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REVIEW

Anterolateral complex of the knee: State of the art

Luigi Sabatini, Marcello Capella, Daniele Vezza, Luca Barberis, Daniele Camazzola, Salvatore Risitano, Luca Drocco, Alessandro Massè

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Abstract

Rotatory instability of the knee represents the main reason for failure and poor clinical outcomes regarding anterior cruciate ligament (ACL) reconstruction techniques. It is now clear that the anterolateral complex (ALC) of the knee possesses a fundamental role, in association with the ACL, in controlling internal rotation. Over the past decade, ever since the anterolateral ligament has been identified and described as a distinct structure, there has been a renewed interest in the scientific community about the whole ALC: Lateral extra-articular tenodesis have made a comeback in association with ACL reconstructions to improve functional outcomes, reducing the risks of graft failure and associated injuries. Modern ACL reconstruction surgery must therefore investigate residual instability and proceed, when necessary, to extra-articular techniques, whether functional tenodesis or anatomical reconstruction.This review aims to investigate the latest anatomical and histological descriptions, and the role in rotational control and knee biomechanics of the ALC and its components. The diagnostic tools for its identification, different reconstruction techniques, and possible surgical indications are described.. In addition, clinical and functional results available in the literature are reported.

Key Words: Knee; Knee dislocation; Anterior cruciate ligament reconstruction; Fascia lata; Tenodesis; Joint instability

Core Tip: Residual rotatory instability is present in a significant percentage of patients who underwent anterior cruciate ligament (ACL) reconstruction. Regardless of the injured structure of the anterolateral complex involved, whether the anterolateral ligament itself or different iliotibial band layers, the combination of a lateral extra-articular tenodesis technique has proven to be a safe, easily reproducible, and effective practice in reducing tibial internal rotation, improving ACL graft survival, reducing the overall reintervention rate, and improving the rate of return to previous athletic activity.

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INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction techniques have sought to restore knee kinematics and reduce rotational instability. Since the 1970s[1] the idea that anterolateral rotatory instability (ALRI) was due not only to ACL injury, but also to the structures of the anterolateral complex (ALC), began to catch on. Over the last decade, awareness of the ALC has increased, especially since the anterolateral ligament (ALL) has been described and identified[2]. Several biomechanical studies have been carried out and different reconstruction techniques have been proposed.

The anterolateral ligament of the knee is a distinct ligamentous structure about which there is no consensus regarding its function and existence. Some authors deny the existence of such a structure, emphasizing the importance of other anatomical structures, such as the deeper portion of the iliotibial band (ITB) and the anterolateral capsule[3,4]. In contrast, other studies have identified the ALL as a ligament in its own right[5,6]. This disagreement originates from the anatomic dissection techniques that are performed[7,8].

Associated ACL and ALL injury have been shown to significantly increase knee rotational laxity and tibial internal rotation (IR), posing as the background for suboptimal outcomes, potential failure of an isolated ACL reconstruction (ACLR), and secondary meniscal or cartilage injury, as well as for early development of arthritic degeneration[9]. Controlling rotational laxity in ACLR still remains a challenge, with evidence of ALRI persistence in up to 25% of patients regardless of the ACLR technique used[10]. Several studies, in the last years, have identified the ALC as responsible for this residual instability and have pointed at the ALL and the ITB as the main players to internal tibial rotation restrain.

To improve residual rotational instability, more anatomical ACLR techniques have been developed, seeking a more oblique path of the femoral tunnel using the medial portal technique. Recently, the addition of a posterolateral bundle to the anteromedial bundle in double-bundle ACLR has been proposed; however, the technique did not improve rotatory stability and it has now been almost abandoned[11].

HISTORY

Although there have been sporadic references before 2013 about the existence of a capsuloligamentous structure connecting the femur and tibia in the anterolateral region, descriptions have been vague and often in disagreement. The first reference to the ALL date back more than 100 years. Segond[12], in 1879, described an avulsion fracture of the anterolateral margin of the tibia. He reported a "pearly band extending in an oblique fashion from the femur inserting into the avulsed tibial bone" without elaborating further on the details and anatomical relationships of this structure. However, this finding was ignored until it was rediscovered in a study by Hughston *et al*[1] in the 1970s in which they illustrated different patterns of rotational instability. They described a structure, called the "mid-third lateral capsular ligament", that was intimately connected to the lateral meniscus and how it could be involved in rotational instability. This structure, however, was not mentioned again, except sporadically in subsequent studies. In the same year, Johnson[13] described "the anterior oblique band of the lateral collateral ligament." On the other hand, Terry *et al*[14] pointed out that the main players in the antero-lateral region were the deep, capsulo-osseous and superficial layers of the ITB without making references to distinct structures that could refer to the ALL.

In 2007, Vieira *et al*[15] described how the capsulo-osseous layer acts as "an anterolateral ligament". This term was used a few years later by Vincent *et al*[16] who identified, during TKA implantation, a ligamentous structure with connections to the distal femur, proximal tibia, and lateral meniscus in the anterolateral region of the knee. Nevertheless, before the study by Claes *et al*[2] in 2013 that was the first to provide a detailed description of ALL, this term was used to identify likely different structures and to

describe their role in the rotational control.

ANATOMY

According to Claes *et al*[2], a distinct anatomical structure connecting the distal femur and proximal tibia can be distinguished on the anterolateral portion of the knee. The structure is entirely extracapsular. The proximal insertion point lies on the prominence of the lateral femoral epicondyle, anterior to the fibular collateral ligament (FCL) insertion and proximal and posterior to the insertion of the popliteus tendon; the distal insertion of the ALL is located posterior to Gerdy's tubercle and anterior to the head of the fibula[17-19]. However, it is possible to recognize more superficial fibers that continue into the lateral intermuscular septum of the thigh and more posterior fibers that are closely connected to the more proximal portion of the FCL[2]. Connections to the body of the lateral meniscus also belong to the ALL, divided into meniscofemoral and meniscotibial portions. The lateral inferior geniculate artery and the vein invariably run between the ALL and the lateral meniscus.

Since the femoral insertion points of ALL and FCL are in close relationship, both structures can be described with the term "lateral collateral ligament complex." Likewise, the ALL could be the lateral counterpart of the deep medial collateral ligament[2]. However, some studies, have emphasized how the ALL structure and location can vary[20]. While several authors agree in identifying the tibial insertion, the disagreement about the femoral insertion is of particular interest. This discordance has biomechanical implications: The femoral insertion has been described as anterior and distal to the insertion of the FCL[2] or posterior and proximal with the fibers overlapping the FCL itself[18,21]. It is unclear whether this difference is due to interindividual differences or different dissection techniques.

In contrast, another model described by Helito *et al*[22] shows the existence of 2 distinct bundles: A more superficial one with femoral insertion posterior and proximal to the epicondyle and a deeper one with insertion in the center of the epicondyle. It is also likely that the ALL has an intimate relationship with the ITB, supported by a high association of lesions of the ALL and distal ITB[23].

The latest evidence emphasizes that the control of the ALRI is due to the entire anterolateral complex. The ALC works together with the ACL to restrain internal tibial rotation. The ALC consists of the ALL, the superficial and deep portion of the ITB, the capsulo-osseous layer, and the anterolateral capsule. Indeed, the deep part of the ITB and its complex insertion points at the distal femur contribute significantly to rotational control. Kaplan's fibers (KFs) play a role, along with the ITB, as a secondary passive stabilizer after the ACL[24]. They are described as a deep, posterior portion of the ITB connected to distal femur, divided into two bundles, the proximal fibers (PKF) and the distal fibers (DKF).

The capsulo-osseous layer has been described by Lobenhoffer *et al*[25] as a deep portion of the ITB, an arcuate retrograde fiber tract extending from the intermuscular septum of the femur in the lateral supracondylar region to the Gerdy's tubercle. This ligament-like unit forms a sling around the postero-lateral aspect of the distal femur. More recent studies[26] have confirmed the presence of this layer as a distinct anatomic entity separated from the ALL and have also suggested a synergistic role of these structures in restraining IR.

HISTOLOGY

The histologic analysis provides evidence of particular interest in demonstrating the existence of the ALL as a distinct ligamentous structure with the presence of dense, well-arranged connective tissue and not as a simple capsular thickening that would have less organized and less cellular tissue[6]. The primary composition is type I collagen (90%) with a fibroblast concentration of 121/m^2 in adults and 1631/m^2 in fetal preparations[27]. In a study, by Caterine *et al*[28], the ALL shows fascicular organization in cross-section and also mechanoreceptors and nerve terminal fibers. Likewise, in an *in vivo* study of patients undergoing TKA, it was shown that the structure of ALL, compared to ACL, owned a similar pattern of collagen fibers orientation, nuclei's form, and a similar cellularity[29]. Furthermore, a clear distinction between ALL and capsule is present since the joint capsule resembles a loose connective tissue. Additionally, the ALL femoral insertion shows a transition from ligamentous tissue to mineralized cartilage and bone; this transition indicates ligamentous tissue[28].

IDENTIFICATION OF ALL

Although ALRI must be clinically assessed, there are diagnostic tools that allow visualization of the ALL.

Magnetic resonance imaging

Scientific studies that have investigated anterolateral complex lesions in patients with ACL injuries with

magnetic resonance imaging (MRI) often highlight conflicting results with association rates from 40% to 80%[30,31]. These discrepancies may be due to inclusion criteria, in some studies, of patients with chronic ACL injuries.

To visualize more easily a thin structure, such as the ALL, the use of a 3 T MRI with 0.4-mm slice and fat-suppressed acquisition is recommended[28] (Figure 1). In a study by Helito[32], MRIs of patients with acute ACL lesions were analyzed to point out the injured structures that were most frequently associated with an ALL lesion: FCL (P = 0.004), popliteal tendon (P = 0.005), MCL (P = 0.011), anterolateral capsule (P = 0.000034), and ITB with an increased correlation with a greater degree of injury (P = 0.000021). Tears of the ALL are found in 40% of acute ACL injuries, whereas no association was found with meniscal injuries. There was also no association between ALL injury and partial ACL injury, suggesting that the ALL is torn only in major traumas or that its integrity is a protective factor for ACL [32].

A systematic review by Puzzitiello *et al*[33] concluded that at least a portion of the ALL is visualizable on MRI in 76-100% of knees, and its possible injury in patients with acute ACL injury is identifiable from 10.8% to 62.5% of cases. Additionally, the level of inter- and intra-observer reliability varies from moderate to almost perfect. A higher prevalence of ALL lesions has been identified in MRI in patients with acute ACL injury and high-grade pivot shift with a positive correlation between pivot shift grade and lesion severity (P < 0.013)[34]. The finding of these injury associations helps to delineate how the anterolateral rotational stability of the knee is due to the synergistic work of these structures.

Arthroscopy

Several authors have described the possibility of arthroscopic identification of ALL and have provided step-by-step descriptions[35]. According to Zein[35], it is possible to identify it with a 30° scope through the AL portal. It is necessary to place the limb in a figure of-4-position. In the lateral compartment, the popliteal tendon (PT), popliteal hiatus and synovial bulge anterior to the meniscal bare area are identified. By advancing the arthroscope into the lateral gutter above the synovial bulge, PT, FCL, and ALL can be identified, which run in different planes and directions. Applying an internal rotation, a tensioning of ALL can be observed. It is also possible to identify the meniscotibial attachment of the ALL below the lateral meniscus, anterior to the PT.

BIOMECHANICS

Regarding the ALL, there is no agreement in the literature regarding its role in knee biomechanics. While in some studies it has been shown that the ALL possesses a stabilizing role in an extension and internal rotation position[36], in a cadaveric study[37], the ALL limits internal rotation only at flexion angles greater than 35°, while providing minimal resistance to anteroposterior translation. However, it must be pointed out that the differences reported in these studies may be due to the dissection techniques adopted. In the study by Rasmussen *et al*[36], the ALL was not dissected but all anterolateral structures, from Gerdy's tubercle to the head of the fibula, were sectioned not considering that additional structures of the ALC might affect stabilization. Given that additional evidence points to the ITB as the main restrain to internal rotation[38], having it removed may have overestimated the role of the ALL.

It must be remembered that the ligamentous structures of the knee are unlikely to possess isometric behavior, and the various surgical techniques that seek isometric reconstruction fail to achieve anatomic positioning. Although the geometry of the condyles would make the area through which the transepicondylar axis passes a relatively isometric insertion zone, the roll-glide mechanism of the lateral condyle makes it impossible to find isometric femorotibial connections[39]. Structures, that therefore insert posteriorly to the epicondyle, are strained in extension, whereas anterior structures are strained in flexion.

In agreement with previous studies, Sonnery-Cottet *et al*[40] demonstrated how a section of the ALL did not lead to an increase in tibial IR at 20° of flexion angle but increased it at 90° and also showed that the ITB also participates in rotational control. In a study by Noyes *et al*[41], after sectioning of the ALL and the ITB, in agreement with evidence demonstrating a synergistic role of these structures in limiting IR, an increase of 5.1° at 60° of flexion and 6.7° at 90° of flexion has been observed. The latest evidence (in cadaver biomechanical studies) agrees that the ALL possesses an IR stabilizing function only at high degrees of flexion. Only at flexion angles of 60° and 90° a restriction to the IR by the ALL can be observed[42]. These results indicate that the ALL does not own a role in the pivot shift phenomenon that occurs at flexion degrees of 20°-30°[43], and one must therefore look for the ALRI responsible not in a single structure, but in the entire ALC. Terry *et al*[14] showed, in a cadaveric study of 82 knees, an anterolateral capsular lesion in 93% of patients with ACL injury and that this damage was significantly correlated with the degree of pivot shift.

It must be pointed out, however, that this evidence come from *in vitro* studies. Since anatomical dissections demonstrate connections between the ALL and ITB by Kaplan fibers, the actual function *in vivo* might prove to be different as the ITB might dynamically influence the ALL tension[42]. Zens *et al*

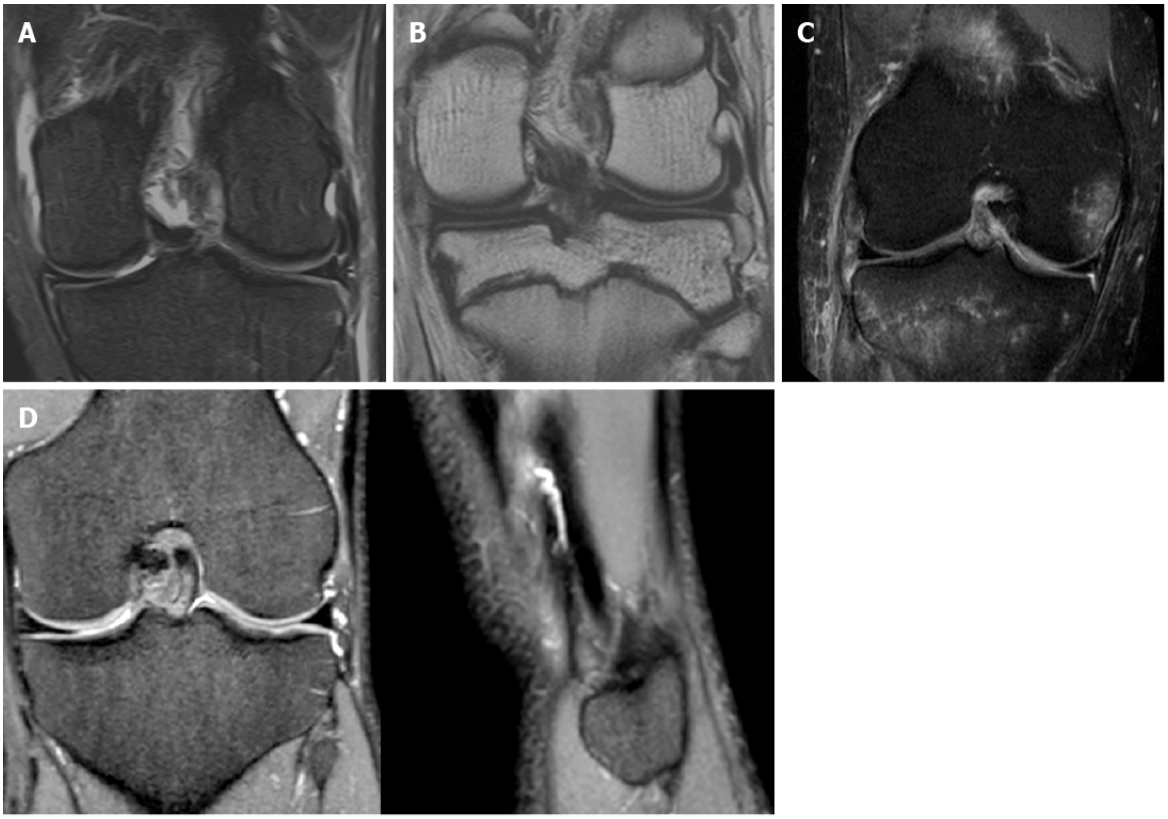

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Figure 1 Magnetic resonance imaging. A: Coronal T2 magnetic resonance imaging (MRI) showing a partial anterolateral ligament (ALL) lesion; B: Coronal T1 MRI showing a partial ALL lesion; C: Coronal STIR MRI showing a complete ALL lesion; D: Coronal and Sagittal T2 MRI showing an intact ALL.

[44] observed, in a cadaveric study, a progressive increase in the length of the ALL in the passive range of motion from 0° to 90° with an average increase of 0.15% per degree of flexion. They also observed that the greatest change in length (+33.77% ± 9.62%) was observed at 90° flexion in 25° internal rotation.

Through biomechanical studies, the failure of the ALL has also been demonstrated to occur in: Ligamentous tear at the tibial or femoral insertion point, intrasubstance tear, or complete tibial detachment with bone fragment avulsion (Segond fracture)[45].

In contrast, according to a robotic study by Kittl *et al*[46], it is the ITB that provides the greatest resistance to tibial IR (44%). The deep fibers of the ITB, Kaplan fibers, act as an IR stabilizing ligament, fixing the ITB against the lateral epicondyle[47]. Indeed, after a section of the KFs, it's been observed that the ITB is no longer attached to the lateral epicondyle, thus losing its effectiveness in rotational control[48]. The role of the KFs was also confirmed by Geeslin *et al*[49], demonstrating that sectioning of the KFs resulted in an IR control loss from 30° to 90° of flexion.

In summary, anterolateral soft tissues contribute to rotational stability in ACL-deficient knees, with the deep ITB possibly playing a more important role closer to extension than the ALL, which has a greater control of IR at higher flexion angles.

ALC STIFFNESS

A study by Wytrykowski *et al*[50] analyzed the stiffness of the ALL (21 N/mm) and the load at failure (141 N), and also described the load at failure of the gracilis tendon (200.7 N) and ITB (161.1 N). Other biomechanical studies have measured the mean maximum load during pull-to-failure testing of KFs (170 N for DKF and 71.3 N for PKF), and thus, suggest an important role for resistant structures like the ALL[26]. It follows that both LETs and anterolateral ligament reconstructions (ALLRs) with ITB strips and gracilis grafts own sufficient strength for anterolateral procedures.

INDICATIONS

The clinical indications for ALLR or LET are not clearly defined, and level one clinical studies are currently lacking. It has not yet been established whether there is significant clinical knee instability that

requires correction with an additional procedure.

Currently, the indication to perform an extra articular procedure associated with ACL reconstruction is based on preoperative clinical evaluation and patient characteristics. Radiologic investigation is not routinely used as an objective assessment of ALL stability because relatively small lesions can be easily missed in a setting of more obvious associated injuries. Some authors recommend the routine use of such procedures in all ACL reconstruction[51,52].

In contrast, other authors recommend an associated procedure only in selected cases[41] based on comparative studies that have demonstrated significant benefits in specific populations, such as: ACL revisions[53,54], chronic ACL injuries[55], patients with high-grade pivot shift[10,56], patients with Segond's fracture[10], patients with hyperlaxity[55], or in high demanding patients with a need to return to high levels of sports activity and pivoting activities[52] (Table 1).

LATERAL EXTRA-ARTICULAR TENODESIS (LET)

Lateral extra-articular tenodesis was originally used as an isolated technique in patients with ACL deficiency. Several LET techniques showed good clinical results in the short term[57]. However, long-term results highlighted that isolated LETs tended to fail, returning again to a condition of rotatory instability[58].

After performing LETs extensively in the early 1980s, there is now renewed interest in these techniques as combined procedures for ACL reconstruction. These procedures were initially abandoned because of concerns about excessive constraint of the lateral compartment and potential development of osteoarthritis.

More than 12 LETs (Table 2) have been described, most of which use a variable-length ITB strip passed underneath the FCL and attached at various points on the lateral femoral condyle or at Gerdy's tubercle. The FCL acts as a pulley above the graft while maintaining a relative isometry of the graft itself. However, clinical studies to determine the superiority of one technique over the others are lacking. A correlation can be established on the biomechanical function of KF and LET techniques since both provide a connection between the ITB and the distal femur to control IR.

Recently, some authors have described a "more anatomical" extra-articular tenodesis that aims to tension the capsulo-osseous layer and reconstruct the distal KFs[59]. An ITB strip is elevated, maintaining the distal insertion, passed over the FCL, and then fixed into a tunnel drilled at the level of a bony prominence 31.4 mm proximal to the lateral epicondyle (DKF insertion point).

Over the past few years, the authors have tried the use of different LETs and have decided to use mainly the Cocker-Arnold technique. It is a simple technique, easily reproducible, and does not require the preparation of tunnels or the use of suture anchors. The Cocker Arnold technique has proven effective in patients with a preoperative pivot shift 2+ or 3+ at decreasing the phenomenon and reducing the ALRI[60]. Good results were also found in ACLR revisions in high function demand patients with an excellent return to sport rate[61].

Cocker Arnold Mod. Technique[62]

A longitudinal, 10-cm, slightly curved incision is made just posterior to the lateral femoral epicondyle. Dissection continues by identifying the posterior margin of the ITB and removing any fascial attachments down to the level of Gerdy's tubercle. A 1-cm-wide, 8 to 10-cm-long strip of ITB is elevated from the anterior aspect of the posterior half of the ITB. The insertion of the ITB strip to Gerdy's tubercle is preserved, removing any deep attachments of the strip from the vastus lateralis. Identification of the FCL is performed by palpation, facilitated by placing the knee in a figure-of-4 position, which stretches the ligament. Once the FCL has been identified, a blunt dissection is made anteriorly and posteriorly to the proximal portion of the ligament. Efforts should be made to remain extracapsular in order not to damage the popliteal tendon. The ITB graft is then guided under the FCL from distal to proximal, flipped over the Gerdy's tubercule, and sutured to itself using a high resistance non adsorbable suture, with the knee in near full extension and neutral rotation (Figure 2).

ANTEROLATERAL LIGAMENT RECONSTRUCTION

The concepts of ALLR and LET are sometimes used synonymously, since these procedures share conceptual similarities in terms of technique and goals. However, in ALLRs an anatomical reconstruction of the ALL is sought, while in LETs a functional and not an anatomical reconstruction is performed.

Several studies have shown that isometry of the graft used in ALLRs is achieved by fixing it distal to Gerdy's tubercle and very proximal and posterior to the distal metaepiphyseal junction of the femur [63]. However, this positioning does not match the anatomic insertions of the ALL. The ALL is an anisometric structure: the length and tension of the ligament changes with knee flexion. The best

Table 1 Indications for an extra-articular procedure

Patients with specific characteristics:
ACL revisions
Chronic ACL injuries
High-grade pivot shifts
Segond's fracture
Hyperlaxity
High demanding patients

ACL: Anterior cruciate ligament.

