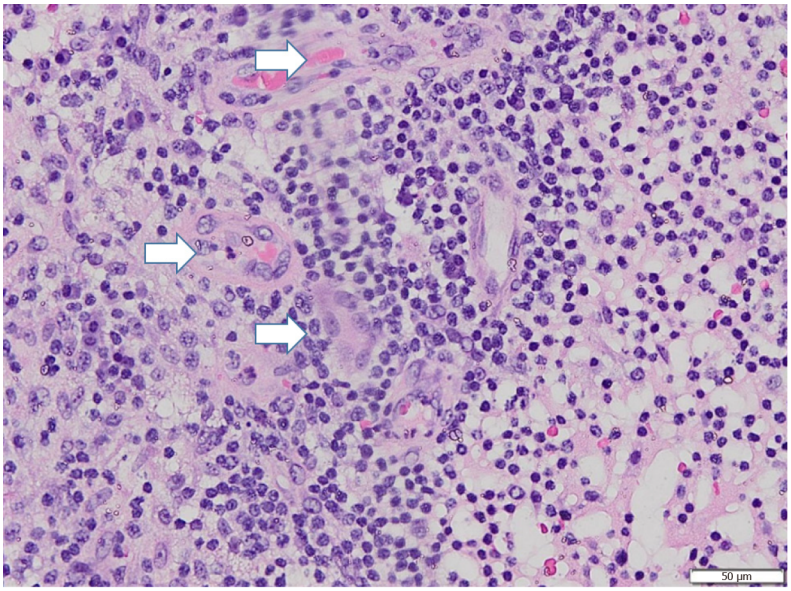

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Figure 4 Histopathological image showing multinucleated giant cells (arrows).

mechanically hindering blood and nutrient supply to the joint and causing damage to the synovium and cartilage[22]. In tuberculous arthritis, cartilaginous tissue is more resistant to destruction. However, penetration of the epiphyseal cartilage plate occurs more often in tuberculous disease than in pyogenic infection . In these cases, anti-tuberculosis drugs were directly given to the patients after a positive scan. All patients had received systemic antituberculosis drugs under an extrapulmonary tuberculosis treatment protocol consisting of two months of combined rifampin, isoniazid, pyrazinamide, and ethambutol, followed by ten months of rifampin and isoniazide. This treatment approach was in line with a prior report that allowed the anti-tuberculosis regimen to proceed to the histopathological examination first[3]. In our institution, technetium-99m-ethambutol scintigraphy has been chosen for many orthopedic cases with tuberculosis suggestion. Kartamihardja *et al*[7] had reported that as much as 78% subjects with tuberculosis infection were positive on both technetium-99m-ethambutol scintigraphy and microbiological/histopathological findings, and 14.9% subjects presented negative results on both examinations, yielding more than 90% specificity. However, there are still 12 (7.1%) discordant results between examinations[7].

CONCLUSION

This report showed that technetium-99m-ethambutol scintigraphy is simple and effective for detecting subclinical tuberculosis in the ankle joint. Patients with a positive result could be directly treated with anti-tuberculosis drugs. The advantages of this method include the rapid results, noninvasive features,

ability to detect disease in early stages, and avoidance of the risk of inadequate tissue specimens. The use of this method for diagnosing such cases should be advocated, especially in tuberculosis endemic regions, to avoid treatment delays.

FOOTNOTES

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