Table 2 The most performed lateral extra-articular tenodesis

Technique	Description
Lemaire *et al*[87], 1967	An ITB strip is harvested while maintaining the distal insertion, and then passed under the FCL and through a semi-circular tunnel created on the lateral aspect of the distal femur. The strip is then reflected and sutured onto itself.
Mod. Lemaire[21,88,89]	An ITB strip is harvested while maintaining the distal insertion, passed under the FCL, and secured to the lateral condyle with an interference screw or a staple.
MacIntosh *et al*[90], 1976	An ITB strip is harvested while maintaining the distal insertion, passed under the FCL, through a subperiosteal tunnel, through the intermuscular septum, back under the FCL, and sutured onto itself.
Losee *et al*[91], 1978	An ITB strip is harvested while maintaining the distal insertion, passed under the FCL, through a femoral tunnel originating at the gastrocnemius insertion point and ending anterior to the FCL. The strip is then sutured onto itself.
Ellison *et al*[92], 1979	A strip of ITB is elevated distally with a bony bract, passed under the FCL, and attached anteriorly to the original insertion.
Arnold and Coker *et al*[62], 1979	An ITB strip is harvested while maintaining the distal insertion, passed under the FCL, reflected, and sutured to itself at Gerdy's tubercle.
Benum[93], 1982	A lateral portion of the patellar tendon is harvested while maintaining the distal insertion, passed under the FCL, and secured with a staple to the lateral condyle.
Andrews and Sanders[94], 1983	Two ITB strips are elevated proximally, whipstitched with sutures that are passed through two parallel tunnels from the lateral condyle to the medial condyle, and then tied together.
Zarins and Rowe[95], 1986	The semitendinosus tendon is harvested while maintaining the insertion, passed through a tibial tunnel, through the joint, and over the lateral condyle below the FCL ,and sutured to the ITB. Similarly, a strip of ITB is harvested proximally, passed under the FCL, over the lateral condyle, through the tibial tunnel, and sutured to the semitendinosus tendon.
Wilson and Scranton[96], 1990	An ITB strip is harvested while maintaining the distal insertion, passed under the FCL and lateral gastrocnemius tendon, and sutured onto itself.
Marcacci and Zaffagnini[97], 1998	The semitendinosus and gracilis tendons are harvested while maintaining the insertion, sutured together, passed through a tibial tunnel, through the femoral notch, and over the top of the lateral condyle. The graft is then passed deep to the ITB, over the FCL, and attached distally to Gerdy's tubercle.

FCL: Fibular collateral ligament; ITB: Iliotibial band.

compromise[64,65] between the anatomic reconstruction and the ideal location of the graft insertions is as follows: At the femur, fixation proximal and posterior to the lateral epicondyle; at the tibia, fixation midway between Gerdy's tubercle and the ALL insertion. Fixation should also be done with the knee extended and the foot in neutral rotation. It is critical not to tension the graft in external rotation to avoid stiffening the knee and increasing stress.

The ALLR technique with the most clinical data available in the literature is reported by Sonnery-Cottet *et al*[10]: They described a combined ACL and ALL reconstruction technique using a 3-strand semitendinosus graft coupled with a free gracilis tendon graft. That resulted in a graft that, therefore, had a quadruple section, used for ACL reconstruction, that continues into a single gracilis strand used for ALL reconstruction. An isometric point near the femoral condyle is identified and drilled with an outside-in technique to serve as both the femoral tunnel for the intra-articular ACL and the femoral attachment for the extra-articular ALL reconstruction. The gracilis strand is then advanced distally into a tibial tunnel with an entry point superolateral to Gerdy's tubercle and then flipped back on itself, resulting in an inverted Y shape. This distal double bundle technique differs from most other ALL reconstruction techniques, which tend to use a free graft and a single tibial fixation point[66,67].

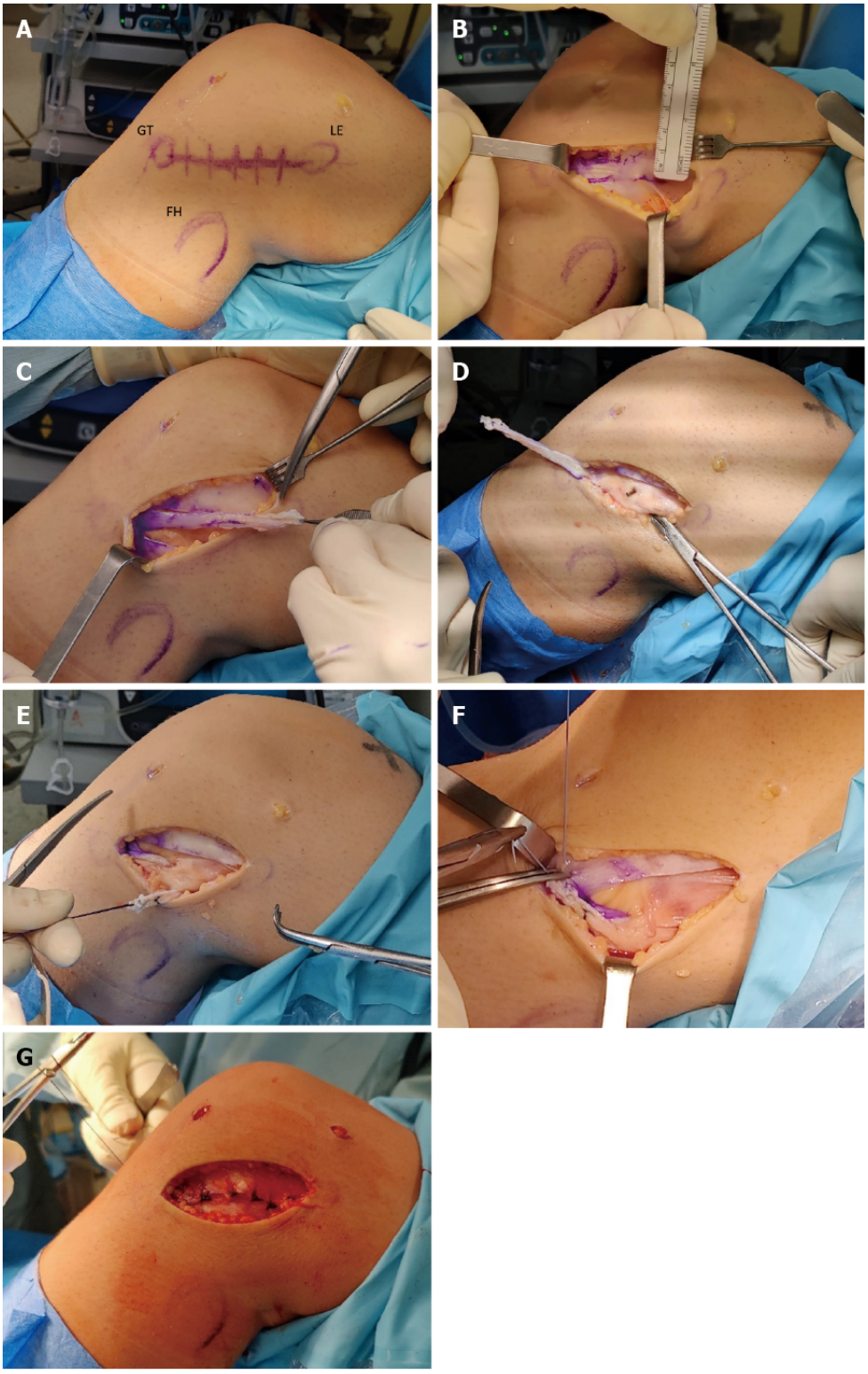

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Figure 2 Cocker Arnold Mod Technique. A: Bony landmarks on the anterolateral aspect of the knee: Gerdy's tubercle, lateral epicondyle, fibular head; B: An iliotibial band (ITB) strip 1cm-wide, 8 cm-long is prepared; C: ITB strip harvesting maintaining the distal insertion; D: Identification of the fibular collateral ligament (FCL) and blunt dissection; E: The graft is passed under the FCL and reflected to itself; F: The graft is sutured to Gerdy's tubercle with knee in extension and neutral rotation; G: The ITB is sutured in a standard fashion.

ALLR *VS* LET

Biomechanical studies explain that LET procedures have an advantageous lever arm in resisting IR compared to ALLR techniques. This is due to the more anterior point of fixation at Gerdy's tubercle, which provides a more efficient force vector[68].

Since a major concern lies in the overconstraint of the lateral compartment[69], several studies have been concerned with analyzing the effectiveness of different techniques at different degrees of tension [70]. The authors verified the optimal graft tension by applying different fixation tensions. The results show that a modified Lemaire tenodesis (in which an ITB strip is elevated, passed under the FCL, and fixed to the distal femur with a suture anchor) can restore proper knee kinematics with a tension of 20 N regardless of the degree of flexion (0°, 30°, and 60°) while maintaining the foot in neutral rotation. An ALL-anatomical reconstruction, on the other hand, cannot sufficiently reduce rotational laxity even at 40 N tension. According to the research of Inderhaug *et al*[71], a double-bundle ALLR (with one femoral attachment point and two distinct tibial attachment point) procedure can restore rotatory laxity when the graft is fixed in full extension. However, it has been reported that flexion-extension of the knee leads to the detensioning of one of the 2 bundles, and therefore the use of a stronger single bundle, has been recommended.

Long-term effects on articular cartilage wear in outcomes of LET or ALLR procedures do not yet have high levels of evidence[72]; however, it makes sense to opt for effective procedures at lower levels of tension in order not to increase the contact pressure of the articular surfaces. In a study by Marcacci *et al* [52], in which patients who underwent ACLR and LET were prospectively followed for up to 13 years, there was no evidence of increased arthritic degeneration when comparing patients who underwent ACLR alone.

Previous studies recommended fixation of the graft (in LET procedures) by maintaining the tibia in an external rotation position. However, more recent studies recommend fixing the graft while keeping the tibia in a neutral rotation position so as not to inhibit physiologic rotational motion[73]. Since anterolateral structures are thought to affect ALRI, it is reasonable to assume that fixation while keeping the knee in extension (at a flexion angle where pivot shift occurs) is favorable for seeking normal knee kinematics[71]. Additionally, the ALL or LET graft is stretched and fixed after ACL graft fixation to minimize the overconstraint.

Regarding the choice of graft, both an ITB strip and a gracilis graft own sufficient strength to vicariate the function of the ALL. In a study by Kittl *et al*[64], patterns of change in length and isometry in lateral extra-articular reconstructions were analyzed. Of the variables examined, only two effectively and reproducibly predicted a relative isometric graft behavior in different degrees of flexion: a graft path below the FCL and a femoral graft fixation proximal and posterior to the lateral epicondyle. In a biomechanical study, it was shown that an anatomic reconstruction of the ALL did not significantly reduce IR or anterior translation. In contrast, a LET procedure significantly improved anterior translation and rotational laxity[21].

Several *in vitro* biomechanical studies have attempted to quantify the efficacy of LET procedures. However, it is difficult to reach objective conclusions of superiority and durability given the large variability in different surgical techniques, graft selection, and type of fixation.

RESULTS

The indication for performing an anterolateral procedure is based on the concept of reducing stress forces on the ACL graft and more accurately restoring normal knee kinematics[74]. Improved knee stability results in a protective effect of the ACL graft and on the menisci[75]. These biomechanical advantages translate into clinical benefits, including reduced risk of ACL graft rupture, higher rates of return to previous sports physical activity, and lower risk of meniscal repair failure[76].

As early as 1990, LET combined with ACLR was shown to reduce graft stress by 43%[77] and combined use is being sought to improve joint kinematics and reduce graft failure rates[78].

Combining an ALLR reduces IR compared to isolated ACLR while having no significant effect on anterior translation. The resulting decrease in IR is more pronounced by increasing the degree of flexion. Specifically, applying a torque of 6 N/m decreased internal rotation of 1.64° ($P < 0.001$) in patients undergoing ACLR + ALLR compared to patients undergoing isolated ACLR[79].

Historically, several ACL reconstruction techniques have been proposed to restore rotational instability. Isolated ACL reconstructions, whether single or double bundle, have failed in the attempt by resulting in a residual rotational laxity. In a study by Monaco *et al*[51], it was demonstrated "*in vivo*" that the combination of a LET with a single-bundle ACLR procedure was significantly more effective than an isolated double-bundle technique ($P = 0.0001$) in reducing tibial IR.

In a study with 2-year follow-up in 502 patients[80], it was shown that the combination of ACLR (with hamstring graft) and ALLR had a 2.5-fold lower rate of ACL graft failure than isolated ACLR with BTPB and 3.1-fold lower rate than isolated ACLR with hamstring graft.

In a recent study by Sonnery-Cottet *et al*[81], it was shown at an average follow-up of 104 mo that patients undergoing ACLR combined with ALLR experienced significantly better ACL graft survival ($P = 0.0027$), lower overall revision rates ($P < 0.05$), lower ACLR revision rates ($P < 0.05$), and comparable complication rates to patients undergoing isolated ACLR. Overall, patients undergoing isolated ACLR had a 5-fold increased risk of ACL revision.

Regarding the concern of developing osteoarthritis in patients undergoing ALLR, there are two possible opposing scenarios to consider. The first factor relates to a possible overconstraint of the lateral compartment resulting in increased contact forces. The second factor, in contrast, concerns the possible residual rotational instability in case an ALLR is not performed, resulting in poor tibial rotation control and the consequent risk of secondary meniscal and chondral injuries. Several studies, however, state that there is no association between ALLR and early development of osteoarthritis compared with patients undergoing isolated ACLR[52,82]. In a multicenter study with 675 patients at 12 years of follow-up[83], there was no evidence of an association between ALLR and arthritic degeneration, which was instead reported mainly in cases of medial meniscectomy.

Recent literature states that, in agreement with biomechanical studies, associating an anterolateral procedure significantly improves a high-grade pivot shift, ensuring better clinical functional outcomes [84,85]. Additionally, subjective scores, such as IKDC and Lysholm and objective tests, such as the KT-1000, are also significantly better ($P < 0.05$) in patients who underwent a combined procedure[86].

ACTUAL LIMITS AND FUTURE PERSPECTIVES

A more complete and comprehensive understanding of ALC has encouraged surgeons to perform combined reconstructions to improve clinical results and long-term outcomes. It should be noted, however, that the heterogeneity of the techniques used in the studies examined cannot provide valid data and results for each anterolateral procedure. Although recent studies have shown the efficacy and safety of these techniques[80,81], randomized clinical trials and level one studies are required to analyze the superiority of a LET or ALLR technique over the others in terms of ALRI reduction and total revision rate.

CONCLUSION

From the latest evidence, it appears that it is not a single anterolateral structure that determines rotational stability, but rather that several structures act synergistically: the ALL, the superficial and deep layers of the ITB, the capsulo-osseous layer, and the Kaplan fibers. Regardless of the distinct structures that are injured and cause an ALRI, the authors consider it important to obtain a careful clinical evaluation of the patient, repeated just before the surgical procedure under anesthesia. In a scenario where there is no demonstrated superiority of one technique over the others, the authors opted to use the Cocker Arnold Modified Tenodesis as a combined procedure in ACLR deciding to perform it according to […] patient's characteristics (such as a high-grade pivot shift, hyperlaxity, Segond's fracture) and functional demands. They also use it in any revision surgery where there has been a previous ACL graft failure in order to reduce the ACL graft stress and the risk rate of a new failure.

FOOTNOTES

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Social media growth of orthopaedic surgery residency programs in response to the COVID-19 pandemic

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Abstract

BACKGROUND

In the Spring of 2020, residency programs across the country experienced rapid and drastic changes to their application process as a result of the coronavirus disease 2019 (COVID-19) pandemic. In response, residency programs shifted to virtual events and began harnessing social media to communicate with applicants.

AIM

To analyze the changes in social media usage by orthopaedic surgery programs in response to the COVID-19 pandemic.

METHODS

Based on the 2019 residency and fellowship electronic database, accredited US orthopaedic surgery programs were reviewed for social media presence on Instagram and Twitter. Approximately 47000 tweets from 2011-2021 were extracted through the Twitter application programming interface. We extracted: Total number of followers, accounts following, tweets, likes, date of account creation, hashtags, and mentions. Natural language processing was utilized for

tweet sentiment analysis and classified as positive, neutral, or negative. Instagram data was collected and deemed current as of August 11, 2021. The account foundation date analysis was based on the date recognized as the start of the COVID-19 outbreak in the United States, before or after March 1, 2020.

RESULTS

A total of 85 (42.3%) orthopaedic surgery residency program Twitter handles were identified. Thirty-five (41.2%) programs joined Twitter in the nine months after the 2020 covid outbreak. In 2020, there was a 126.6% increase in volume of tweets by orthopaedic surgery residency accounts as compared to 2019. The median number of followers was 474.5 (interquartile range 205.0-796.5). The account with the highest number of tweets was Hospital for Special Surgery (@HSpecialSurgery) with 13776 tweets followed by University of Virginia (@UVA_Ortho) with 5063 and Yale (@OrthoAtYale) with 899. Sentiment analysis before 2020 revealed 30.4% positive, 60.8% neutral, and 8.8% negative sentiments across tweets. Interestingly, the positive sentiment percentage increased in 2020 from 30.4% to 34.5%. Of the 201 ACGME-accredited orthopaedic residency programs on Fellowship and Residency Electronic Interactive Database, 115 (57.2%) participate on Instagram, with 101 (87.8%) identified as "resident"-managed *vs* 14 (12.2%) identified as "department"-managed. Over three quarters (77.4%) of Instagram accounts were created after March 1, 2020. The average number of followers per account was 1089.5 with an average of 58.9 total posts.

CONCLUSION

Our study demonstrates a substantial growth of Instagram and Twitter presence by orthopaedic surgery residency programs during the COVID-19 pandemic. These data suggest that orthopaedic residency programs have utilized social media as a new way to communicate with applicants and showcase their programs in light of the challenges presented by the pandemic.

Key Words: Social media; COVID-19; Orthopaedic surgery; Residency

Core Tip: In response to the challenges of the coronavirus disease 2019 (COVID-19) pandemic, orthopaedic surgery residency programs drastically increased their presence on social media. Our paper investigates the use of social media by orthopaedic surgery residency programs in response to the COVID-19 pandemic. We analyzed how ACGME-accredited programs have substantially increased their social media presence to address the gaps created by changes in the application and recruitment processes. With continued uncertainty regarding the pandemic, we demonstrate why programs currently not employing social media as a resource should consider it as a legitimate opportunity for outreach and recruitment.

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INTRODUCTION

Social media has proven to be a valuable tool for education and collaboration. There are almost 4 billion social media users around the globe, equating to over 50% of the global population[1]. As the use of social media continues to grow in the general population, it has also become an increasingly popular platform for healthcare and global outreach. Other social media platforms, such as Instagram and Twitter, are used for public health outreach, professional networking, and the dissemination of research findings[2]. In the past, orthopaedic surgery social medial presence has been primarily limited to practice management and patient outreach[3].

In the Spring of 2020, residency programs across the country experienced rapid and drastic changes to their application process due to the coronavirus disease 2019 (COVID-19) pandemic. Applicants and programs alike faced novel challenges including the elimination of visiting rotations, in-person interviews, open houses, and social exchanges. For very competitive specialties, such as orthopaedic surgery, applicants lost critical opportunities to display their abilities, earn letters of recommendation,

and build relationships at institutions of interest[4]. Similarly, residency training programs did not have the opportunity to showcase their programs and evaluate applicants in person. In response to these changes, residency programs adopted virtual events and began harnessing social media to communicate with applicants. Prior literature reported 85% of interviewees utilized at least one social media platform to learn more about individual programs[5]. Another study showed up to 77.8% of applicants feel that residency programs should be utilizing social media as a means of communication, and the majority of applicants (54.3%) in the 2021 application cycle were influenced by social media with regards to interest in specific residency programs[6]. Considering the new challenges that emerged, social media has allowed programs and applicants with a platform to engage with one another in meaningful ways.

Several studies have looked at social media use in other surgical subspecialties including plastic surgery, urology, general surgery, and otolaryngology[4,7-10]. However, there is limited literature about the changes and trends of social media implementation by orthopaedic surgery residency programs during the COVID-19 pandemic. In the present study, we investigate the use of social media by orthopaedic surgery residency programs in response to the COVID-19 pandemic. We hypothesize that programs have substantially increased their social media presence to address the gaps created by changes in the application and recruitment processes because of the pandemic.

MATERIALS AND METHODS

A list of ACGME-accredited orthopaedic surgery residency programs was compiled from the Fellowship and Residency Electronic Interactive Database (FREIDA) in August 2021. A total of 201 programs were identified. Prior studies have suggested that residency programs more often utilize Instagram and Twitter as platforms for delivery of information as opposed to other similar social media alternatives such as Facebook[11,12]. Therefore, all programs were reviewed for ownership of Instagram and Twitter accounts. Programs were determined to have social media accounts through a Google search and extensive search within each social media platform. On the Google search engine, residency programs were searched using the corresponding program name followed by "orthopaedic surgery residency" and the social media platform of interest. If no evidence of the account of interest, social media specific searches were conducted on Instagram and Twitter using the text "(Program name) orthopaedic surgery residency." Private or personal social media accounts were excluded. All social media accounts were identified as residency only or department only. A residency account was defined as one that specifically denoted its affiliation with the institution's residency program. Instagram data was collected and deemed current as of August 11, 2021. Twitter data was collected and deemed current as of July 5, 2021. This study did not require Institutional Review Board approval as all information is publicly available and did not directly involve patient care.

Approximately 47000 tweets from 2011-2021 were extracted through the Twitter application programming interface on July 5, 2021. The following information was extracted: total number of followers, accounts following, tweets, likes, date of account creation, hashtags, and mentions. Natural language processing was utilized for tweet sentiment analysis and classified as positive, neutral, or negative. Statistical analysis was performed using Python 3.8.9 with the libraries NumPy 1.21 and NLTK 3.6.2. Figures were generated using Python, Matplotlib 3.4.2, and Seaborn 0.11.1.

For identified Instagram accounts, the date of first post was used as a proxy for account foundation date. The foundation date was assessed for establishment before or after March 1, 2020 – the date recognized as the start of the COVID-19 outbreak in the United States. Accounts were classified as either a residency or department account and the total number of posts and followers were recorded. Additionally, accounts were noted for having their program website in the biography section as well as specific highlights on their Instagram "story."

RESULTS

Twitter

We identified Twitter handles for 85 (42.3%) orthopaedic surgery residency programs, 35 (41.2%) of which joined Twitter in 2020 (Figure 1). From 2011 to 2021, 46807 tweets were extracted. In 2011, there were a total of 127 tweets compared to 8195 in 2019, 10377 in 2020, and 5,270 in 2021 (through July 5, 2021) (Table 1). From 2019 to 2020 alone, there was a 126.6% increase in volume of tweets by orthopaedic surgery residency accounts (Figure 2).

The median number of tweets for all orthopaedic surgery residency programs was 103.5 [interquartile range (IQR) 32.5-563.0], the median number of followers was 474.5 (IQR 205.0-796.5), and the median number of accounts following was 152.5 (IQR 54.5-431.75) (Table 2).

The account with the highest number of tweets was @HSpecialSurgery with 13776 tweets followed by @UVA_Ortho with 5063 and @OrthoAtYale with 899. Before 2020, the most commonly used hashtag (#) by orthopaedic surgery twitter accounts was #hughston, followed by #RothmanOrtho (Figure 3A).

Table 1 Total number of tweets per year

Year	Tweets by orthopaedic surgery programs
2011	127
2019	8195
2020	10377
2021	5270

Table 2 Orthopaedic surgery residency program twitter accounts

	Median	IQR
Number of tweets	103.5	[32.5-563.0]
Number of followers	474.5	[205.0-796.5]
Number following	152.5	[54.5-431.75]
Number of likes	84.5	[22.25-525.75]

IQR: Interquartile range.

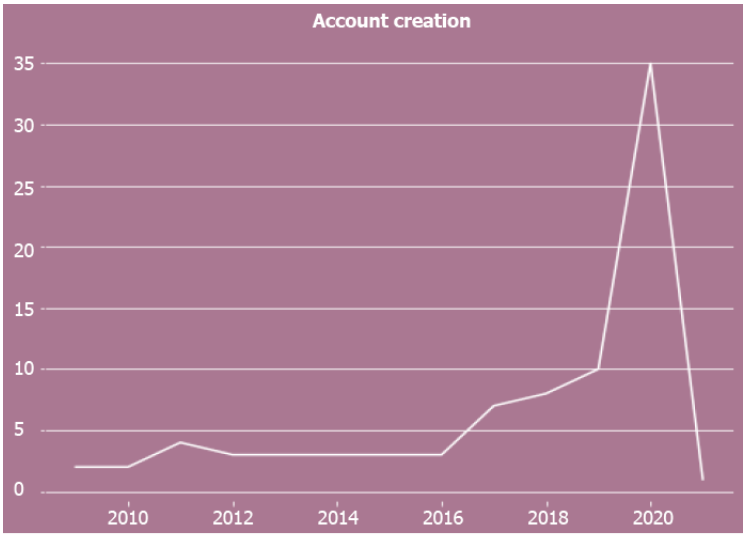

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Figure 1 Orthopaedic surgery residency twitter accounts created. This figure demonstrates the number of new orthopaedic surgery residency Twitter accounts that were created from 2009-2021.

After 2020, the most used hashtag by orthopaedic surgery twitter accounts was #COVID-19, followed by #orthotwitter and #OrthoMatch2021 (Figure 3B). Before 2020, the account with the highest number of mentions was @BrianColeMD, followed by @MOR_Docs and @AAOS1 (Figure 4A). After 2020, the account with the highest number of mentions was @HSpecialSurgery, followed by @AAOS1 and @BillLevineMD (Figure 4B).

Sentiment analysis before 2020 revealed 30.4% positive, 60.8% neutral, and 8.8% negative sentiments across tweets (Figure 5A). Interestingly, the positive sentiment percentage increased in 2020 from 30.4% to 34.5% (Figure 5B). Word cloud analysis, a visual representation of word frequency, revealed an emergence of "resident," "covid," and "virtual" after 2020 (Figure 6A) compared to before 2020 (Figure 6B).

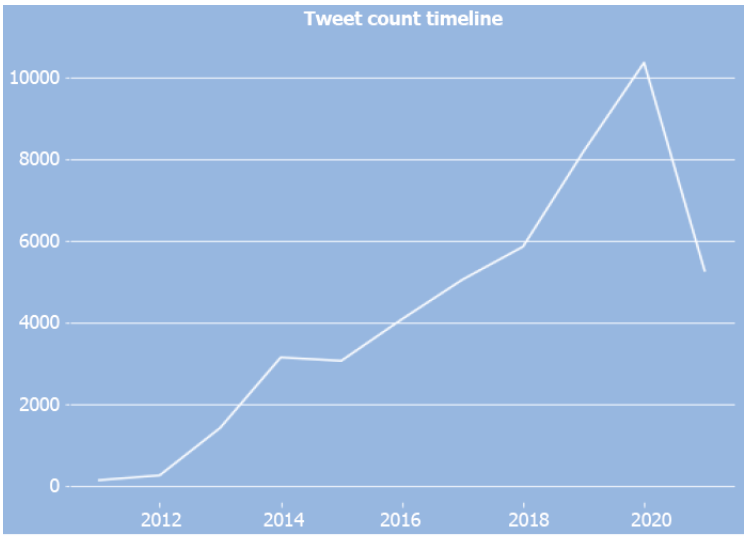
Instagram

Of the 201 ACGME-accredited orthopaedic surgery residency programs on FREIDA, 115 (57.2%) participate on Instagram, with 101 (87.8%) identified as residency-run *vs* department-run. Over three quarters (77.4%) of accounts were created after March 1, 2020. Additionally, 90 (78.3%) of the identified accounts had a link to the program website in their Instagram (Table 3). To quantify the level of activity

Table 3 Instagram accounts

	Number of accounts (%)	Created after March 1, 2020 (%)	Residency run accounts (%)	Website link in bio
Instagram accounts	115 (57.2)	89 (77.4)	101 (87.8)	90 (78.3)

Out of 201 identified orthopaedic surgery residency programs.



DOI: 10.5312/wjo.v13.i8.693

Figure 2 Tweet count timeline. This figure demonstrates the number of 'tweets' generated by orthopaedic surgery residency Twitter accounts from 2011-2021.

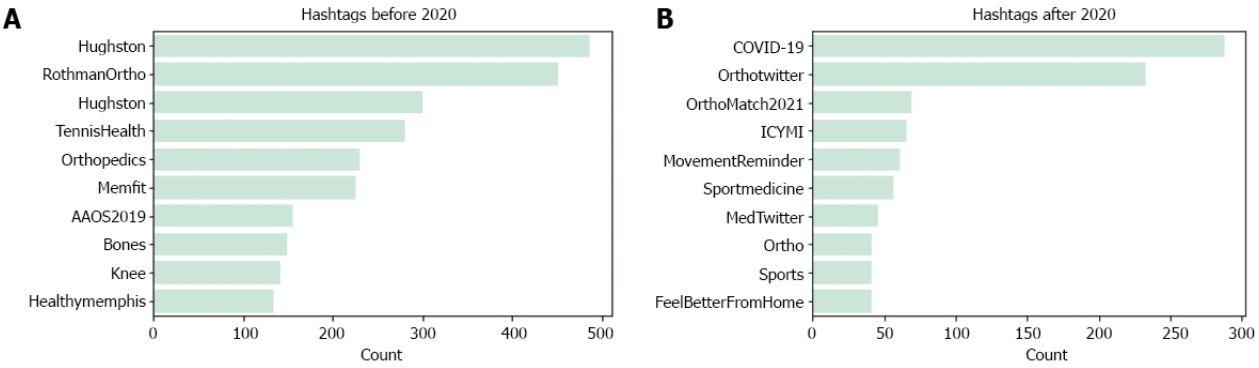


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Figure 3 Top 10 most common twitter hashtags. A: This figure illustrates the ten most common hashtags used by orthopaedic surgery residency Twitter accounts prior to the year 2020; B: This figure illustrates the ten most common hashtags used by orthopaedic surgery residency Twitter accounts after the year 2020. A hashtag is defined as using the "#" symbol and associating it with a word or phrase.

and engagement *via* Instagram, we examined the number of followers and posts by programs. The average number of followers per account was 1089.5 (SD = 606.4) with an average of 58.9 (SD = 56.5) total posts (Table 4). The most common post type included advertisements for virtual sessions, resident spotlights, and photos illustrating resident life.

DISCUSSION

The complex nature of COVID-19 has made the residency application process challenging for programs and applicants alike. As a result, orthopaedic surgery residency programs have turned to online platforms such as Instagram and Twitter to showcase their institutions and interact with applicants. Social media has helped fill the void left by limited away rotations, virtual interviews, and an uncertain application process. With the proliferation orthopaedic surgery programs social media use, it is

Table 4 Instagram data

	Mean
Number of followers	1089.5
Number of posts	58.9

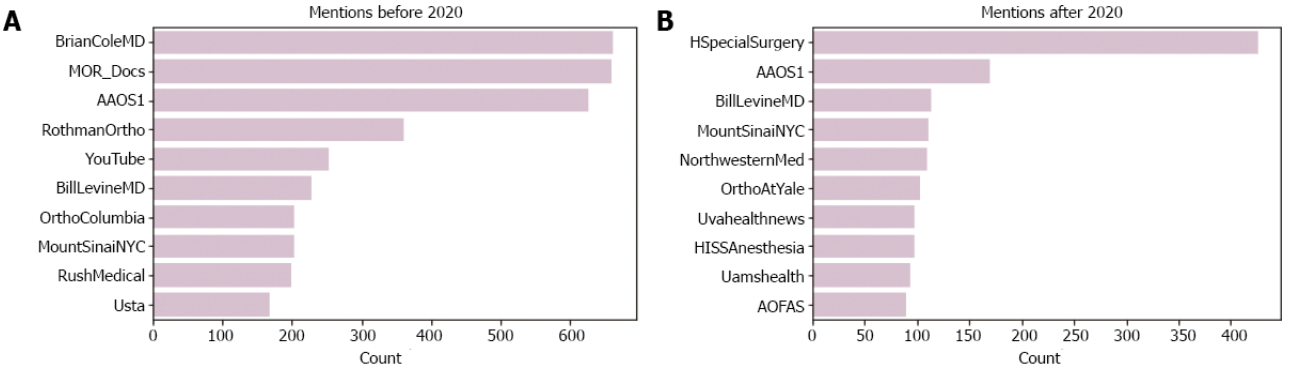

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Figure 4 Top 10 most common twitter mentions. A: This figure illustrates the ten most common Twitter mentions used by orthopaedic surgery residency Twitter accounts prior to the year 2020; B: This figure illustrates the ten most common Twitter mentions used by orthopaedic surgery residency Twitter accounts after the year 2020. A Twitter "mention" is defined as tagging or mentioning another account using the @ symbol.

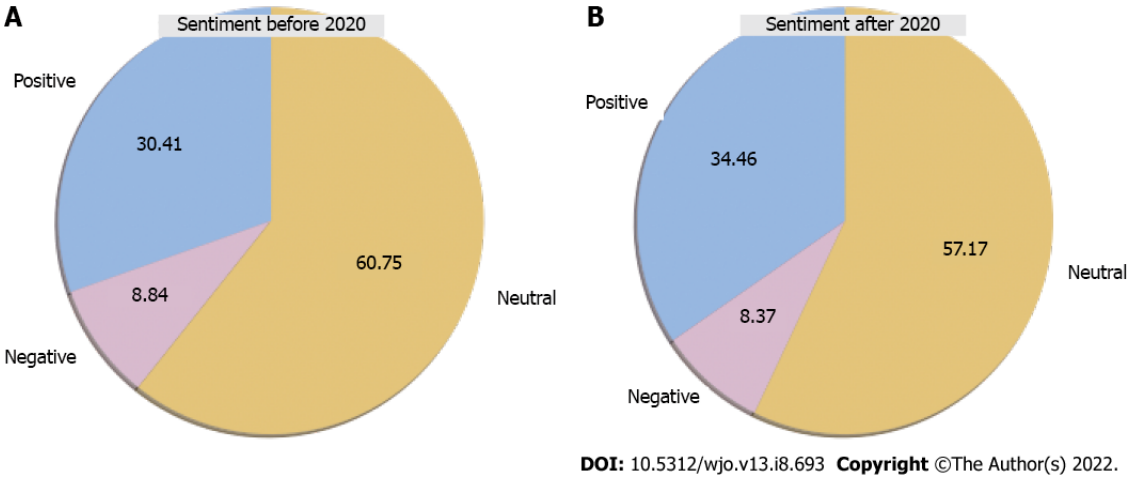

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Figure 5 Tweet sentiment analysis. A: This figure illustrates the percentage of positive, negative, and neutral tweets sent out by orthopaedic surgery residency accounts prior to the year 2020; B: This figure illustrates the percentage of positive, negative, and neutral tweets sent out by orthopaedic surgery residency accounts after the year 2020.

increasingly important to understand the uses and trends associated with each platform.

After March 1, 2020, Instagram account creation amongst orthopaedic surgery residency programs grew 342%. Instagram's platform, which allows users to post captioned images with no character limit, offers opportunities for posts about resident life and culture. For example, Instagram "stories" offer real-time snapshots documenting the day-to-day life of a resident. Accounts have also posted resident spotlights filled with information about residents' backgrounds, interests, and personal lives, ultimately providing a glimpse into the personalities and diversity of a programs' residents[11]. Twitter, on the other hand, is a more text-centered platform and is commonly used in an academic or informative manner[12]. It has provided applicants with the opportunity to directly converse with program directors, residents, and educators in the absence of in-person events. It has also been used as a source of reliable information regarding virtual events and program specific details[13].

To our knowledge, there is just one prior study evaluating the effects of the COVID-19 pandemic on social media among orthopaedic surgery residency programs. Yong *et al*[3] evaluated Facebook, Twitter, and Instagram use by orthopaedic surgery residency programs in May 2019, July 2020, and November 2020. In their cross-sectional study, the authors found a 300% increase in social media account

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Figure 6 Word cloud analysis. A: This figure illustrates a word cloud of the most common words used in tweets sent out by orthopaedic surgery residency Twitter accounts prior to the year 2020. Larger words indicate words that were detected more often; B: This figure illustrates a word cloud of the most common words used in tweets sent out by orthopaedic surgery residency Twitter accounts after the year 2020. Larger words indicate words that were detected more often.

prevalence amongst orthopaedic surgery residency programs from May 2019 to November 2020, with Instagram experiencing the largest account growth and creation. The authors conclude that the proliferation in social media use by residency programs was directly related to the effects of the COVID-19 pandemic.

Based on the results of Yong *et al*[3], we attempted to further evaluate the trends in social media use among orthopaedic surgery residency programs. There are several important differences between the current study and Yong's results. Our complex algorithm extracted important data from twitter to evaluate a significant number of variables over a ten-year period. Yong examined trends at three points in time over 18-mo. In addition to the variables evaluated by Yong (account creation and number of followers), the present study provides data on total number of tweets per year and median number of tweets per account, allowing for a more in-depth understanding of twitter use amongst orthopaedic surgery programs. Furthermore, we provide specific information on the most active twitter accounts before and after the pandemic, as well as the accounts with the most mentions, which may be important information for applicants looking to network or for programs hoping to increase their twitter presence. Finally, a unique strength of the present study is our use of word cloud analysis, which provides a visual representation of the most tweeted words and phrases by orthopaedic surgery programs, unsurprisingly showing an increased use of the words "covid" and "virtual" after the start of the pandemic.

Several studies have shown similar increases in social media usage within other specialties, including neurology, pediatrics, and otolaryngology. Following the start of the pandemic, Gaini *et al*[14] reported almost half of the neurology residency programs on social media announced at least one online virtual event *via* their website or social media. This suggests that social media has not only been used to connect with applicants, but also to announce virtual opportunities. Pruett *et al*[15] found that pediatric residency programs utilize social media to highlight resident wellness, program culture, and resident lifestyle. The authors also suggest that residency programs should increase the number of virtual opportunities applicants have to engage in live conversation with residents and faculty. Ahmadmehrabi *et al*[16] found that 61% of otolaryngology programs have at least 1 social media account, with Twitter being used to facilitate dialogue between applicants, programs, and various institutions. In short, many residency programs across numerous medical specialties have found unique ways to harness social media in the post-pandemic application process.

For most applicants, the transition to a virtual application process has provided increased schedule flexibility, virtual access to information, and a decreased financial burden that comes with interviewing and traveling[7]. Excluding away rotations, the average orthopaedic surgery applicant spends about $7000 on the interview process and submits 85.7 applications[17]. While the virtual application process provides some obvious benefits to applicants, it also creates disadvantages for both programs and applicants. A lack of in-person interviews may prevent programs and applicants from being able to candidly evaluate one another. Furthermore, an inability to experience a program's culture and city in person may make it difficult for an applicant to picture him or herself moving to that location for five or more years. These challenges are magnified by the fact that most away rotators are limited to one externship, whereas prior to the pandemic, applicants would routinely complete two or more away rotations. This is especially difficult for applicants, as many view their sub-internships as an opportunity to make an impression, obtain letters of recommendation, show interest at specific programs, and evaluate their comfort and lifestyle in a new city. Based on the aforementioned information, orthopaedic surgery programs should continue to utilize virtual platforms to supplement the traditional interview process, as they have been shown to influence interest in certain programs for the majority of orthopedic surgery applicants[6]. However, virtual interactions should not be seen as a replacement to externships and in-person interviews.

The proliferation of social media use amongst orthopaedic surgery residency programs may pose unforeseen risks to applicants. While following the social media account of a prospective residency program may signal an applicant's interest, it can also draw attention to the applicant. A 2015 study found that 18% of general surgery residency program directors reported visiting applicants' social media accounts and 11% admitted to lowering an applicants' rank as a result of their online activities [18]. The authors of the present study believe programs will increasingly visit the social media accounts of applicants, especially as applicants provide their usernames when they choose to follow the program's social media account. Applicants must be cognizant of their online etiquette and must consider how their posts may be viewed by future colleagues, employers, and patients[19].

The rise of social media usage amongst orthopedic surgery residency programs has been clearly identified as a factor in the application process for medical students. Social media usage within orthopedic surgery has also been reported in the context of patient education and clinical implications. Specifically, studies have shown that social media is a growing platform for surgeons to communicate with and educate patients in order to improve patient outcomes, but long-term efficacy and practicality of social media in patient communication is still unclear[20]. Within the scope of orthopedic surgery residency programs, the clinical implications of social media are unclear and have not yet been thoroughly studied. It is clear, however, that social media is quickly becoming a critical component of education and training with one study revealing 77% of internal medicine residents utilizing social media for medical education purposes[21]. Several programs have included resident education and training, as well as patient outcomes, as a component of their social media content, but the implications of this with regard to clinical outcomes have not yet been reported in the literature.

There are several limitations to our study. Because social media use can only be reported as a snapshot in time, the reported number of posts, followers, and content at the time of data collection may no longer be up to date. Furthermore, while we were thorough in our efforts to identify social media accounts, it is possible that we may not have identified all social media accounts or may have misidentified some. Additionally, we included all social media accounts of orthopaedic surgery programs that have residency programs, whether the account itself was specifically geared towards applicants. While our data shows a decrease in activity from 2020 to 2021, it must be noted that only about half of the year 2021 was included, as data collection was performed on July 5, 2021. It remains to be seen whether twitter and Instagram use will continue to increase as the delta variant surges. Despite these limitations, the authors' multi-faceted evaluation of social media use amongst orthopaedic surgery residencies is the most comprehensive of its kind in the orthopaedic literature to date.

CONCLUSION

In response to the challenges of the COVID-19 pandemic, orthopaedic surgery residency programs drastically increased their presence on social media. It is likely that the utilization of social media will continue to persist into the future as platforms such as Instagram and Twitter have illuminated new ways for programs to interact with applicants. With continued uncertainty regarding the pandemic, programs currently not employing social media as a resource should consider it as a legitimate opportunity for outreach and recruitment. Orthopaedic surgery programs should continue to utilize virtual platforms to supplement the traditional interview process; however, virtual interactions should not be seen as a replacement to externships and in-person interviews. Further studies are needed to evaluate the true impact that increased social media use by orthopaedic surgery residency programs has on the application process, as well as the training and education of resident surgeons.

ARTICLE HIGHLIGHTS

Research background

As a result of the coronavirus disease 2019 (COVID-19) pandemic, orthopaedic surgery residency programs across the country experienced rapid and drastic changes to their application process. In response, residency programs shifted to virtual events and began harnessing social media to communicate with applicants.

Research motivation

Social media has become an integral part of business, education, and networking. However, there is scarce literature that explores the use of social media amongst orthopaedic surgery residency programs, specifically in response to the ongoing COVID-19 pandemic.

Research objectives

The aim of the study analyze and discuss the various changes in social media usage by orthopaedic surgery residency programs before and during the COVID-19 pandemic.

Research methods

Orthopaedic surgery programs were reviewed for social media presence on Instagram and Twitter. Instagram accounts were tallied for followers, number of posts, and date of creation. Twitter posts were characterized *via* type of post and sentiment using natural language processing.

Research results

In response to the pandemic, orthopaedic surgery residency programs greatly increased their presences on Instagram and Twitter. Both platforms were used in a similar manner to engage with applicants, however, it remains unknown what the impact this had on prospective applicants.

Research conclusions

Our study demonstrates a substantial growth of Instagram and Twitter presence by orthopaedic surgery residency programs associated with the COVID pandemic. This data suggest that orthopaedic surgery residency programs have utilized social media as a new way to communicate with applicants and showcase their programs in light of the challenges presented by the pandemic. The authors anticipate the current trend in social media will plateau as the visiting student precautions are returned to normal before stabilizing as a present but less pervasive means of communication.

Research perspectives

Further studies are needed to evaluate the true impact that increased social media use by orthopaedic surgery residency programs has on the application process.

FOOTNOTES

Author contributions: Geller JS, Massel DH, Rizzo MG, Schwartz EC, Milner JE, and Donnally CJ contributed to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript; all authors have read and approve the final manuscript.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Fluctuation of visual analog scale pain scores and opioid consumption before and after total hip arthroplasty

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Abstract

BACKGROUND

Patients who undergo orthopedic procedures are often given excess opioid medication. Understanding the relationship between pain and opioid consumption following total hip arthroplasty (THA) is key to creating safe and effective opioid prescribing guidelines.

AIM

To evaluate the association between the quantity of opioid consumption in relation to pain scores both pre-and postoperatively in patients undergoing primary THA.

METHODS

We retrospectively reviewed patients who underwent primary THA from November 2018-May 2019 and answered both the visual analog scale (VAS) pain and opioid medication questionnaires pre-and postoperatively. Both surveys were delivered daily for 7-days before surgery through the first 30 postoperative days. Survey results were divided into preoperative, postoperative days 1-7, postoperative days 8-14, and postoperative days 15-30 for analysis. Mean opioid pill consumption and VAS pain scores in each time period were determined and compared to patients' preoperative status using hierarchical Poisson and linear regressions, respectively.

RESULTS

There were 105 patients included. Mean VAS pain scores were the highest preoperatively 7.41 ± 1.72. However, VAS pain scores significantly declined in each successive postoperative category compared to preoperative scores: postoperative day 1-7 (5.07 ± 1.79; $P < 0.001$), postoperative day 8-14 (3.60 ± 1.64; P

< 0.001), and postoperative day 15-30 (3.15 ± 1.63; P < 0.001). Mean opioid pill consumption preoperatively was 0.68 ± 1.29 pills. Compared to preoperative opioid consumption, opioid use was significantly greater between postoperative days 1-7 (1.51 ± 1.58; P = 0.001) and postoperative days 8-14 (1.00 ± 1.27; P = 0.043). Opioid consumption declined below preoperative levels between postoperative days 15-30 (0.35 ± 0.72; P = 0.160) which correlates with a VAS pain score of 3.15.

CONCLUSION

All patients experienced significant benefit and pain relief from having undergone THA. Average postoperative opioid consumption decreased below preoperative consumption between postoperative days 15-30, which was associated with a VAS pain score of 3.15. These results can be used to appropriately guide opioid prescribing practices and set patient expectations regarding pain management following THA.

Key Words: Opioids; Narcotics; Pain; Visual analog scale; Total hip arthroplasty

Core Tip: Our results should be used to appropriately guide opioid prescribing patterns and set patient expectations regarding expected pain management following total hip arthroplasty (THA). This will not only give patients a baseline to reference during their recovery but also limit redundant billing expenses related to unnecessary prescription of medication and avoidable outpatient visits due to post-operative pain. However, without further research that considers other patient factors that influence pain severity, our understanding of the independent impact of pain on opioid consumption after THA remains uncertain.

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INTRODUCTION

Total hip arthroplasty (THA) is one of the most common and successful orthopedic procedures[1]. Arguably one of the greatest improvements in THA peri-operative management over the last decade has been the continuous advancements in pain management regimens that have greatly improved the rate of recovery following the procedure[2-4]. However, due to the highly invasive nature of the procedure, postoperative pain becomes difficult to avoid entirely despite advancements in surgical techniques and perioperative protocols[5]. While joint-related pain is expected to steadily subside after surgical rehabilitation, numerous patients report persistent pain leading to the development of chronic pain postoperatively[6]. Furthermore, the amount of pain that patients experience may perhaps be the most important determinant of satisfaction after THA[7]. Some previous studies suggest that patients who consume more opioids report less satisfaction with pain relief and greater pain intensity[8,9].

Opioids have long been established as a primary analgesic modality for patients undergoing THA and are prescribed routinely for acute pain management following surgery[10]. However, opioid misuse remains a rapidly growing public health crisis which has led to a heightened focus on conservative prescribing patterns in orthopedic surgery[11]. Recent data suggests that the United States ranks number one among all other countries worldwide in daily narcotic consumption[12]. Specifically, orthopedic surgeons are the third-highest group of opioid prescribers among physicians, accounting for almost 8% of all opioid prescriptions in the United States[13]. Limiting access to unused medications while ensuring adequate pain management has been a proposed strategy for improving current prescription practices[14-16]. Although recent studies have highlighted a pattern of patients receiving excess opioid medication after undergoing various orthopedic procedures, there has been minimal evidence to suggest an optimal supply of pain medication postoperatively[16-23]. Therefore, in order to create a safe and effective prescribing guideline that minimizes the over-prescription of opioids and to effectively advise patients pre- and postoperatively, it is imperative to discern the relationship between pain severity and opioid consumption.

The visual analog scale (VAS) is a simple and frequently used method to quantify variations in pain intensity for both clinical and investigational purposes[24-26]. The assessment of pain is generally difficult due to its multifaceted subjective nature, which can vary among individuals. Despite this diversity, the VAS pain questionnaire is widely used in the literature and clinical practice. It is a simple

patient-reported outcome tool and requires relatively little patient training to measure pain scores. To our knowledge, no previous study has analyzed the relationship between VAS pain scores and perioperative opioid consumption in patients undergoing THA.

The purpose of this study is to evaluate the association between the quantity of opioid consumption in relation to VAS pain scores both pre- and postoperatively in patients undergoing primary THA. We hypothesize that both opioid consumption and VAS pain scores will decrease for all patients following surgery when compared to their preoperative status.

MATERIALS AND METHODS

Study design

A retrospective review of prospectively collected data was performed at a tertiary, urban, academic medical center to identify consecutive patients who underwent primary, elective THA from November 2018 to May 2019. The inclusion criteria comprised patients who answered both the VAS pain and opioid medication questionnaires pre- and postoperatively. Results from both surveys were separated into four time points for analysis (preoperative, postoperative days 1-7, postoperative days 8-14, and postoperative days 15-30). Patients under the age of 18, those undergoing THA for non-elective or oncologic reasons, revision THA, those who did not have a recorded response for both questionnaires, and any patient receiving opioid pain medications for conditions not related to their operative hip were excluded from this study. A total of 1142 primary THAs were performed at our institution within the period of interest, of which, 270 (24%) were performed by the senior author (Davidovitch RI). All cases included in this study were performed by the senior author (Davidovitch RI) utilizing a direct anterior approach with the assistance of fluoroscopy.

All patients participated in our institutional-wide comprehensive total joint pathway program, which encompasses standardized protocols for all aspects of perioperative care and postoperative rehabilitation. The records and existing data are de-identified and are part of our institutional quality improvement program; therefore, the present study was exempt from human-subjects review by our institutional review board.

Outcome measures

The primary outcomes measures included VAS pain scores and opioid consumption over time. VAS pain scores were calculated based on a 0 to 10 scale, with 0 representing no pain and 10 being the worst pain imaginable[24,25]. The VAS pain score was selected as an outcome measure based on its ability to detect immediate changes with a minimal clinically important difference (MCID) ranging from 1.86 to 2.36 for THA[25]. Opioid consumption was defined as the number of narcotic pills taken per day. The various opioids reported by patients included tramadol, hydromorphone, hydrocodone, oxycodone, and morphine sulfate[27]. Mean VAS pain scores and opioid pills consumed preoperatively were compared to the means on postoperative days 1-7, days 8-14, and days 15-30 to determine the time point at which postoperative opioid consumption decreases below preoperative consumption and its relation to VAS pain scores. Postoperative time points and the calculation of their means were chosen to provide a comparison to the baseline seven-day interval measured preoperatively.

Opioid-sparing pain protocol

Our institution implemented a novel opioid-sparing protocol for all patients undergoing THA beginning in October 2018 (Supplementary material). The previously established World Health Organization (WHO) analgesic ladder was used as a framework for the development of this novel protocol[28]. With the addition of this protocol, our healthcare providers and patients adhere to standardized order sets for the administration of multimodal analgesia medications throughout the perioperative period[4,29]. Within one month of planned THA, patients are evaluated at our institution's preadmission test center. Thorough medication reconciliation is performed and patients who are actively consuming opiates are advised and instructed to taper or discontinue its usage prior to undergoing surgery.

In the operating room, patients are given initial propofol infusions for sedation. Subsequently, patients receive a single dose of spinal anesthetic containing 0.5% ropivacaine or 0.5% bupivacaine. Prior to wound closure, patients are administered two separate homogenously diluted 60-cc injections by the operating surgeon. The first injection was a cocktail containing 20 cc of liposomal bupivacaine (one vial) mixed with 40 cc of 0.9% normal saline solution while the second injection was a cocktail containing 40 cc of non-liposomal bupivacaine (0.25% weight/volume) and 15 mg of ketorolac with 20 cc of 0.9% normal saline solution. All patients receive a total of two grams of intravenous (IV) tranexamic acid (TXA). One gram before surgical incision and another gram during surgical wound closure. Patients who could not receive IV TXA [contraindication for TXA administration: (1) Subarachnoid hemorrhage (2) Intravascular clotting; and (3) Known tranexamic acid hypersensitivity] received 3 g topically in the wound mixed in 100cc saline solution.

All patients receive similar postoperative multimodal analgesia medications during the immediate post-anesthesia care unit period, on the surgical floor, and discharge. Postoperative pain management was accomplished using mostly non-narcotic medications. Patient-controlled analgesia, as well intravenous opioid administration, was strongly discouraged, except in rare situations of breakthrough pain when alternatives had been exhausted. Additionally, patients receive a prescription of aspirin 81 mg twice daily as the primary deep venous thrombosis prophylaxis, which also has analgesic effects as part of our multimodal approach. Following discharge, patients are assessed for adequate pain control (and severity) at multiple time points *via* telephone and during scheduled follow-up visits.

Data collection

As part of our institutional standard of care, patients were preoperatively registered for an electronic patient engagement application (EPEA; Force Therapeutics, New York, NY) by clinical care coordinators at the time of surgical scheduling. The EPEA is a mobile and web-based technology that wirelessly delivers digital patient reported outcome questionnaires to patients at pre-defined time intervals. This application was used to collect VAS pain scores and quantity of opioid consumption daily for seven days before surgery through the first 30 postoperative days.

The collected baseline patient demographic data included gender, age, body mass index (BMI; kg/m^2), American Society of Anesthesiologists (ASA) classification, race, smoking status, length of stay (LOS; days), and surgical time (minutes). LOS was determined by calculating the difference between the time of admission and discharge following surgery. Surgical time was derived from calculating the time difference between the initial skin incision and the completion of skin closure. All demographic data were extracted from our institution's electronic data warehouse (Epic Caboodle. version 15; Verona, WI) using Microsoft SQL Server Management Studio 2017 (Redmond, WA).

Statistical analysis

All statistical analyses were performed using SPSS v25 (IBM Corporation, Armonk, New York). The data were organized using Microsoft Excel software. Baseline demographic characteristics of the study participants were tallied for each variable collected. Descriptive data are represented as means ± SD or counts (%). Hierarchical Poisson regression was used to compare mean opioid pill consumption preoperatively to postoperative days 1-7, days 8-14, and days 15-30. Hierarchical linear regression was used to compare VAS pain scores preoperatively to postoperative days 1-7, days 8-14, and days 15-30. The incidence rate ratio and exponentiated beta coefficients are also reported along with an associated 95% confidence interval (CI). A P value of less than 0.05 was considered to be statistically significant.

RESULTS

A total of 105 patients were identified who underwent primary THA *via* a direct anterior approach with the assistance of fluoroscopy. The majority of the study participants were female (63%), between the age 65-74 years old (38%), had a BMI < 30 kg/m^2 (62%), ASA class II (74%), Caucasian (90%), and non-smokers (68%). Additionally, the majority of the patients in this study had a surgical time spanning between 60-120 min (78%) and an in-hospital LOS of 1 day or less following surgery (75%). Full demographic details are highlighted in Table 1.

Opioid consumption and VAS pain scores

The average number of opioid pills consumed preoperatively was 0.68 ± 1.29. The number of opioids consumed between postoperative days 1-7 (1.51 ± 1.58; P = 0.001) and postoperative days 8-14 (1.00 ± 1.27; P = 0.043) was significantly greater when compared to patients' preoperative opioid consumption. However, opioid consumption between postoperative days 15-30 did not significantly differ from their preoperative status (0.35 ± 0.72; P = 0.160). This suggests that despite an initial rise in opioid requirements postoperatively, patients experience a decreased need for pain relief 15-30 postoperatively and in fact have a similar if not less opioid consumption in comparison to their preoperative opioid consumption level (Figure 1). These findings are summarized in Table 2.

The mean VAS pain score for the study participants preoperatively was 7.41 ± 1.72. This significantly differed from the VAS pain scores between postoperative days 1-7 (5.07 ± 1.79; P < 0.001), days 8-14 (3.60 ± 1.64; P < 0.001), and days 15-30 (3.15 ± 1.63; P < 0.001) (Table 3). The differences exceeded the proposed MCID for the VAS pain score, making these findings clinically significant. Furthermore, the mean VAS pain score between postoperative days 15-30 correlated with a decline in opioid consumption below patients' preoperative opioid consumption status. The average postoperative VAS pain score of patients who did not take opioids was approximately 3.50, which suggests that a general decline in pain occurs at roughly days 8-14 postoperatively and becomes much lower between postoperative days 15-30 (Figure 2). Additionally, there was a significant linear relationship between VAS pain scores and the number of opioid capsules consumed, which may indicate that as patients' perception of their pain intensified, their reliance on opioid pain medication increased accordingly (P < 0.001; Table 4).

Table 1 Patient demographics (*N* = 105)

Patient demographics (*N* = 105), *n* (%)	
Gender	
Male	39 (37)
Female	66 (63)
Age (yr)	
< 55	17 (16)
55-64	30 (29)
65-74	40 (38)
≥ 75	18 (17)
BMI (kg/m)^2	
Underweight (< 18.5)	2 (2)
Normal (18.5-24.9)	30 (29)
Overweight (25.0-29.9)	33 (31)
Obese (> 30)	40 (38)
ASA Classification	
I	9 (9)
II	78 (74)
III or IV	18 (17)
Race	
Caucasian	94 (90)
Non-caucasian	11 (10)
Smoking Status	
Current smoker	2 (2)
Former smoker	31 (30)
Never smoker	71 (68)
LOS (d)	
0	34 (32)
1	45 (43)
> 1	26 (25)
Surgical Time (min)	
< 60	20 (19)
60-120	82 (78)
> 120	3 (3)

DISCUSSION

Over the past few decades, the number of opioids prescribed to manage patients with chronic non-cancer related pain such as osteoarthritis has dramatically increased[16,18,30-33]. This reported rise carries substantial implications for orthopedic surgeons, as patients who undergo orthopedic procedures are prescribed more opioid medications on average than patients of most other specialties [13]. The impact of opioids has gained significant clinical and research interest given their potential to prognosticate postoperative outcomes and patient satisfaction. Recent evidence now suggests that opioids provide no additional benefits compared to non-opioid medications such as ibuprofen and acetaminophen to manage pain associated with osteoarthritis and have higher rates of adverse events [34-38]. Additionally, previous studies have also reported that patients who used more opioids postoperatively experienced less satisfaction and greater pain intensity irrespective of the procedure type[8,9]. Therefore, gaining a better understanding of the relationship between opioid use and pain is

Table 2 Number of opioid pills consumed per day (*N* = 105, 564 observations)

Time	Average daily opioid use (SD)	Incidence rate ratio (95%CI)	*P* value
Preop	0.68 (1.29)	---	---
Postop days 1-7	1.51 (1.58)	2.43 (1.44, 4.10)	**0.001**
Postop days 8-14	1.00 (1.27)	1.76 (1.02, 3.03)	**0.043**
Postop days 15-30	0.35 (0.72)	0.66 (0.36, 1.18)	0.160

SD: Standard deviation; CI: Confidence interval.

Table 3 Visual analog scale pain score (*N* = 105, 504 observations)

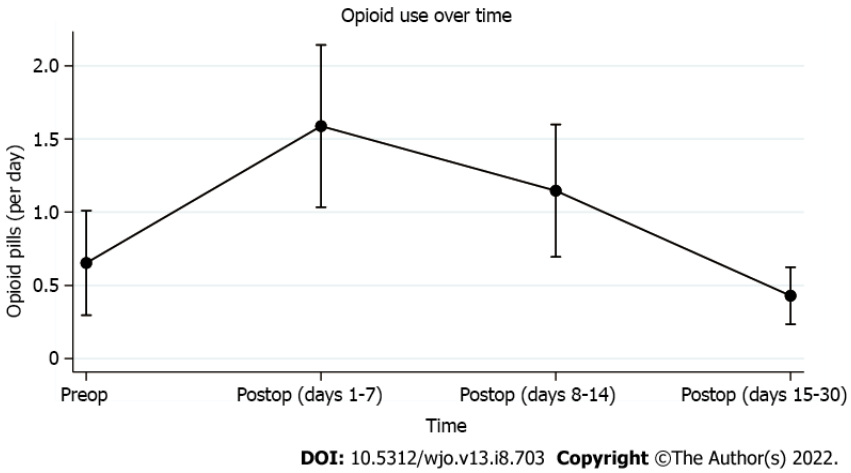
Time	Average VAS pain score (SD)	Beta coefficient (95%CI)	*P* value
Preop	7.41 (1.72)	---	---
Postop days 1-7	5.07 (1.79)	-3.00 (-3.34, -2.65)	**< 0.001**
Postop days 8-14	3.60 (1.64)	-4.43 (-4.79, -4.07)	**< 0.001**
Postop days 15-30	3.15 (1.63)	-5.21 (-5.57, -4.86)	**< 0.001**

VAS: Visual analog scale; SD: Standard deviation; CI: Confidence interval.

Table 4 Comparison of mean postop visual analog scale pain score and opioid use (*N* = 105)

	No opioid use (50.2%)	1 Opioid pill (22.3%)	2+ Opioid pills (27.5%)	*P* values
VAS pain score (SD)	3.48 (1.81)	4.30 (1.63)	5.32 (1.76)	**< 0.001**

SD: Standard deviation.

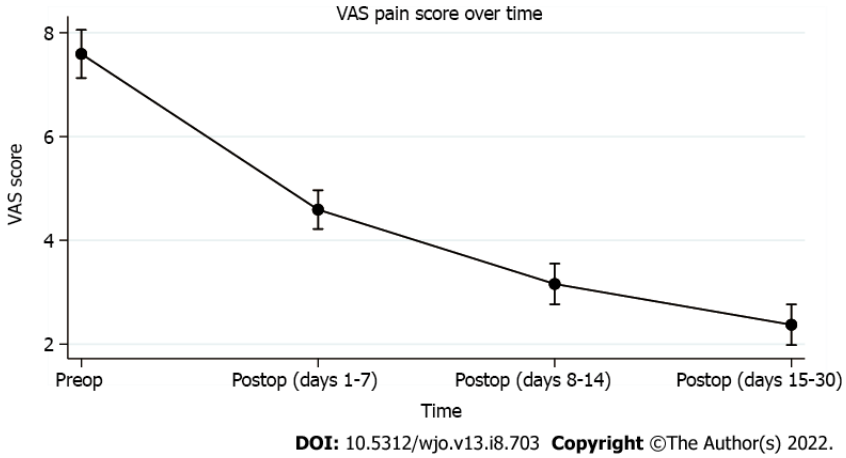


DOI: 10.5312/wjo.v13.i8.703

Figure 1 Mean opioid consumption over time.

essential given the shifting emphasis placed upon health safety and quality. The findings of the present study not only demonstrate that all patients achieve significant pain relief following THA, but that average postoperative opioid consumption decreased below preoperative consumption by days 15-30 postoperatively.

Bot *et al*[9] found that opioid use preoperatively along with lower patient self-efficacy were the best predictors of decreased satisfaction, and the administration of more opioids does not improve satisfaction with pain relief. This is consistent with our findings as patients reported higher VAS pain scores as their opioid intake increased. However, there have been few studies that have documented a correlation between greater opioid use and higher satisfaction with pain relief[39,40]. Carragee *et al*[41]



DOI: 10.5312/wjo.v13.i8.703

Figure 2 Mean visual analog scale pain score over time.

compared morphine use following a femur fracture in both the American and Vietnamese populations and found that although American patients used much more morphine in comparison to Vietnamese patients (30 mg/kg *vs* 0.9 mg/kg), they were less satisfied with their pain relief. Perhaps, drug dependence or addiction may be a confounding factor in achieving satisfaction with pain relief. Vranceanu *et al*[42] previously cited effective coping strategies (higher self-efficacy) as the most effective pain reliever. It may be that significant preoperative opioid intake reflects greater psychologic distress that translates to higher reported subjective pain scores postoperatively.

In our study, both opioid consumption and VAS pain scores decreased successively at each of the timeframes evaluated. This implies that patients needed fewer opioid pills as time progressed but were still able to achieve significant pain relief. Implementing standardized, evidence-based opioid prescribing protocols may optimize the number of opioid prescriptions provided to patients and are particularly paramount for patients at risk of transitioning from short-term to long-term opioid therapy postoperatively[4,16,43-45]. Interestingly, the VAS pain score between postoperative days 1-7 was less than patients' preoperative status; however, the number of opioid pills consumed was higher during postoperative days 1-7. We postulate this may be due to the increased perceived pain burden experienced by patients after undergoing such an invasive procedure.

The amount of opioids prescribed after orthopedic procedures vary widely in the literature, and only a few established guidelines exist that have standardized acceptable duration and magnitude of opioid use[17,46]. Our findings showed that patients ceased to depend on opioids between postoperative days 15-30 compared to their preoperative consumption status, which correlated to a mean VAS pain score of 3.15. This information can be used to set patient expectations and allows surgeons to tailor their prescribing habits based on pain intensity reported by their patients. However, other risk factors in addition to pain also need to be considered. Patients with mental health conditions, such as depression and anxiety are more likely to be prescribed opioids at both higher doses and for longer durations[47, 48]. Not only have previous studies reported that prolonged opioid use may induce depression, but also that depressed patients seek medical attention for pain more frequently, and are three times more likely to be prescribed chronic opioid therapy[49,50]. Rhon *et al*[51] found that the use of pain medication prior to surgery, younger age, female, lower socioeconomic status (education and household income), high health-seeking behavior, and presence of substance abuse, insomnia, or mental health disorders prior to surgery were all significant in predicting chronic opioid use after surgery. However, it is likely that a combination of these variables may provide a greater predictive value for determining the likelihood of chronic opioids following surgery.

A recent study by Cook *et al*[52] showed that nearly 40% of THA patients do not fill their opioid prescriptions after surgery and proposed that strong consideration should be given to alternative pain control methods. It has been previously documented that many patients who fill an opioid prescription do not use any pills[16], thus the true number of patients who require opioids following surgery is likely lower than the number of patients who fill a prescription. Ideally, opioid prescriptions after surgery should balance adequate pain management against the duration of treatment. Although their analysis did not include THA, Scully *et al*[46] proposed that the optimal length of opioid prescriptions for common orthopedic procedures is around 6 to 15 d. This is corroborated by the findings of our study as opioid consumption quantity reached below the preoperative levels between days 15-30 postoperatively.

This study is not without limitations. The retrospective nature of this study has the potential to introduce inherent bias. The study population was majority female and age 65 years or older which causes inherent selection bias. Both the opioid and pain surveys that were administered relied on self-reporting by the patients. Due to the nature of the self-reported survey, opioid dependence could be

undetected in our study cohort. All patients in this study underwent THA *via* the direct anterior approach by a single surgeon, thus our results may not be generalizable to patients who undergo THA *via* other surgical approaches. Additionally, we excluded any patients who underwent revision of their primary implant or were hospitalized due to any postoperative complications. These patients may be the heaviest postoperative users of opioids due to a difficult and prolonged recovery resulting in higher pain intensity. Indeed, most patients included in the present study had a LOS of less than two days, and further analyses may benefit from addressing how lengthened in-patient stays affect VAS and the subsequent prescription of opioids postoperatively. In addition, the pain threshold of each patient is different making the generalizability of our results relatively difficult. Although we accounted for all non-THA related pain indications, we could not quantify all possible pain events after surgery that could necessitate prescription opioid therapy. Theoretically, a patient could have obtained an opioid prescription after undergoing THA for an issue unrelated to their orthopedic procedure. Patients who have pre-existing psychiatric conditions, anxiety, and/or fear of pain may confound the data, as they are unlikely to show improvement in pain, regardless of pain score. We did not quantify both opioid and non-opioid oral analgesic use such as meloxicam and aspirin according to oral morphine equivalent or collect the duration of preoperative opioid use. In addition, our analysis of PO opioid medication did not take into account IV opioids received perioperatively. This study only considered opioid intake; therefore, analgesics consumed by patients that may reduce the need for opioid intake could have possibly skewed the results. Furthermore, while VAS scores may be generalizable, an individual's immediate post-operative opioid consumption is dictated by subjective measures such as anesthesia type could introduce confounding variables that are difficult to quantify[53]. Lastly, we did not account for patients who may have had unreported adverse effects (constipation, nausea, vomiting, hypotension, *etc.*) due to opioid consumption and stopped their intake during the postoperative periods evaluated in this study. Future investigations comparing multiple surgical approaches for THA and including patients from different regions of the country and various parts of the world would help further elucidate our findings. Despite these limitations, the results presented can aid surgeons' opioid prescribing patterns based on their patients' reported pain levels following THA.

CONCLUSION

All patients experienced significant pain relief from having undergone THA. The average postoperative opioid consumption decreased below preoperative opioid consumption status between days 15-30 postoperatively. This decline in opioid consumption was associated with a relative VAS pain score of 3.15. Our results should be used to appropriately guide opioid prescribing patterns and set patient expectations regarding expected pain management following THA. This will not only give patients a baseline to reference during their recovery but also limit redundant billing expenses related to unnecessary prescription of medication and avoidable outpatient visits due to post-operative pain. However, without further research that considers other patient factors that influence pain severity, our understanding of the independent impact of pain on opioid consumption after THA remains uncertain.

ARTICLE HIGHLIGHTS

Research background

The purpose of this study is to evaluate the association between the quantity of opioid consumption in relation to visual analog scale (VAS) pain scores both pre- and postoperatively in patients undergoing primary total hip arthroplasty (THA). The amount of opioids prescribed after orthopaedic procedures vary widely in the literature, and only a few established guidelines exist that have standardized acceptable duration and magnitude of opioid use. Our findings showed that patients ceased to depend on opioids between postoperative days 15-30 compared to their preoperative consumption status, which correlated to a mean VAS pain score of 3.15. This information can be used to set patient expectations and allows surgeons to tailor their prescribing habits based on pain intensity reported by their patients.

Research motivation

The impact of opioids has gained significant clinical and research interest given their potential to prognosticate postoperative outcomes and patient satisfaction. Therefore, gaining a better understanding of the relationship between opioid use and pain is essential given the shifting emphasis placed upon health safety and quality.

Research objectives

The purpose of this study is to evaluate the association between the quantity of opioid consumption in relation to VAS pain scores both pre- and postoperatively in patients undergoing primary THA. We hypothesize that both opioid consumption and VAS pain scores will decrease for all patients following

surgery when compared to their preoperative status.

Research methods

Administer surverys to aassociate VAS pain scores with opioiid pill consumption.

Research results

Our findings showed that patients ceased to depend on opioids between postoperative days 15-30 compared to their preoperative consumption status, which correlated to a mean VAS pain score of 3.15.

Research conclusions

This information can be used to set patient expectations and allows surgeons to tailor their prescribing habits based on pain intensity reported by their patients.

Research perspectives

Future research should aim to consider other patient factors that influence pain severity. Our current understanding of the independent impact of pain on opioid consumption after THA remains inconclusive.

FOOTNOTES

Author contributions: Singh V, Tang A, and Bieganowski T write the manuscript; Singh V collected the data; Singh V and Anil U did the analysis; Macaulay W did the edits. Schwarzkopf R and Davidovitch RI are responsible for conceptualization and manuscript editing.

Institutional review board statement: The present study retrospectively analysed de-identified data for institutional quality improvement initiative and was therefore exempted from human-subjects review by our Institutional Review Board.

Informed consent statement: Informed consent was not needed for this study. This was a quality improvement initiative at our institution.

Conflict-of-interest statement: Singh V, Tang A, Bieganowski T and Anil U have nothing to disclose. Macaulay W holds stock options in OrthoAlign. Schwarzkopf R is a paid consultant for Smith & Nephew and Intellijoint. He also has stock options in Gauss Surgical outside the submitted work. Davidovitch RI is a paid consultant for Radlink, Schaerer Medical, Exactech, and Medtronics.

Data sharing statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

STROBE statement: The authors have read the STROBE Statement—checklist of items, and the manuscript was prepared and revised according to the STROBE Statement—checklist of items.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Functional and clinical outcome with modified lateral approach total hip arthroplasty in stiff hips with ankylosing spondylitis

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Abstract

BACKGROUND

Ankylosing spondylitis at total hip arthroplasty (THA) has significant hip stiffness with flexion deformity, restricted mobility, and function. Range of movement (ROM) improvement with good functional outcome is seen following THA in these hips. The modified Hardinge approach without abductor compromise is helpful in these stiff hips with associated flexion deformity.

AIM

To assess improvement in ROM and functional outcomes with a modified lateral approach THA in ankylosing spondylitis with stiff hips.

METHODS

A total of 69 hips that underwent THA with a modified Hardinge approach in 40 patients were evaluated at a mean follow-up of 38.33 mo. All individuals ambulated with weight-bearing as tolerated and ROM exercises from the 1st postoperative day. Modified Harris hip score and ROM were assessed during follow-up. Quality of life assessments using the 36-item and 12-item short form health surveys were done along with clinical and functional outcomes at follow-up. SPSS 22.0 was used for statistical analysis. The correlation of ROM and functional score change was performed using Pearson's correlation coefficient.

RESULTS

Sixty-nine hips with a significant decrease in ROM preoperatively with 32 clinically fused hips showed significant improvement in flexion range. The mean flexion in 69 hips improved from 29.35 ± 31.38 degrees to 102.17 ± 10.48 degrees. The mean difference of 72.82 with a P value < 0.0001 was significant. In total, 45 out of 69 hips had flexion deformity, with 13 hips having a deformity above 30

degrees. The flexion during the follow-up was below 90 degrees in 3 hips. Eleven hips had flexion of 90 degrees at follow-up, while the remaining 55 hips had flexion above 100 degrees. Modified Harris hip score improved from 17.03 ± 6.02 to 90.66 ± 7.23 (P value < 0.0001). The 36-item short form health survey at the follow-up indicated health status in 40 patients as excellent in 11, very good in 20, good in 5, fair in 3, and poor in 1. The mean mental health score was 84.10 ± 11.58. Pain relief was good in all 69 hips. Altogether, 28/40 patients (70%) had no pain, 9 patients (22%) had occasional pain, and 3 patients (8%) had mild to moderate pain with unusual activity. Heterotopic ossification was seen in 21 hips with Brooker class 1 in 14 hips.

CONCLUSION

Modified Hardinge approach THA in ankylosing spondylitis with stiff hips with flexion deformity significantly improved ROM, Harris hip score, and quality of life indicated by the 36-item and 12-item short form health surveys.

Key Words: Ankylosing Spondylitis; Stiff; flexion deformity; Harris hip score; Hip range of movement; 36-item short form health survey score; Total hip arthroplasty modified Hardinge approach

Core Tip: Ankylosing spondylitis is characterized by significant hip stiffness with mobility restriction and decreased quality of life. Range of movement is reduced with coexistent flexion deformity. Total hip arthroplasty improves mobility by enhancing the quality of life. The modified Hardinge approach leaves the posterior two-thirds of the abductors intact. This approach is helpful in these hips with flexion deformity with good clinical and functional outcomes. Range of movement, Harris hip score, and quality of life indicated by the 36-item short form health survey score have shown promising results.

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INTRODUCTION

Ankylosing spondylitis (AS) belongs to the spondyloarthropathy group of disorders affecting the young with progressive stiffness of the spine and hip joints. The hip joint is involved in 25%-50% of patients [1], with bilateral hip disease seen in 50%-90% of AS[2-5]. Disability in these individuals is predominantly due to decreased movement resulting in stiffness restricting their activities. The hip involvement presents varying degrees of stiffness with bony ankylosis seen in about 40% at total hip arthroplasty (THA)[6]. The majority of these young patients have fixed deformities with loss of spinal mobility. THA improves the functional outcome in these patients with significant activity limitations and progressive stiffness in their spine and hips.

THA in these hips significantly improves the range of movement (ROM) and pain relief with marked improvement in function and mobility[4]. However, the associated risks are ectopic bone formation, reduced ROM, and re-ankylosis after THA in AS[6].

We aimed to assess the functional and clinical outcome in AS with stiff hips after THA with the modified lateral approach. ROM and functional outcomes using the modified Harris hip score (HHS), 36-item short-form health survey score (SF-36), and 12-item short form health survey (SF-12) scores were calculated for assessment.

MATERIALS AND METHODS

A retrospective analysis of clinically stiff hips with AS who underwent THA in our unit between 2012 to 2018 were included. The criteria for inclusion were individuals over 18 years of age diagnosed with AS with decreased ROM with THA in our unit and had come for follow-up more than 6 mo after the procedure. Based on these criteria, 168 patients fulfilled the criteria for this study. In total, 69 hips in 40 patients who could be assessed clinically during the study period were included in this study. Sixty-two patients with AS were reviewed, and 22 patients had to be excluded due to insufficient data. The

remaining were not available for a clinical evaluation during the study period. Data for the 40 patients were collected for clinical review. Information was also obtained from the medical records. Preoperative details regarding ROM, pain, and other data regarding the hip joint involvement were collected and compared with the data obtained at clinical follow-up. SPSS 22.0 was used for statistical analysis. The correlation of ROM and functional score change was done using Pearson's correlation coefficient.

Data regarding medical management by the rheumatology department was also collected. Informed consent was obtained from all patients. Institutional Review Board approval was obtained for this study.

Surgical technique

Sixty-nine hips were stiff, and 32 were clinically fused. Bilateral hip arthritis in 24 individuals had simultaneous THA in the same sitting. Five patients had staged THA for bilateral hip arthritis. Eleven individuals underwent unilateral THA. Two of the senior authors carried out all the THAs. The modified Hardinge approach was used for all the hips[7,8]. The Mallory modification with preservation of the posterior two-thirds of the abductors is the approach routinely utilized in our unit for all THAs except hips with a requirement for posterior or posterosuperior augmentation and reconstruction. The Mallory modification essentially preserves the posterior two-thirds of the gluteus medius rather than detaching the entire abductor in the classical Hardinge approach. The anterior one-third was cut at the musculotendinous junction to enable effective repair at the end of the procedure.

Templating was done preoperatively for all cases to assess the size of the acetabulum and femur. Lateral positioning for THA was challenging in the fused and stiff hips. Circumferential capsular release was done to enable mobilization of the proximal femur and provide complete exposure to the acetabulum. The capsule in these stiff hips was opened anterolateral and released from the entire bony acetabular margin. The capsular tissue was elevated, and the thickened fibrotic tissue interfering with the acetabular preparation was excised.

A femoral neck osteotomy was done in situ for 26 fused hips that could not be dislocated after defining the acetabular margins and the proximal femur with soft tissue release. Care was taken to support the limb on completion of the osteotomy to prevent additional propagation to the calcar region and the acetabular margins. Additional bony resection was done on the neck cut to leave enough calcar for stable femoral component implantation. Acetabulum reaming was done only after defining the margins. Sequential reaming onto the resected neck and head was done after ensuring to avoid eccentric reaming and maintaining the anterior and posterior wall thickness. The residual pulvinar identified the medial wall, and reaming continued gradually to obtain the best fit of the acetabular component.

The acetabulum was cementless in all our cases. Acetabular components in this series were Pinnacle (Depuy, United States) in 34 hips, R3 (Smith and Nephew, United States) in 29 hips, Trident (Stryker, United States) in 2 hips, and Latitud (Meril, India) in 4 hips. Screw fixation was used in 42 hips to augment fixation. The femur was prepared with the limb adducted and externally rotated to accommodate a cementless component in 61 hips, while 8 hips required a cemented fixation for Dorr type C femur. Cementless femur components were Corail (Depuy, United States) in 30 hips, Synergy (Smith and Nephew, United States) in 12 hips, Polarstem (Smith and Nephew, United States) in 13 hips, Latitud (Meril, India) in 4 hips, and Accolade (Stryker, United States) in 2 hips. The 8 cemented femoral implants were C stem (Depuy, United States) in 2 hips, CPCS (Smith and Nephew, United States) in 4 hips, and CPT (Zimmer, Warsaw, United States) in 2 hips. The head size depended on the acetabular component, with a mean head size of 32.92 mm (28 mm in 9 hips, 32 mm in 35 hips, 36 mm in 25 hips).

No constrained or dual mobility liners were used. Copious lavage with saline to remove all the bone debris was done before closure to reduce the chances of heterotopic ossification. A stable calcar cortical split was seen in the proximal femur in 2 hips at THA with the last broach size used, which required wiring for additional stability. Fracture of the greater trochanter was seen at the final reduction in 1 hip, which required stabilization with stainless steel wires.

All patients were given parenteral antibiotics for 48 h and ambulated with weight-bearing as tolerated by the next day after surgery. Deep vein thrombosis prophylaxis with aspirin was given for 6 wk. The patients with stiff hips were initially encouraged prolonged sitting as soon as tolerated to ensure spinal posture and muscle balance and then mobilized actively as mobility restriction was significant before surgery. The patients were ambulated as soon as tolerated with support, which was gradually weaned after 6 wk.

The preoperative and follow-up flexion and total ROM for each hip were compared. The ROM measurement was done with a goniometer. The total ROM for each hip was compared with the total ROM possible at the last follow-up. The improvement in flexion was compared for each hip. The SF-36 and SF-12 scores were calculated to assess the overall quality of life (QOL). Neuromuscular studies or magnetic resonance imaging were not used to assess hip abductors. The modified HHS, ROM, SF-36, and SF-12 scores were used to assess the overall outcome in these patients. The X-rays were evaluated for heterotopic ossification (HO), the presence of any radiolucent lines, lysis in the Charnley acetabular zones, and the Gruen femur zones with the implants.

The mean ± SD was analyzed based on the distribution of HHS and SF-12 and SF-36 scores. The distribution of the HHS, SF-12, and SF-36 were tabulated for all patients. SPSS 22.0 was used for statistical analysis. P value < 0.05 was considered as statistical significance.

RESULTS

There were 69 hips in 40 patients diagnosed as AS with stiff hips that underwent THA at our unit between January 2012 and December 2018 were included in this study. There were 36 males and 4 females with a mean age of 36.6 years (24 to 58). Sixty-nine hips were studied as 24/40 patients (60%) underwent simultaneous bilateral THA.

ROM

Forty-three hips were found to have preoperative flexion less than 30 degrees (Figure 1). In total, 45/69 hips had flexion deformity, with 13 hips having a deformity above 30 degrees. Three hips had preoperative flexion of 90 degrees, and two hips had preoperative flexion of 100 degrees. Five hips had external rotation deformity of 30 degrees. Significant internal and external rotation restriction was seen in the remaining 64 hips. All hips included had considerable restriction of daily activity with arthritis. The mean preoperative total ROM in 69 hips improved from 45.29 ± 47.20 to a mean of 223.59 ± 27.41. The mean flexion in 69 hips improved from 29.35 ± 31.38 degrees to 102.17 ± 10.48 degrees. The mean difference was 72.97, with a P value < 0.0001 being statistically significant. The total ROM in 32 clinically fused hips improved from a mean of 5.47 ± 9.22 to 223.59 ± 23.33 degrees at the last follow-up.

The flexion at follow-up was below 90 degrees in 3 hips. Eleven hips had flexion of 90 degrees at follow-up, while the remaining 55 hips had flexion above 100 degrees.

The modified HHS improved from 17.03 ± 6.02 to 90.66 ± 7.23 at follow-up. This improvement was found to be statistically significant (P < 0.001). At the follow-up, 30/40 patients had a modified HHS > 90 (Table 1).

Pain score

Pain scoring was done as part of the HHS assessment. All 40 patients had pain with restriction of movement for 31.08 ± 36 mo before THA. Pain relief was good in all 69 hips. Altogether, 28/40 patients (70%) had no pain, while 9 patients (22%) had occasional pain without any compromise in activity. Three patients (8%) had mild to moderate pain with unusual activity.

QOL SF-36 score and general health

SF-36 is to date the most commonly used health-related QOL measure in research and has been used to assess the health status of AS patients and compared with normal individuals[9-11]. SF-36 focuses on eight domains with physical and mental components with outcome measures indicating the health-related QOL[12]. The responses are assessed in all domains, and the score is generated with higher scores indicating better health. This assessment has been used in the evaluation of patients after THA and total knee arthroplasty[12,13].

The SF-36 measures eight scales that include physical functioning, role limitations due to physical health, bodily pain, general health, vitality, social functioning, role limitations due to emotional problems, and mental health. This used extensively assessment tool is a reliable, detailed measure of overall physical and mental health. The mental health score of 84.10 ± 11.58, along with all other subscores, favored the assessment as an excellent overall outcome (Table 2). The SF-36 questionnaire scores calculated at the follow-up in 40 patients indicated general health as excellent or very good in 31 out of 40 patients (Table 3).

SF-12

This short form survey instrument used in outcome assessment is quicker with fewer details and two components. The mean physical score of the physical component summary in 40 patients was 45.22 ± 8.94, and the mean score of the mental component summary was 57.63 ± 5.18.

Radiology

Preoperative assessment included spine as well as hip anteroposterior and lateral views. The anteroposterior view was done in all hips for immediate postoperative assessment. All 69 hips at follow-up showed implants with stable acetabular and femoral components. No radiolucent lines, lysis, or implant loosening was seen in all the Charnley and Gruen zones. HO was seen in 21 hips with Brooker class 1 in 14 hips, class 2 in 5 hips, and class 3 in 2 hips (Figure 2).

Complications

There were no dislocations or early infections in our series. One bilateral THA presented 73 mo postoperatively with symptoms suggestive of low-grade infection. He had been on irregular medical treatment and was also diagnosed with chronic venous insufficiency secondary to perforator incompetence in his lower limbs. He underwent a staged revision for his coagulase-negative *Staphylococcus* infection. There were no other early or delayed complications detected through the last follow-up.

Table 1 Comparison of preoperative and follow-up flexion, range of movement, and Harris hip score

Movement	Preoperative	Follow-up	Mean difference (95%CI)	*P* value
Flexion	29.35	102.17	65.76 ± 71.37	< 0.0001
ROM total	45.29	220.65	132.97 ± 171.86	< 0.0001
ROM score	1.71	4.95	3.33 ± 3.18	< 0.0001
MHHS	17.03	90.66	53.84 ± 72.16	< 0.0001

ROM: Range of movement; MHHS: Modified Harris hip score.

Table 2 Distribution of general health status and the 36-item short form health survey in 40 patients

SF-36 scores		
Mental health	(*n* = 40)	84.10 ±11.58
Role limitations due to emotional problems	(*n* = 40)	94.17 ± 19.81
Social functioning	(*n* = 40)	86.25 ± 16.70
Energy fatigue/vitality	(*n* = 40)	71.87 ± 16.63
General health	(*n* = 40)	63.12 ± 24.22
Bodily pain	(*n* = 40)	80.00 ± 19.23
Physical functioning	(*n* = 40)	69.63 ± 18.58
Role limitations due to physical health	(*n* = 40)	85.00 ± 33.87

SF-36: 36-item short form health survey.

Table 3 The 36-item short form health survey scores compared to other series

SF-36 scores	Our series	Bahardoust *et al*[10], 2012	Dagfinrud *et al*[9], 2004	van Tubergen *et al*[19], 2002
Mental health	84.10 (11.58)	39.9 (28.2)	70 (19)	65.5 (18.1)
Role limitations due to emotional problems	94.17 (19.81)	79.1 (19.2)	66 (42)	68.5 (41.3)
Social functioning	86.25 (16.70)	28.5 (29.2)	70 (27)	64.6 (24.6)
Energy fatigue/vitality	71.87 (16.63)	56.2 (21.4)	43 (23)	42.6 (16.5)
General health	63.12 (24.22)	42.1 (26.3)	51 (24)	42.8 (20.2)
Bodily pain	80.00 (19.23)	48.2 (28.4)	44 (22)	48.3 (19.2)
Physical functioning	69.63 (18.58)	28.3 (11.1)	71 (23)	55.8 (23.4)
Role limitations due to physical health	85.00 (33.87)	31.2 (12.6)	44 (41)	35.6 (38.1)

SF-36: 36-item short form health survey.

DISCUSSION

THA effectively relieves pain and improves ROM and function in AS. Five percent of AS patients have been reported to need hip replacement surgery, and the overall rate of joint replacement surgery in AS has increased by 40%[14]. Previous studies have shown and established that AS has a higher male-to-female ratio of about 2:1 to 3:1, and it was evident in this series as 90% of patients were males.

Patients with stiff hips or bony ankylosis have significant functional disabilities. THA brings about dramatic changes in function and QOL in these young patients. The increased hip ROM and subsequent functional improvement in these individuals support THA in this condition.

The Mallory modification of the Hardinge approach is used routinely for THA in our unit. A lateral approach with trochanteric osteotomy has been described[3]. There is a lack of data regarding functional outcomes following THA in AS with fused hips with this approach. There has been a concern with the

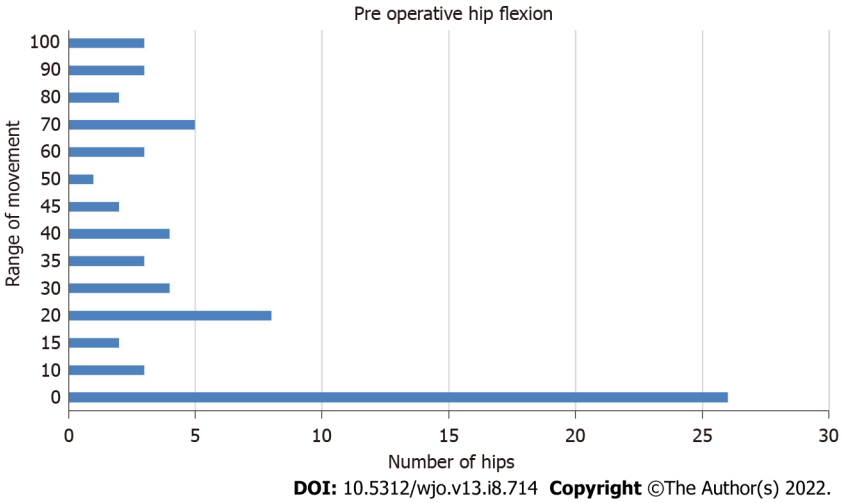

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Figure 1 Distribution of preoperative flexion range in 69 hips.

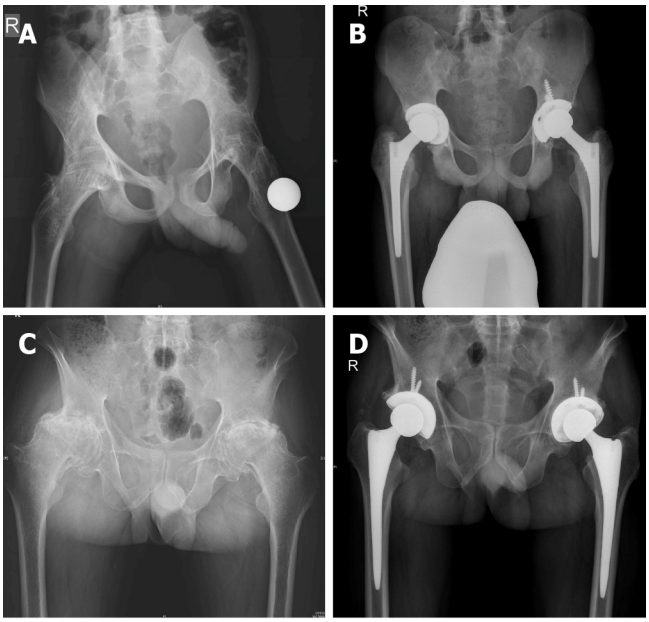

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Figure 2 Preoperative assessment and immediate postoperative assessment of hips. A: Eighteen-year-old male with 4 year history of progressive stiffness presented with bony ankylosis and flexion deformity of 25 degrees in the right hip; B: Four years postoperative bilateral simultaneous total hip arthroplasty. Brooker grade 2 heterotopic ossification left hip, flexion 90 degrees bilateral, Harris hip score 88, flexion 90 degrees, 12-item short form health survey physical component summary 39.83, and mental component summary 58.36; C: Forty-six-year-old male bilateral hip progressive stiffness for more than 10 years, flexion deformity 30 degrees bilateral with 20 degrees further range of movement in flexion; D: Two-year-postoperative bilateral simultaneous total hip arthroplasty, flexion 100 degrees right, 90 degrees left, Harris hip score 95, 12-item short form health survey physical component summary 52.88, and mental component summary 56.12.

approach in AS fused hips related to abductor compromise. Hence the posterior approach has been advocated[4]. The modified lateral approach preserves the posterior two-thirds of the abductor and is helpful, especially in stiff hips with flexion deformity, as the approach facilitates the anterior capsular release.

Flexion deformity in the 45 hips was successfully corrected with this modified lateral approach's extensive soft tissue release. The in situ neck resection in 26 fused hips was performed to prevent damage to the posterior acetabular wall during osteotomy[4]. Limb positioning with external rotation of the femur helps in posterior capsular release between the gluteus medius and the iliopsoas insertions. Femoral broaching and optimal sizing without damage to the residual abductor insertion is facilitated by external rotation of the limb with the modified lateral approach. Femoral anteversion assessment is enabled with proximal femur access provided through this approach. The posterior approach could be challenging for femoral neck osteotomy, especially in fused hips with external rotation deformity. Early mobilization after flexion deformity correction with extensive anterior release in these hips improves

ROM and prevents stiffness.

The choice of implant for the acetabulum was based on the bone quality at the time of preparation. Gradual sequential reaming with information obtained from preoperative templating aided in cementless fixation with optimum fit and bone stock utilization in all 69 hips with additional screws when necessary. A cemented femur was used in 8 Dorr C femurs, and cementless components achieved stable fixation in the remaining 61 hips. Increased risk of intraoperative femur fracture would be high if uncemented fixation is attempted with larger sizes to achieve stable fixation in the larger canal with thin cortices. The proximal femur required wiring in 2 hips for medial femur calcar split seen at preparation. Cementless implants in AS have found favor with long-term survivorship in recent series[4] instead of cemented fixation, which was advocated earlier[5].

The average follow-up of patients in our series was 38.33 mo with no evidence of clinical or radiological signs of implant loosening. There were 21 hips with HO seen at follow-up with no functional limitations. Our protocol with copious lavage before closure to remove bone debris and active postoperative mobilization was to reduce the risk of HO. With rheumatology input, the patients were restarted on their disease-modifying antirheumatic drugs 1 wk after THA.

The mean flexion in 69 hips changed from 29.35 ± 31.38 to 102.17 ± 10.48 degrees, indicating a mean improvement of 72.82 degrees. The ROM in 43 hips with flexion less than 30 degrees and 23 fused hips also recorded significant improvement in their flexion at follow-up compared to patients who had preoperative ROM of more than 90 degrees. This significant improvement in ROM in the 69 hips resulted in considerable improvement in the hip function at follow-up.

Modified HHS improved from 17.03 ± 6.02 to 90.66 ± 7.23, which was statistically significant ($P < 0.001$) as 30/40 patients had a modified HHS > 90 at follow-up. This improvement in HHS is due to the significant increase in the activity levels achieved in these stiff hips. In this study, 92% of our patients had no pain or ignorable pain that did not compromise any activity, and 8% had moderate pain with unusual activity that required occasional analgesics for pain relief.

Thirty-one out of 40 patients showed excellent or good scores in SF-36 and SF-12 physical and mental component analysis, which was comparable with other QOL analyses done in spondyloarthropathy [15]. Improvement in ROM with HHS and SF-36 indicates an overall improvement in the hip joint function and the QOL. Data regarding the functional outcome and health-related QOL after THA in AS has been limited[4,15].

The functional scores and the QOL assessment have been reported in patients with AS[10]. The mental component did not significantly change, and the mean physical component score was significantly lower in the study group[10,16]. The SF-36 scores in this series did not have a preoperative value for comparison. AS patients have significantly impaired QOL, with most domains affected in the SF-36 assessment.

SF-36 at follow-up indicated significant improvement in the QOL after THA in this group of patients with AS. The overall QOL was good in all the domains assessed. The number of cases may have been too small (69 THAs) for analyzing the short-and mid-term effects of THA in AS. However, good scores were obtained in the physical and emotional quotient[17] (Table 3).

The SF-36 scores, which evaluate eight domains used as a functional outcome measure, have added value when used with the modified HHS and the ROM improvement in these stiff hips. SF-12 has a physical and mental component assessment and has fewer elements when compared to SF-36. The SF-36 used to assess functional outcomes in THA and total knee arthroplasty was found to significantly improve following THA[12]. Our series considered the improvement in ROM and the modified HHS. The modified HHS allows evaluation of the hip joints studied, as the HHS allows evaluation of the whole patient. The evaluation of the individual joint deformity and ROM, especially in the bilateral THAs, is possible with the modified HHS. These scores and the SF-36 showed a significant overall improvement in these patients with stiff hips in AS (Table 4).

The limitations of this study include a relatively short duration of follow-up and a small number of patients that could be included in this series. The retrospective nature of this study is another limitation. A 5-year follow-up with radiological and clinical outcomes would have been ideal for studying the various outcomes, while our study's average follow-up was 38.33 mo (range 6-83 mo). We will continue to follow up on these patients to study the clinical, radiological, and overall outcomes. The risk of complications in THA with AS is associated with stiffness of the spine. The possibility of fractures and component loosening are a few complications that could be seen at longer follow-up times[18].

CONCLUSION

THA with a modified lateral approach in AS with stiff hips has significant improvement in the ROM, HHS, overall function, and QOL as indicated by functional outcome measures with SF-12 and SF-36 scores.

Table 4 Comparison of parameters with other series

Ref.	Patients (hips)	Follow-up in mo	Pain relief, %	Final MHHS	ROM score/mean flexion	Approach	Complications, %
Bisla *et al*[20], 1976	23 (34)	42.5	91	NS	ROM-3	NS	5.88
Resnick *et al*[21], 1976	11 (21)	36	NS	NS	NS	NS	0
Williams *et al*[22], 1977	56 (99)	36	NS	NS	NS	NS	10
Baldursson *et al*[23], 1977	10 (18)	45.6	94	NS	Flexion-90	NS	0
Shanahan *et al*[24], 1982	12 (16)	89	94	NS	NS	NS	6.25
Finsterbush *et al*[25], 1988	23 (35)	90	NS	NS	Flexion-86	NS	14.28
Walker *et al*[26], 1991	19 (29)	58	97	NS	ROM-4	NS	0
Gualtieri *et al*[27], 1992	39 (73)	90	89	NS	NS	NS	0
Brinker *et al*[28], 1996	12 (20)	75	90	89.1	ROM-4	Posterior, lateral	0
Sochart *et al*[29], 1997	24 (43)	276	100	NS	ROM-4	NS	27.9
Lehtimäki *et al*[30], 2001	54 (76)	240	NS	NS	NS	NS	3.94
Joshi *et al*[31], 2002	103 (181)	120	96	NS	NS	Lateral, Hardinge	10.5
Kim *et al*[32], 2007	12 (24)	132	NS	82.3	NS	Lateral	12.5
Bhan *et al*[6], 2008	54 (92)	102	62	82.6	ROM-4	Posterior	14
Li *et al*[33], 2009	24 (39)	36	NS	91	ROM-4	Posterolateral	2.5
Tang *et al*[2], 2000	58 (95)	135.4	94	88.8	ROM-4.2	Posterior	20
Bangjian *et al*[34], 2012	12 (24)	50.4	100	86.25	Flexion-84	Posterolateral	0
Malhotra *et al*[35], 2012	23 (32)	42	NS	87.1	ROM-4	Posterior	4.7
Siavashi *et al*[36], 2014	77 (NA)	12	NS	88.22	ROM-5	Posterior, lateral	20.8
Xu *et al*[37], 2017	54 (81)	42	NS	86.1	Flexion-82.5	Posterolateral	0
Our series	40 (69)	38.33	92	90.67	Flexion-102.1739, ROM-4.9514	Modified Hardinge	1.4

ROM: Range of movement; MHHS: Modified Harris hip score; NS: Not specified; NA: Not available.

ARTICLE HIGHLIGHTS

Research background

Total hip arthroplasty (THA) with modified lateral approach has been used routinely in our unit for arthritic hips not requiring posterior wall reconstruction. A good exposure of the acetabulum with preservation of the posterior abductors is optimal for hips with flexion deformities.

Research motivation

THA with modified lateral approach is not associated with abductor compromise and results in good functional outcome as seen in individuals coming back for follow-up.

Research objectives

The objective was to have a functional and overall assessment of hips with ankylosing spondylitis at follow-up after THA. Assessment of functional outcome with described tools such as the 36-item and 12-item short form health surveys with the hip scores would provide adequate information.

Research methods
Patients with ankylosing spondylitis were assessed at follow-up after THA. Functional, clinical, and radiological assessment was done at the follow-up.

Research results
The results showed significant improvement in the functional scores in all domains with improvement in range of movement and quality of life.

Research conclusions
Modified lateral approach THA in ankylosing spondylitis improves range of movement, function, and quality of life.

Research perspectives
Long-term follow-up of 5 years to 10 years with comparison to other approaches would provide a better comparison of the efficacy of the lateral approach.

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FOOTNOTES

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ORIGINAL ARTICLE

Retrospective Cohort Study

Higher cost of arthroplasty for hip fractures in patients transferred from outside hospitals *vs* primary emergency department presentation

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Abstract

BACKGROUND

In 2016 Centers for Medicare and Medicaid Services proposed bundled payments for hip fractures to improve the quality and decrease costs of care. Patients transferred from other facilities may be imposing a financial risk on the hospitals that accept these patients.

AIM

To determine the costs associated with patients that either presented to the emergency department or were transferred from another hospital or skilled nursing facility (SNF) with the diagnosis of a hip fracture requiring operative intervention.

METHODS

A retrospective single institution review was conducted for all arthroplasty patients from 2010 to 2015. Inclusion criteria included a total or partial hip replacement for a hip fracture. Exclusion criteria included pathologic, periprosthetic, and fracture non-union. Data was collected to compare total observed costs for patients from the emergency department, patients from skilled nursing facilities, and patients from an outside hospital.

RESULTS

A total of 223 patients met the inclusion criteria. 135 (60.54%) of these patients presented primarily to the emergency department, 58 patients (26.01%) were transferred from an outside hospital, and 30 patients (13.43%) were transferred from a SNF. Cost data analysis showed that outside hospital patients demonstrated significantly greater total cost for their hospitalization ($43302) compared to emergency department patients ($28875, P = 0.000) and SNF patients ($28282, P = 0.000).

CONCLUSION

Patients transferred from an outside hospital incurred greater costs for their hospitalization than patients presenting from an emergency department or SNF. This is a strong argument for risk-adjustment models when bundling payments for the care of hip fracture patients.

Key Words: Total hip arthroplasty; Cost; Transfer; Outside hospital; Hip fracture

Core Tip: Transfers to regional tertiary care centers of critically ill and severely injured patients have been shown to decrease morbidity and mortality. Many of these patients have increased morbidity, length of stay, blood transfusion requirements, and intensive care utilization has been previously documented in transferred patients. To our knowledge, this study is the first to document this phenomenon in patients with femoral neck fractures being treated with arthroplasty. With the nationwide implementation of bundled payments looming, determining the additional risks and costs associated with providing referral services for community and regional hospitals is essential. It is clear from our data that patients transferred from an outside hospital more significantly strain the resources of the receiving tertiary care hospital compared to those patients who present primarily to the emergency department. This is a strong argument for robust risk-adjustment models that potentially even include patient point of origin.

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INTRODUCTION

The Centers for Medicare and Medicaid Services (CMS) began the Comprehensive Care for Joint Replacement (CJR) model in 2016, which aims to hold hospitals accountable for the quality of care delivered from surgery until 90 d after discharge. As has already been reported, episode-of-care payments for elective Total Joint Arthroplasty (TJA) can vary widely and depend on a number of factors. These factors may include the type of procedure, patient comorbidities, discharge disposition, and readmission rates[1,2]. In July 2016, the CMS proposed implementing bundled payments for hip fracture care in order to control costs and improve quality[3]. This has led to concern that patients with multiple comorbidities or surgically complex patients may either be denied necessary care or transferred to other facilities to prevent financial loss at the initial institution. Transfer to a tertiary care facility is necessary in medically complex or critically ill patients and is protected by the Emergency Medical Treatment and Active Labor Act of 1986 (EMTALA). Furthermore, while EMTALA requires hospitals with special capabilities to accept transfers from less specialized facilities, there are no guidelines defining appropriateness of transfers. The implementation of this bundled care model may result in an increase in unnecessary transfers of high-risk patients to tertiary care centers and safety-net hospitals[4,5]. As a result, it is important to understand not only the greater financial risk associated with accepting these patients, but also, the potential for increased morbidity and mortality of patients who are transferred.

Transfers to tertiary care centers, in general, can reduce mortality associated with critically ill and complex patients[6,7]. However, several studies in the orthopaedic literature demonstrate that transfers can be influenced by factors such as insurance status and time of the week with inappropriate transfers rates ranging between 16%-52%[8-13]. Other studies have shown that the transfer of medically and surgically complex patients can negatively impact the receiving hospitals' outcome measures and mortality rates[4,14]. These hospital quality metrics are available to the public. If these metrics are negatively influenced by inappropriate transfers, this may deter a patient from undergoing an elective procedure at these institutions. However, this has not been demonstrated in the literature as of yet.

The goal of this study was to examine financial and clinical outcomes in hospitalizations for unplanned arthroplasty in hip fractures between patients transferred from outside hospitals, patients presenting to the emergency department, and patients transferred from skilled nursing facilities. This study will help to further characterize the differences in cost and outcomes between these subsets of unplanned arthroplasty patients, which has not been previously documented to the best of our knowledge. This information is useful to physicians, hospital administrators, and payers as it may identify patient groups that utilize increased resources and suffer increased morbidity and/or mortality.

MATERIALS AND METHODS

Between 2010 and 2015, demographic, financial, and outcomes data were collected on all arthroplasty patients at our institution, a tertiary care center, as part of an Institutional Review Board-approved patient safety initiative. All patients underwent either total hip arthroplasty or proximal femoral hemiarthroplasty by one of three fellowship trained arthroplasty surgeons at this institution. In all cases, the procedural billing code for the arthroplasty procedure was the primary code submitted to the patient's insurance or medicare. For the purposes of this study, we included all patients with a diagnosis of basicervical, midcervical, or transcervical femoral neck fractures. Exclusion criteria included pathologic fractures, periprosthetic fractures, and fracture non-unions.

The data collected for the patient safety initiative included age, sex, race, diagnosis, facility of origin, secondary diagnoses, American Society of Anaesthesiologists (ASA) score, length of stay, length of intensive care unit stay, total observed cost, charges, mortality, discharge disposition, and procedure codes. Total observed cost include all costs related to the arthroplasty procedure and subsequent inpatient care of the patient. The patient's point of origin was determined to be our own institution's emergency department (ED), outside skilled nursing facility (SNF) or intermediate care facility, and outside hospital (OSH). These locations were verified by reviewing the patient's individual medical record. Patients who were transferred from an outside hospital or nursing facility to the emergency department were considered as transfers from an outside hospital or SNF, respectively. Patients who were transported to the emergency department from a physician's office or urgent care were considered emergency department patients. Finally, two patients that were directly admitted from clinic with a diagnosis of femoral neck fracture were not included in the study as they were previously known to and followed by the treating team and could be a potential source of bias in the analysis.

Statistical analysis

The data was utilized to examine differences in morbidity, mortality, cost, length of stay, and discharge disposition between hip fracture patients based on the individual point of origin prior to presenting to our institution. Each diagnosis, ASA score, Charlson comorbidity index, and surgical procedure performed were confirmed with individual chart review. For categorical variables, a Pearson chi-square analysis was performed.

RESULTS

A total of 223 patients met the inclusion criteria and were included in the study. The number of patients that presented primary to the ED at our institution, typically by EMS or medical transport, was 135 (60.54%). The number of patients that were transferred from an outside hospital to an inpatient unit or to the emergency department was 58 (26.01%). Lastly, the number of patients transferred from a SNF or intermediate care facility was 30 patients (13.43%). Patient cohorts and demographics are presented in Table 1.

ED patients and SNF patients were significantly older than OSH patients (P = 0.001). ED and SNF patients were not significantly different from each other in age.

There was a larger percentage of ASA 4 patients amongst OSH and SNF patients and significantly lower percentage of ASA 1 and ASA 2 patients compared to the ED patients (P = 0.001). There was no significant difference in average age-adjusted Charlson comorbidity index across all three groups. There was a significantly higher number of female patients (80.00%) who presented to the ED compared to transfers from OSHs (53.45%) and SNFs (53.33%) (P = 0.000). There was a trend toward increased utilization of hemiarthroplasty in SNF patients compared to ED and OSH patients that did not reach statistical significance (P = 0.070). Finally, there was no significant difference in race (white *vs* non-white) between the three groups (P = 0.583).

Cost data analysis showed that OSH patients demonstrated significantly greater total cost for their hospitalization ($43302) compared to ED patients ($28875, P = 0.000) and SNF patients ($28282, P = 0.000). OSH patients' costs per hospitalization average 149% and 153% of the cost per hospitalization of ED patients and SNF patients, respectively. There was no significant difference in total cost between ED patient and SNF patients (P = 0.805). This data is summarized in Figure 1. For reference purposes, the average total inpatient cost for the 1540 elective total hip arthroplasties performed at our institution

Table 1 Patient demographics by cohort

Variable	Emergency department patients (*n* = 135)	Outside hospital transfer patients (*n* = 58)	Skilled nursing facility and intermediate care facility patients
Average age	79.53	72.25 (*P* = 0.001)	83.25
Sex	80.00% female (*P* = 0.0000)	53.45% female	53.33% female
ASA score			
ASA 1 or 2	25.92% (*P* = 0.0007)	17.24%	3.33%
ASA 3	62.22%	56.90%	70.00%
ASA 4	11.85%	25.86% (*P* = 0.0007)	26.67% (*P* = 0.0007)
Average Charlson comorbidity index	5.17	5.51	6.07
Percentage hemiarthroplasty (*vs* THA)	71.11%	68.97%	90.00%
Race	88.14% white	93.10% white	90.00% white

ASA: American Society of Anaesthesiologists; THA: Total hip arthroplasty.

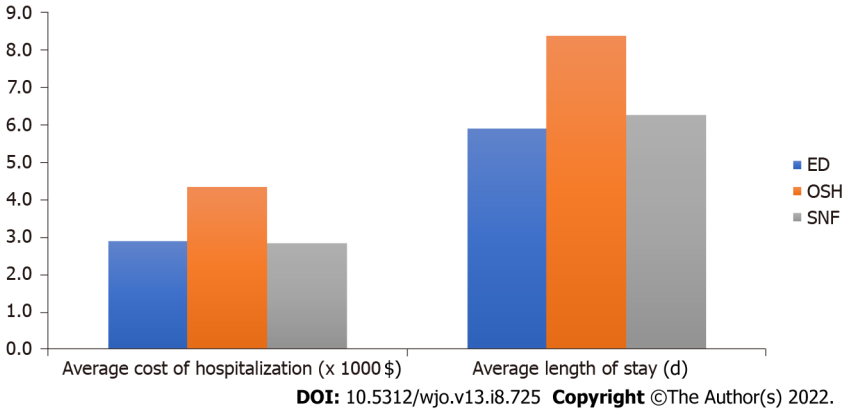

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Figure 1 Average cost of hospitalization and average length of stay of patients from different points of origin. ED: Emergency department; OSH: Outside hospital; SNF: Skilled nursing facility.

during the same time period as our study population is $22,182. Therefore, the non-elective hip arthroplasty patients' costs per hospitalization average 193%, 130%, and 127% of the cost per hospitalization of elective total hip patients for OSH, ED, and SNF patients, respectively.

Average LOS was significantly greater in the OSH patients (8.38 d) compared to ED patients (5.89 d, *P* = 0.003) and SNF patients (6.27 d, *P* = 0.027). No significant difference was found between ED patients and SNF patients in average LOS (*P* = 0.599). This data is also summarized in Figure 1.

Of the 135 ED patients, there were 3 in-hospital deaths (2.22%). There were 2 in-hospital deaths among the 58 patients transferred from outside hospitals (3.45%) and 3 in-hospital deaths among the 30 patients transferred from SNFs or intermediate care facilities (10.00%). Owing to the low number of mortalities, these differences did not reach statistical significance.

Average intensive care unit (ICU) days per hospitalization was significantly greater in the OSH patients (1.86 d) compared to ED patients (0.28 d, *P* = 0.001) and SNF patients (0.80 d, *P* = 0.002). There was no significant difference in ICU days per hospitalization between SNF and ED patients. This data is summarized in Figure 2.

Analysis of patient discharge destination showed that ED patients were more likely to be discharged home than OSH and SNF patients. There were no other statistically significant differences in discharge destination based on point of origin. This data is summarized in Figure 3.

DISCUSSION

Transfers to regional trauma centers and tertiary care centers of critically ill and severely injured

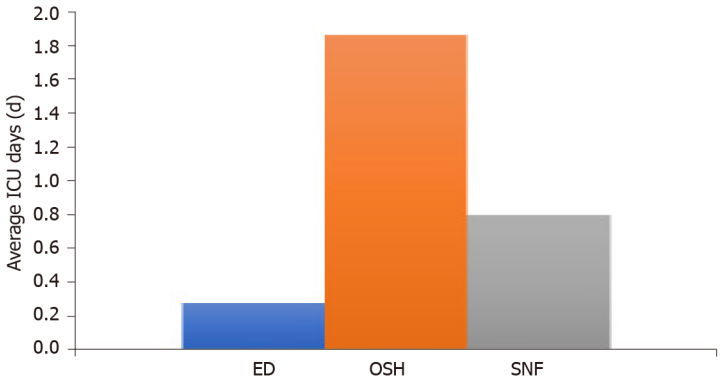

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Figure 2 Average intensive care unit days per hospitalization (days) from patient point of origin. ICU: Intensive care unit; ED: Emergency department; OSH: Outside hospital; SNF: Skilled nursing facility.

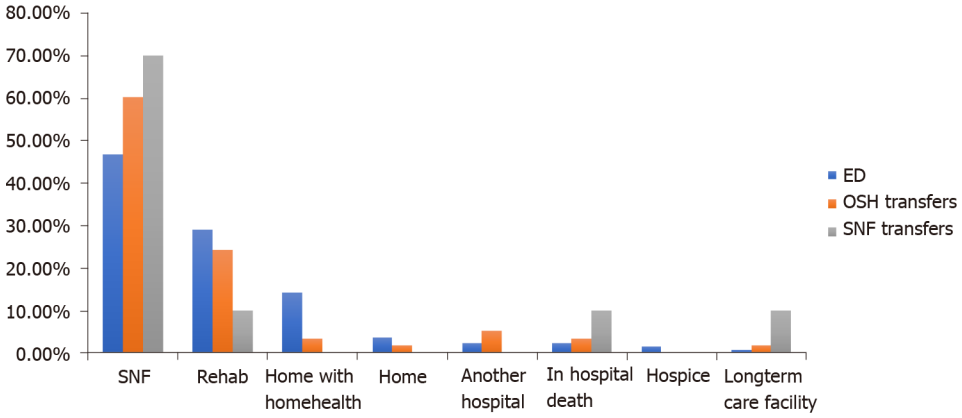

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Figure 3 Discharge destination based on patient point of origin. ED: Emergency department; OSH: Outside hospital; SNF: Skilled nursing facility.

patients have been shown to decrease morbidity and mortality[15,16]. As one might expect given the illness severity seen in many of these transferred patients, increased morbidity, length of stay, blood transfusion requirements, and intensive care utilization has been previously documented in transferred patients[8,11,17]. To our knowledge, this study is the first to document this phenomenon in patients with femoral neck fractures being treated with arthroplasty.

The aim of this study was to compare demographic information, procedure utilization, cost differences, morbidity, and mortality in non-elective hip arthroplasty performed for fracture at an academic medical center based upon patient point of origin. With the nationwide implementation of bundled payments looming, determining the additional risks and costs associated with providing referral services for community and regional hospitals is essential. It is not surprising that patients transferred from an OSH incurred greater costs for their hospitalization than ED and SNF patients. Medically complex patients with significant comorbidities, associated injuries, or critical illness are often difficult for community hospitals to manage and are frequently transferred to tertiary care centers. Previous studies have also found increased cost with non-elective hip arthroplasty compared to elective total hip replacement[4,5].

Our study showed increased length of stay and increased number of average ICU stays per hospitalization for transfered patients from an OSH compared to those patients presenting to our ED. These results are not surprising but demonstrate the greater burden OSH patients place on facilities, staffing, and healthcare providers. It may also reflect that a delay in getting the patient to the operating room can lead to medical complications and morbidity. Our study also found that ED patients were more likely to have ASA 1 or ASA 2 scores compared to SNF and OSH patients. Patients transferred from an OSH also incurred greater costs than those who presented primarily to our ED.

It is clear from our data that patients transferred from an OSH more significantly strain the resources of the receiving tertiary care hospital compared to those patients who present primarily to the ED. This is an important finding in light of proposed bundled care programs. Bundled care programs, which can disincentive hospitals and providers from taking care of sick and costly patients, may increase the number of hip fracture patients being transferred to tertiary care centers especially with clear

appropriate transfer guidelines lacking. This would further strain the resources of the receiving hospital and could potentially penalize those centers that are willing to provide care for these vulnerable patients. This is a strong argument for robust risk-adjustment models that potentially even include patient point of origin.

One obvious strength of our study is that it is the first to specifically look at cost and morbidity of hip fracture patients undergoing arthroplasty based on their point of origin. We were able to include a large number of patients over nearly a five year period. All total hip arthroplasty and hemiarthroplasty procedures were performed by three fellowship trained arthroplasty surgeons and therefore, variation in surgeon skill and experience is minimal. The data from our initial database was able to be corroborated through our electronic medical records and any disparities or omissions corrected. Finally, our study was able to determine differences in cost for hospitalizations, not charges, a more accurate representation of reimbursement from Medicare, Medicaid, or private insurance.

This study is not without its limitations. We did not examine the reason for transfer to our facility. This analysis may have allowed us to subcategorize patients based on the indication for the transfer and further determine which specific patient groups or which comorbidities are most likely to lead to increased cost, prolonged hospitalization, increased morbidity, or mortality. Additionally, we did not examine surgical complications, readmissions, or transfusion requirements which are further indicators of morbidity. Another limitation is that this is a retrospective analysis of prospectively collected data. Finally, our entire study was limited to a single institution and is subject to institution specific policies and biases that may limit the generalizability of our conclusions. However, we feel that any tertiary medical center with a large referral basis is likely to find similar results.

CONCLUSION

Patients transferred from an outside hospital incurred greater costs for their hospitalization than patients presenting from an emergency department or SNF. This is a strong argument for risk-adjustment models when bundling payments for the care of hip fracture patients.

ARTICLE HIGHLIGHTS

Research background

Rising healthcare expenditure, especially with the projected rise in total joint arthroplasty has lead the Center for Medicare Services to propose bundled payments.

Research motivation

Possible effects of bundle payments on tertiary hospital systems have not been evaluated.

Research objectives

This study aims to evaluate potential effects of bundled payment systems on a large tertiary hospital system.

Research methods

This is a retrospective study of a single hospital system evaluating the observed cost of care for patients presenting with hip fractures from the emergency department, skilled nursing facilities and outside hospital transfers.

Research results

Cost data analysis showed that patient transferred from an outside hospital demonstrate significantly higher costs compared to patients from a skilled nursing facility or the emergency department.

Research conclusions

Given the increased costs associated with patients transferred from outside hospitals this may call for a risk adjustment models when bundling for the care of hip fracture patients.

Research perspectives

Future research will have to further evaluate cost originators to adjust payment models appropriately.

FOOTNOTES

Author contributions: Haug EC wrote and revised the manuscript and collected data; Pehlivan H and Macdonell JR contributed equally and helped design the study and collect data; Novicoff W did the statistical portion; Browne J, Brown T and Cui Q are the senior surgeons; and All authors contributed to this study equally.

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ORIGINAL ARTICLE

Retrospective Study

Risk modeling of femoral neck fracture based on geometric parameters of the proximal epiphysis

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Abstract

BACKGROUND

Fractures of the proximal femur epiphysis are problematic for state health care because they are associated with severe medical and social problems and high morbidity and mortality rates.

AIM

To model the potential risk of hip fracture *via* femur geometric parameters.

METHODS

Seventy educational cadaveric femurs from people aged 14 to 80 years, 10 X-ray images from the records of the Human Anatomy Department and 10 X-ray images from the Department of Traumatology, Orthopedics and Disaster Surgery of Sechenov University, were evaluated. The parameters of the fractured bone were measured using images captured with a Canon d60 camera. The projection values of the proximal epiphysis of the cadaveric femurs and geometric parameters of the bones shown in the X-ray images were measured with Autodesk software

(AutoCAD 2018). Analysis of the video frames showing bone rotation reveal that the greater trochanter can be inscribed in a parallelepiped, where one of the faces is parallel to the plane of view in the frontal standard projection and is rectangular. The angle of bone rotation obtained by turning the cube corresponded to the angle measured with the second technique. This reliable method of calculating the rotation of the bone relative to the anterior projection was employed in subsequent calculations. The geometric parameters of the femur were measured using X-ray images according to the proposed method.

RESULTS

The geometric parameters of 70 femurs were analyzed, and correlation coefficients were calculated. Our measurement results were compared with those reported by other authors. The potential influence of femur geometry on force distribution in the proximal epiphysis of the femur was described, and a 2-dimensional model of the femur epiphysis associated with minimal neck fracture risk was provided. The assessment of the geometric parameters of the femoral epiphysis indicated the greatest risk of a varus fracture of the neck if the angle of the minimal resistance zone (AMRZ) index > 24° and the neck-shaft angle (NSA) < 127.5°. In contrast, the minimum risk was observed at AMRZ < 14° and NSA > 128.87°.

CONCLUSION

The proposed method provides the potential femur neck fracture risk based on geometric parameters.

Key Words: Fracture; Proximal epiphysis of femur; Risk; Traumatology; Hip neck; Risk assessment scale

Core Tip: The neck-shaft angle (NSA) and angle of the minimal resistance zone [the area located in Ward's triangle (AMRZ)] were most associated with femoral neck fracture risk, and a method for calculating the true value of these parameters and risk stratification was developed. Assessment of the geometric parameters of the femoral epiphysis revealed the greatest risk of a varus fracture of the neck if the AMRZ index > 24° and NSA < 127.5°. In contrast, the minimum risk was observed at AMRZ < 14° and NSA > 128.87°.

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INTRODUCTION

Fractures of the proximal epiphysis of the femur are problematic for state health care because they are associated with severe medical and social problems[1], high morbidity rates[2], disability[3,4], and high mortality rates[5]. Bone strength depends on the mineral density, architectonics and remodeling ability of bones[6], which change over time due to various factors. Characteristics such as bone mineral density, bone geometry and the properties of bone materials are factors that constitute bone quality[6]. The process by which bone strength decreases due to chemical composition changes and by which it decreases in trabecular density is referred to as osteoporosis[7].

The results of multiple studies on the causes and risk factors of bone deterioration, such as osteoporosis, have been introduced in clinical practice. The Fracture Risk Assessment Tool (FRAX)[8] scale was developed by individuals at the University of Sheffield to evaluate fracture risk; the scale assesses the influence of factors that cause a decrease in bone strength. The FRAX scale allows us to predict the ten-year probability of fracture, to identify patients who require more detailed examinations, including X-ray densitometry, and to prevent excessive radiation exposure[9].

In recent years, numerous studies have investigated the distribution of strain in bone under an applied load, identified areas that are highly influenced by stress and fracture risk and determined the influence of bone cytoarchitectonics and geometry on stress apportionment. High-resolution computed tomography and magnetic resonance tomography are employed in this field to analyze bone morphometric parameters[10]. Finite element analysis is a technique that is widely employed for bone model

construction[11]. MATLAB is frequently utilized to calculate stress distributions in bone models[1]. The authors assessed changes in bone sample flexibility *via* a microhardness tester[12]. Other authors have detected structures in loaded femurs *via* a tension detector fixed to the bone[13]. The results of these investigations have been implemented in osteosynthesis operations[14] and endoprosthesis engineering applications[15].

This study aimed to determine the geometric parameters of the proximal femur that contribute most to femoral neck fracture. A method for measuring bone geometric parameters *via* X-ray images is provided since X-ray images are widely employed by general practitioners, and thus, may be preferable for use in screening studies. According to this finding, in this study, we will mostly rely on X-ray imaging, as a widely utilized diagnostic method.

MATERIALS AND METHODS

Seventy femurs from the records of the Department of Human Anatomy at Sechenov University from people aged 14 to 80 years were selected to measure geometric parameters of the proximal epiphysis.

A video of femur rotation around the anatomic axis (for the estimation of the bone projection changes during the turning process) and stills from the video and X-ray images of the femur of 10 adult patients (18-24 years) were provided by the Department of Human Anatomy at Sechenov University (18-24 years), and 10 images of adult patients (18-63 years) were provided by the Department of Traumatology, Orthopedics and Disaster Surgery of Sechenov University (18-63 years). These X-ray images contained images of both femurs: one femur was fractured, and the other femur was intact and considered equal. The parameters of the fractured bone were measured using images captured with a Canon d60 camera.

The projection values of the proximal epiphysis of the femurs from the Department of Human Anatomy and geometric parameters of the bones shown in the X-ray images were measured with Autodesk software (AutoCAD 2018).

Method of measuring bone geometry parameters

To ensure accurate measurements, centimeter rulers were attached to the bones, which helped to correctly scale the images. The projection that defines the femoral neck base and accuracy of the neck-shaft angle (NSA) measurements, *i.e.*, the frontal standard projection (FSP), was selected to plot the segments signifying the main geometric parameters of the proximal epiphysis of the femur.

In this study, a method for assessing the morphometric parameters of the proximal femur based on the projection values and angle of rotation around the anatomical axis relative to the FSP was developed. In this study, the rotation angle was determined by the rotation of the cube installed on the tripod turning the bone. The rotation of the cube thus indicated the rotation of the bone at every point in time. The anatomical axis was drawn through the midpoint of the diaphyseal diameter. The mechanical axis passed through the center of the femoral head and the midpoint of the distal epiphysis of the thigh bone (half of the distance between the condyles). The femoral neck axis was determined by the segment passing through the center of the femoral head and the plane perpendicular to the midpoint of the upper base of the femoral neck.

The triangle ABC designations, which are employed in formulas, comprising NSA (angle CAB); AC, the neck axis; and AB, the diaphyseal axis segment (connecting the diameter of the diaphysis to the neck axis), were plotted (Figure 1A) as a major component of the epiphysis of the proximal femur.

The angle between the principal compressive trabecular pattern and the secondary compressive group [angle of the minimal resistance zone (AMRZ)] was applied to assess the value of Ward's triangle. The principal compressive trabecular pattern and secondary compressive group are indicated by segments KL and LJ, respectively. Segment KL was defined as the segment from the upper projection point of the distal base of the neck (point K) to the lower projection point of the lesser trochanter (point L). The segment LJ was defined as the segment parallel to the mechanical axis, which connects the center of the femoral head to the point between the femoral condyles and passes through point L (Figure 1B).

The minimal resistance zone was demonstrated using photos of gross sections of the proximal epiphysis of the femur from the Department of Human Anatomy at Sechenov University. Trabecular patterns, following the course of the main forces acting on the femoral epiphysis under physiological vertical loading, were clearly visualized on the gross sections. The direction of the chosen segments corresponded to the physiological stress lines and comprised a zone containing fewer trabeculae than were present in adjacent areas (Figure 1C).

The projection values of the proximal femoral geometry parameters are equal to their actual values if the bone is positioned such that the planes of the CAB and KLJ triangles are parallel to the plane of the screen onto which the bone is projected. If the bone is somehow rotated, its parameter cannot be measured directly. Therefore, the bone elements that can assist in determining the presence of bone rotation relative to the standard projection and in measuring its angle were selected.

When analyzing the video frames that show bone rotation, we determined that the greater trochanter can be inscribed in a parallelepiped, one of the faces of which is a rectangle when the bone is in FSP.

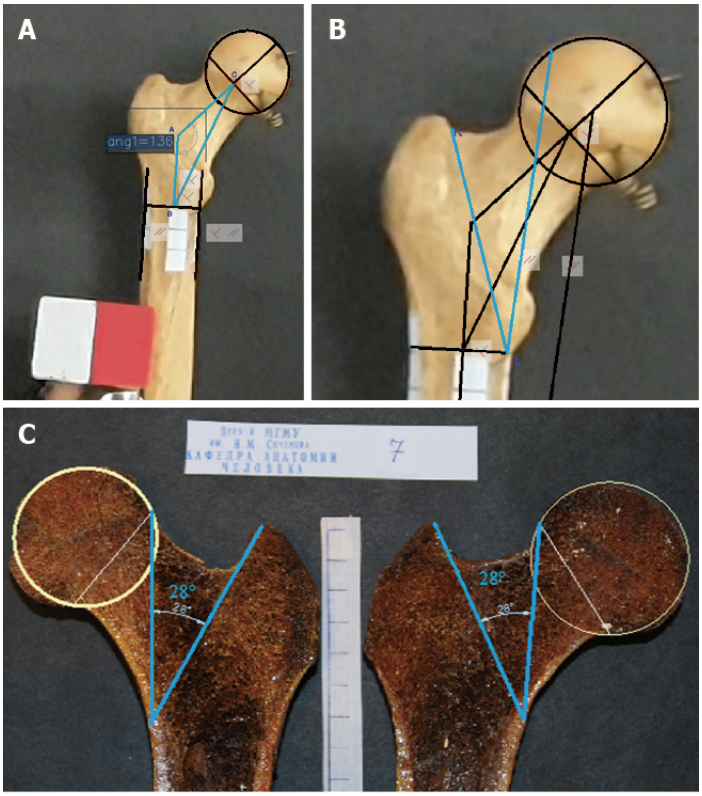

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Figure 1 In this study, a method for assessing the morphometric parameters of the proximal femur based on the projection values and angle of rotation around the anatomical axis relative to the FSP was developed. A: Bone No. 9. Triangle ABC comprised the NSA (angle CAB); AC, neck axis; and AB, diaphyseal axis segment (connecting the diameter of the diaphysis to the neck axis); B: Bone No. 9. Angle KLJ was a part of Ward's triangle, designating the angle of the minimal resistance zone (AMRZ); C: Bone No. 7. The angle, indicating the borders of the AMRZ, was plotted on photos of gross bone sections.

Consequently, this geometric parameter was chosen to evaluate the rotation of triangle ABC relative to the anatomical axis, to which segment AB is parallel. Thus, on an X-ray, the angle of rotation of the bone relative to the FSP can be determined by calculating the angle of rotation of the parallelepiped that contains the greater trochanter using spatial construction (Figure 2).

To assess the reliability of determining the angle of rotation on the basis of the greater trochanter, this angle was calculated by measuring the angle of rotation of the cube fixed to a tripod using the following formula:

QCN =135°- arcos (a1/a), where a is the edge of the cube (whose length is 50 mm) and a1 is the length of the cube verge in a projection other than the FSP.

The angle of bone rotation obtained by turning the cube corresponded to the angle measured with the second technique, which uses the previously described feature of the large spit. Thus, this method of calculating the rotation of the bone relative to the anterior projection was deemed reliable and utilized in subsequent calculations. During the rotation of the bone around axis AB to a random angle, triangle ABC was projected onto ABC1.

The change in the projection value of the NSA as a function of the angle of the rotation is represented by the following equation:

CAB = 180°-arctg (SA/(SC1/cosHSC)), where HSC is the angle of rotation, SA is the segment of the diaphyseal axis, and SC1 is the perpendicular segment, which passes through the center of the head of the femur to the diaphyseal axis (Figure 3A).

Based on the abovementioned findings, the formula for calculating the true value of the AMRZ takes into account the rotation of the bone:

$K_1L_1J_1$ = acrtg (KO/(cos (KOH) × OL)) + arctg (OJ/(cos (JOH) × OL)), where KLJ is the projection AMRZ, $K_1L_1J_1$ is the true AMRZ, KO and OJ are segments of the perpendicular line toward the diaphyseal axis passing through point J (Figure 3A), and KOH and JO indicate the angle of rotation.

Determination of the true parameters of the proximal epiphysis of the femur from an X-ray

A technique is proposed for determining the angle of rotation of the bone relative to the plane of the X-ray image based on the estimated rotation of the greater trochanter. In this technique, a box is created around the greater trochanter. Geometric constructions (Figure 2) are performed to estimate the angle of rotation similar to the technique previously mentioned for native bones and their videos.

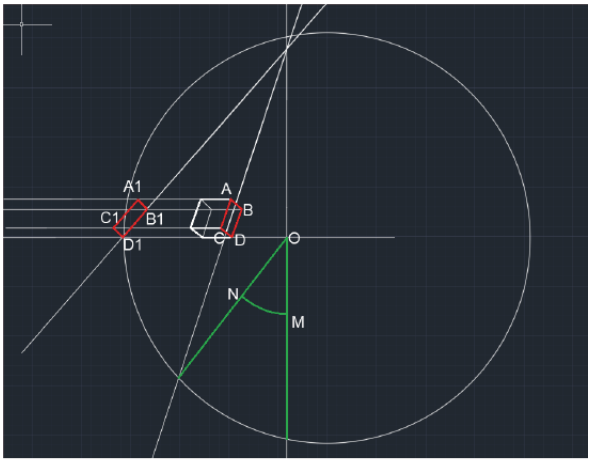

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Figure 2 Scheme of the constructions used to determine the angle of rotation of the bone (NOM).

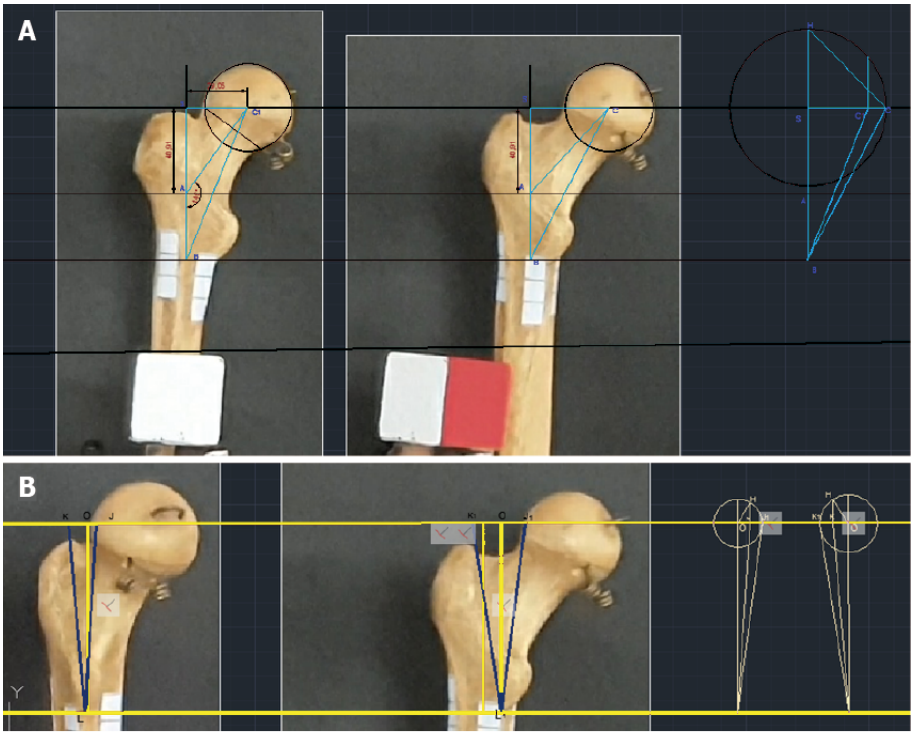

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Figure 3 The angle of bone rotation obtained by turning the cube corresponded to the angle measured with the second technique, which uses the previously described feature of the large spit. A: Bone No. 9. Photo of the NSA and calculation of its true value based on the projection value and the rotation angle; B: Estimation of the true AMRZ based on its projection value and the rotation angle.

Subsequently, this value is used to determine the true AMRZ. The change in the projection magnitude of the NSA as a function of the angle of rotation can be represented by the following equation:

CAB = 180o-arctg (SA/(SC1/cosHSC)), where HSC is the angle of rotation, SA is the segment of the axis of the diaphysis, and SC1 is the segment of the perpendicular line connecting the center of the femoral head to the axis of the diaphysis (Figure 3B).

The true value of the AMRZ was calculated as follows:

$K_1L_1J_1$ = acrctg (KO/(cos (KOH) × OL)) + arctg (OJ/(cos (JOH) × OL)), where KLJ is the AMRZ projection, $K_1L_1J_1$ is the true AMRZ, KO and OJ are segments of the perpendicular line toward the axis of the diaphysis drawn through point J (Figure 2), and KOH and JOH are the angles of rotation (Figure 3B). When the plane including the axes of the neck and diaphysis is parallel to the plane of the X-ray, it is possible to directly measure the AMRZ (Figure 4).

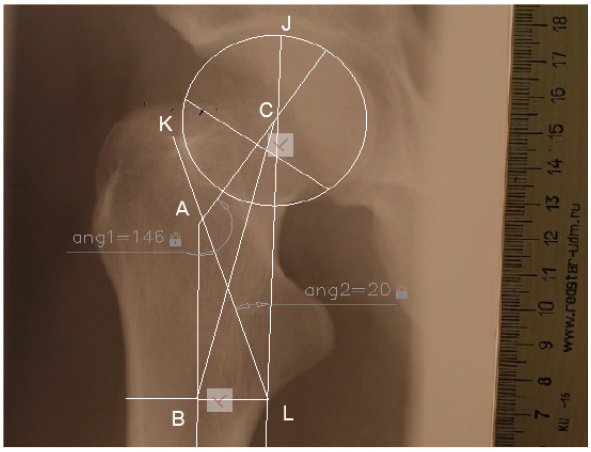

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Figure 4 X-ray image from the Department of Human Anatomy showing triangle ABC and the AMRZ.

This study does not take into account any parameters other than geometric parameters. Sex, age, concomitant diseases and other conditions can affect these parameters, but this study evaluates the results of these effects.

RESULTS

Interrelations among proximal femoral morphometric parameters

The results of a statistical analysis of the geometric parameters of the proximal epiphysis of the femur are presented in Table 1.

The correlation coefficient for the correlation between the NSA and the AMRZ, for the correlation between segment BC and the zone of minimum resistance, and for the correlation between the length of segment BC and the upper-to-lower neck length ratio was -0.155, 0.0617, and -0.119, respectively, which indicates weak negative correlations among these parameters. These findings suggest that the NSA and AMRZ vary independently of each other, and regarding the influence of these changes on the risk of fracture of the femoral neck, they must be evaluated as independent values. The correlation coefficient between the NSA and the upper-to-lower neck length ratio was -0.396, that is, there was a moderate negative correlation between these parameters.

The strongest correlation was found between the AMRZ and the upper-to-lower neck length ratio, with a correlation coefficient of 0.872 (Figure 5). Based on this finding, we use the upper-to-lower neck length ratio to determine the size of the AMRZ.

Model of the proximal epiphysis that provides a minimal risk of femoral neck base fracture

The model of the proximal epiphysis, which provides a minimal risk of femoral neck base fracture, consists of an NSA of 134° (which is 1° smaller than the mean of the maximal and mean values of this parameter shown in our study (144°+125.9°)/2 = 134.99°)) and an AMRZ of 14° (minimal value of the parameter in our study) (Figure 6).

The femoral proximal epiphysis, which has parameters included in this model, is the most resistant to femoral neck base fracture when a patient falls on his or her side, according to our study.

Evaluation of the risk of femoral neck fracture using X-ray images

The scale was developed to evaluate the risk of femoral neck base fracture (Table 2). Scores were assigned to bone parameters within certain intervals, as specified in the table. According to the sum of the points, the degree of fracture risk for a given bone was determined: 2 points indicated low risk, 3-4 points indicated average risk, and 5-6 points indicated high risk. The analysis of 10 X-ray images stored in the Department of Human Anatomy and 10 X-ray images of patients from the Department of Traumatology, Orthopedics and Disaster Surgery of Sechenov University showed that the value of the NSA and AMRZ differed from the optimal value for all bones.

DISCUSSION

We aimed to determine the bone parameters that are risk factors for a fracture of the base of the femoral

Table 1 Values of the geometric parameters of the proximal epiphysis of the femur

	Range	Mean value	Standard deviation	Standard error	Coefficient of variation
Neck-shaft angle (degrees)	103-144	125.99	9.09	1.08	0.07
Angle of the minimal resistance zone (degrees)	14-36	23.90	5.67	0.67	0.24
AC	32.3-61.48	48.60	7.10	0.84	0.15
AB	17.94-57.3	38.61	10.05	1.19	0.26
BC	55.51-94.42	78.00	8.66	1.03	0.11
Upper neck length	14.19-33.79	21.44	5.09	0.60	0.24
Lower neck length	21.72-45.94	33.67	5.19	0.62	0.15

Table 2 Scale for determining the risk of femoral neck base fractures according to the morphometric parameters

	Neck-shaft angle	Angle of minimal resistance zone	The ratio of the top and bottom neck lengths
1 point	130.24 and more	14 and less	0.56 and less
2 points	127.5-130.24	18.95-29.95	0.57-0.74
3 points	Less than 127.5	More than 29.95	0.75 and more

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Figure 5 Scatter plot showing the correlation between these parameters and the corresponding regression line.

neck when the patient falls on his or her side and did not take into account other types and mechanisms of fracture. However, the selected optimal values still remain within the reference values, even if they increase the risk of other mechanisms of femoral fracture.

In our study, we agree with the finding of several authors[16-20] that some bone parameters, such as NSA, have optimal values, and their deviations can cause a higher risk of fracture. In another study, the NSA value had a weak correlation with the size of the minimum resistance zone of the proximal femur (AMRZ), indicating that these parameters can independently influence fracture risk.

According to previous studies, neither a decrease in the NSA nor an increase in the NSA can be considered a reliable risk factor for femoral neck fracture since there are data that both confirm and disprove the influence of these factors on the probability of fracture[21-23]. Nevertheless, it has been confirmed that the strength of the proximal epiphysis decreases when the NSA decreases, and the stress that occurs in the proximal epiphysis under stress conditions shifts to its distal part. The femoral neck can be considered a lever, to the ends of which forces are applied. In this case, the value of the moment of forces that characterize the rotational action of forces acting on the proximal and distal part of the neck relative to the middle of the lever will increase as the NSA decreases. Based on measurements and a fracture risk assessment in another study, we assume that reducing the NSA causes an increase in the

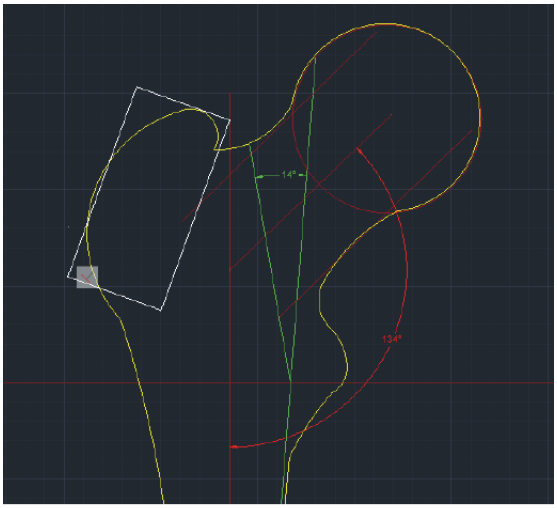

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Figure 6 A two-dimensional model of the proximal femoral epiphysis on the frontal standard projection that provides a minimal risk of femoral neck base fracture after a simple mechanical fall (falling from a patient's own height).

risk of femoral neck base fracture.

In the field of orthopedics, proximal femur modeling is utilized to plan interventions and assess their results[24]. When planning corrective osteotomy, to calculate the true value of the NSA using X-ray images, the researchers employed X-ray images of the hip joints projected directly in the middle position, with internal rotation of the thigh, and in a position proposed by Lauenstein, with the mathematical tables proposed by Strzyzewski or Shartlain[19]. However, these measurements allow only approximate planning of the surgical intervention, so the results of the treatment depend heavily on the personal skills of the surgeon. 3-D modeling is considered a more accurate method; therefore, algorithms for calculating surgical interventions on 3D models have been introduced and are highly distributed[24-27].

Furthermore, modeling of the proximal femoral epiphysis is conducted to create mathematical models to assess the risk of fractures under the influence of external factors. In recent years, special attention has been given to the variability of the shape of the proximal femur and the influence of its geometry on its strength[28]. For this purpose, statistical shape models are employed to simultaneously assess the impact of risk factors and pathological changes in a variety of bone geometric phenotypes [29]. The analysis of the geometric and strength characteristics of cadaveric proximal femurs continues to be applied for more accurate construction of mathematical models[30,31].

However, in most cases, statistical shape models require three-dimensional images using tomographic methods. Since the 3D model is associated with a high computational burden, Jazinizadeh *et al*[32] compared the ability of 2D and 3D femur models to predict hip fracture risk and showed that their productiveness does not differ significantly.

We propose a method for calculating the true parameters of the proximal epiphysis based on one projection obtained using an X-ray image. Our technique is assumed to prevent the occurrence of femoral fracture in primary health care practice, unlike other techniques designed to correct the consequences of a fracture. We assume that our method can be used in combination with existing methods for assessing the risk of fractures, since it does not contradict but can complement other methods.

Our study has a retrospective design, which is its first limitation. In the course of this work, a small number of X-ray images were selected; other types and mechanisms of fracture were not taken into account; and any parameters of bone tissue, other than geometric characteristics, were not taken into account. With regard to the selection of cadaveric bones, the age, gender and other parameters of the owners of the bones were not taken into account. In addition, the impact of other risk factors for hip fractures has not been evaluated, and densitometry studies have not been performed.

The scale needs to be evaluated further in future studies and is not ready for use in clinical practice. However, the measurement of these parameters during screening studies can reduce the risk of severe injuries.

The suggested method for measuring the true parameters of the proximal femur does not require special equipment but is quite difficult to implement. This method can be used when special software is not available and in combination with other screening tools that use X-ray scans of the femur. Further improvements to this method are needed. Nevertheless, performing such measurements with modern X-ray diagnostic systems is not difficult. This method is assumed to be combined with other screening techniques and to be employed when other less complicated measurement methods are not available.

CONCLUSION

Disease prophylaxis *via* the assessment of risk factors and prevention is essential in modern medicine. Therefore, methods for assessing and diminishing risk should be developed. The method described in this article is assumed to be a tool for first-level health care to predict severe disabling damage. Early detection of the anatomic predisposition to fracture as well as the identification of osteoporosis shall allow general practitioners to identify patients who are in the femur fracture risk group because of proximal femur geometry pathological changes and to take opportune actions for bone strengthening. This screening approach will decrease morbidity, mortality and the costs required for treatment and rehabilitation. Simultaneously, with a decline in incidence, mortality is also expected to decrease. The plotting methods proposed in this study could also be applied to design mathematical models for preoperative preparations. However, in this way, these methods should be further developed.

ARTICLE HIGHLIGHTS

Research background

Currently, a fracture of the femoral neck is a serious health problem, as it very often leads to long-term hospitalization, disability and death of patients. Modern medicine implies the prevention of such serious injuries and their consequences. At the moment, there are methods for assessing bone mineral density, but its geometry remains beyond attention.

Research motivation

This study was created for the reasons that existing methods often do not take into account the geometric parameters of the bone, and is aimed at filling this gap and creating techniques that complement existing ones.

Research objectives

The purpose of this work was to study the influence of bone geometry on its strength, as well as to find ways to apply these data in practice. The results of the study were conceived as an addition to the existing methods of assessing the risk of fracture.

Research methods

In our study, we measured 70 cadaveric bones and 20 X-rays by creating digital copies of them and processing them in the AutoCAD environment. The cuts of the proximal epiphyses of bones were studied. An analysis was also carried out aimed at identifying parameters correlating with a high risk of fracture. A scale was created as a possible risk assessment tool.

Research results

In our research, we studied the course of bone beams, the distribution of bone tissue in the proximal epiphysis and found the zone that is most vulnerable to mechanical stress. The parameters of the proximal epiphysis were investigated and those that may indicate a higher risk of fracture were identified. A scale was proposed and tested to assess this risk.

Research conclusions

The geometric parameters of the bone reflect the features of the structure of the bone beams and the distribution of bone matter. There are parameters of the proximal epiphysis, the measurement of which with the help of modern imaging methods can help determine the increased risk of fracture of the proximal epiphysis of the femur. Modern methods of risk stratification often ignore the geometric parameters of the bone and our study suggests a way to take them into account to determine the risks of fracture.

Research perspectives

In order to develop the idea, it is possible to conduct a larger-scale study with a large number of participants. Further refinement of the scale is needed in order to clarify it and possibly expand it. With satisfactory results of refinement, it is possible to introduce the proposed methodology into practice for its clinical trial.

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FOOTNOTES

Author contributions: Shitova AD, Zubkov DD, Gadzhimuradova IA and Kniazev MO are responsible for measurement of bone parameters; Shitova AD, Olsufieva AV, Zubkov DD, Gadzhimuradova IA and Kniazev MO are responsible for data collection and analysis; Shitova AD, Olsufieva AV, Zubkov DD, Gadzhimuradova IA and Zharikova TS did the literature review; Shitova AD and Zubkov DD graphing in AutoCad2018; Zharikova TS created the figures; Kovaleva ON and Zharikov YO: project manager and scientific advisor.

Institutional review board statement: This study was reviewed and approved by the Ethics Committee of the I.M. Sechenov First Moscow State Medical University (Sechenov University).

Informed consent statement: Patients were not required to give informed consent to the study because the analysis of the X-ray images and anonymous clinical data that were obtained after each patient agreed to treatment by written consent. Cadaver material (70 femurs) was bequeathed to the Department of Human Anatomy by people and their relatives from 20 to 35 years ago, when these objects were designated for educational purposes for morphological departments.

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ORIGINAL ARTICLE

Retrospective Study

Epidemiology of pelvic and acetabular fractures across 12-mo at a level-1 trauma centre

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Abstract

BACKGROUND

Despite motor-vehicle safety advancements and increasingly rigorous workplace safety regulations, trauma/suicide remains the leading cause of death under the age of 45 in the United Kingdom. To promote centralisation of care and optimisation of major trauma outcomes, in 2012 the National Health Service introduced the Trauma Network System. To our knowledge, this is the first study to analyse the epidemiology of pelvic and acetabular trauma over a one-year period at a level-1 trauma centre in the United Kingdom, since nationwide introduction of the Trauma Network System.

AIM

To characterize the epidemiology of high-energy pelvic and acetabular fractures over a one-year period at a level-1 trauma centre, and explore both resources required to care for these patients and opportunities for future research and injury prevention initiatives.

METHODS

227 consecutive patients at a level-1 trauma centre with pelvic and acetabular fractures were analysed between December 2017-December 2018. Paediatric patients (< 18 years) and fragility fractures were excluded, leaving 175 patients for inclusion in the study. Statistical analysis was performed using Fisher's exact test for categorical variables.

RESULTS

72% of pelvic and acetabular fractures occurred in male patients at a median age of 45 years. 15% were the result of a suicide attempt. 48% of patients required pelvic or acetabular surgery, with 38% undergoing further surgery for additional

orthopaedic injuries. 43% of patients were admitted to intensive care. The median inpatient stay was 13 days, and the 30- day mortality was 5%. Pelvic ring trauma was more commonly associated with abdominal injury ($P = 0.01$) and spine fractures ($P < 0.001$) than acetabular fractures. Vertical shear pelvic ring fractures were associated with falls ($P = 0.03$) while lateral compression fractures were associated with road traffic accidents ($P = 0.01$).

CONCLUSION

High energy pelvic and acetabular fractures are associated with concomitant orthopaedic fractures (most commonly spine and lower limb), intensive care admission and prolonged inpatient stays. Most pelvic ring injuries secondary to road traffic accidents are lateral compression type, demonstrating the need for future research to drive advancements in lateral impact vehicle safety along with mental health surveillance for those deemed to be potential suicide risks.

Key Words: Pelvis; Acetabulum; Orthopedics; Multiple trauma; Trauma centers

Core Tip: To our knowledge, this is the first study to analyze the epidemiology of pelvic and acetabular trauma over a one-year period at a level-1 trauma centre in the United Kingdom since introduction of the Trauma Network System. This study demonstrates pelvic and acetabular fractures are associated with concomitant orthopaedic fractures (commonly spine and lower limb), intensive care admission and lengthy inpatient stays. Future injury prevention research should focus on advancements in lateral impact vehicle safety alongside mental health surveillance for patients deemed to be potential suicide risks.

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INTRODUCTION

Major trauma/suicide remains the leading cause of death under the age of 45 in the United Kingdom (UK)[1]. In an effort to centralise trauma care and optimise outcomes, the National Health Service (NHS) introduced the Trauma Network System in 2012[2]. This designated 27 hospitals in England as Major Trauma Centres (MTCs) responsible for the specialist management of severely injured patients. 22 MTCs are responsible for the management of adult pelvic and acetabular trauma[3].

To our knowledge, this is the first study to analyze the epidemiology of high-energy (non-fragility) pelvic and acetabular trauma over a one-year period at a major trauma centre in the United Kingdom since introduction of the Trauma Network System. Given evolving safety measures and public travel preferences, the primary objectives were to characterise the epidemiology of current pelvic and acetabular fractures and their associated injuries, to demonstrate the wide-ranging resources required to care for these patients and explore opportunities for future injury prevention research.

MATERIALS AND METHODS

Study design

This retrospective observational study analyzed consecutive patients presenting to a level-1 trauma centre in the UK between December 2017 and December 2018. Research and audit approval was obtained from the Clinical Effectiveness Unit, and the NHS Research Ethics Committee decision tool excluded need for ethical review.

227 patients with pelvic and acetabular fractures were identified using Abbreviated Injury Scale (AIS) codes on the institution's prospectively maintained Trauma Audit and Research Network database. All adult patients (≥ 18 years) with pelvic or acetabular fractures confirmed on computed tomography were included. Paediatric patients (< 18 years), fragility fractures (in accordance with the World Health Organisation definition as falls from standing height or less)[4] and patients who did not undergo computed tomography of the pelvis were excluded. This left a total of 175 patients for inclusion in the study.

Data collection

Orthopaedic multidisciplinary team documentation, consultant radiology reports and electronic patient records were analyzed by orthopaedic registrars (residents) to populate a standardised collection proforma. The following study outcomes were recorded: age, gender, pelvic or acetabular fracture (pelvic ring fracture only, pelvic ring and acetabulum fracture, acetabulum fracture only, iliac wing fracture, sacral body fracture, spinopelvic dissociation, other), Young-Burgess classification for pelvic ring fractures – lateral compression (LC) 1/2/3, anteroposterior compression (APC) 1/2/3, vertical shear (VS) or combined[5], open pelvic or acetabular injury, mechanism (fall, crush injury, other and road traffic accident which was further subdivided into pedestrian *vs* vehicle, vehicle *vs* vehicle and cyclist *vs* vehicle), suicide attempt, intensive care admission, head injury (AIS ≥ 1), abdominal injury (AIS ≥ 1), spine fracture, upper limb fracture / dislocation, lower limb fracture / dislocation, pelvic or acetabular surgery, number of further orthopaedic surgeries during admission, length of stay (days) and 30-d mortality.

Statistical analysis

Statistical analysis to compare groups within the study was performed using Fisher's exact test for categorical variables. This was preferred to the Chi-square test due to small numbers in some categories. The *P*-value for statistical significance was set at < 0.05. Statistical analysis was performed using Stata version 15.1 (Stata Corp LLC, College Station, Texas).

RESULTS

Epidemiological characteristics

72% of all pelvic and acetabular fractures occurred in male patients at a median age of 45 years. 48% of patients required pelvic or acetabular surgery, with 38% undergoing additional surgery for other orthopaedic injuries. 43% of patients were admitted to intensive care with a median total hospital stay of 13 d. The 30-d mortality for all high-energy pelvic and acetabular fractures was 5% with only 1.7% of patients dying within the first 24 h of injury (Table 1).

Spinopelvic dissociation was associated with the greatest likelihood of additional surgery for other orthopaedic injuries (43%), and the highest 30-d mortality rate (14%). 37% of pelvic ring fractures required surgical intervention comparative to 66% of acetabular fractures. Combined pelvic ring and acetabular fractures were associated with the longest median total hospital stay of 28 d (Table 1).

Mechanism of injury

51% of pelvic ring fractures occurred following road traffic accidents, 43% were the result of falls from height and 7% were secondary to crush injuries. Road traffic accidents were responsible for 59% of acetabulum fractures with 39% due to falls. The most common subcategory of road traffic accident in pelvic ring fractures was pedestrian *vs* vehicle (27%). The most common subcategory of road traffic accident in acetabular fractures was cyclist *vs* vehicle (23%).

71% of spinopelvic dissociations and 100% of sacrum body fractures were secondary to falls from height. 15% of all high energy pelvic and acetabular fractures were the result of a suicide attempt (Table 2).

Associated injuries

43% of all pelvic and acetabular fractures had an associated spine fracture. This was followed by lower limb fractures (31%), head injury (27%) and upper limb fractures (22%). 5% of all pelvic and acetabular fractures were open injuries (Table 3).

Comparison of pelvic ring and acetabulum fractures demonstrated a statistically significant association between pelvic ring fractures and both abdominal injury ($P = 0.01$) and spine fractures ($P < 0.001$) (Table 4).

Epidemiological characteristics based on the Young-Burgess classification

The breakdown of pelvic ring fractures based on the Young-Burgess classification is illustrated in Figure 1. There was a statistically significant difference between classification-types when the mechanism of injury was a fall ($P = 0.03$) or road traffic accident ($P = 0.01$). Falls were responsible for 86% of VS fractures, and 96% of all pelvic ring injuries secondary to road traffic accidents were LC-type. Crush injuries occurred more frequently in APC-type injuries (50%) but this did not reach statistical significance ($P = 0.05$) (Table 5).

Table 1 Epidemiological characteristics of pelvic and acetabular fractures

Variable	Pelvic ring fracture only, *n* (%)	Pelvic ring & acetabulum fracture, *n* (%)	Acetabulum fracture only, *n* (%)	Iliac wing fracture, *n* (%)	Sacrum body fracture, *n* (%)	Spinopelvic dissociation, *n* (%)	All pelvic & acetabular fractures, *n* (%)
Age, median [inter-quartile range]	44 [32, 59]	54 [48, 61]	46 [37, 65]	27 [23, 34]	53 [38, 69]	59 [39, 72]	45 [33, 61]
Gender							
Male	60 (64)	9 (82)	39 (89)	11 (92)	2 (29)	5 (71)	126 (72)
Female	34 (36)	2 (18)	5 (11)	1 (8)	5 (71)	2 (29)	49 (28)
ITU admission							
Yes	40 (43)	6 (55)	15 (34)	4 (33)	3 (43)	7 (100)	75 (43)
No	54 (57)	5 (45)	29 (66)	8 (67)	4 (57)	0 (0)	100 (57)
P&A surgery							
Yes	35 (37)	10 (91)	29 (66)	1 (8)	2 (29)	7 (100)	84 (48)
No	59 (63)	1 (9)	15 (34)	11 (92)	5 (71)	0 (0)	91 (52)
Orthopaedic surgeries							
2+	12 (13)	3 (27)	10 (23)	1 (8)	0 (0)	3 (43)	29 (17)
1	25 (27)	0 (0)	7 (16)	3 (25)	2 (29)	0 (0)	37 (21)
None	57 (60)	8 (73)	27 (61)	8 (67)	5 (71)	4 (57)	109 (62)
Length of stay, median [inter-quartile range]	14 [6, 28]	28 [20, 43]	10 [5, 26]	3 [1, 6]	14 [8, 26]	23 [16, 65]	13 [6, 28]
30-d mortality							
Alive	87 (93)	11 (100)	44 (100)	11 (92)	7 (100)	6 (86)	166 (95)
Dead	7 (7)	0 (0)	0 (0)	1 (8)	0 (0)	1 (14)	9 (5)

Table 2 Mechanism of pelvic and acetabular fractures

Mechanism	Pelvic ring fracture only, *n* (%)	Pelvic ring & acetabulum fracture, *n* (%)	Acetabulum fracture only, *n* (%)	Iliac wing fracture, *n* (%)	Sacrum body fracture, *n* (%)	Spinopelvic dissociation, *n* (%)	All pelvic & acetabular fractures, *n* (%)
Fall	40 (43)	4 (36)	17 (39)	7 (58)	7 (100)	5 (71)	80 (46)
Pedestrian *vs* Vehicle	25 (27)	3 (27)	8 (18)	2 (17)	0 (0)	0 (0)	38 (22)
Vehicle *vs* Vehicle	12 (13)	3 (27)	8 (18)	1 (8)	0 (0)	1 (14)	25 (14)
Cyclist *vs* Vehicle	10 (11)	1 (9)	10 (23)	1 (8)	0 (0)	1 (14)	23 (13)
Crush injury	7 (7)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	8 (5)
Gunshot	0 (0)	0 (0)	0 (0)	1 (8)	0 (0)	0 (0)	1 (1)
Suicide attempt	17 (18)	1 (9)	2 (5)	2 (17)	2 (29)	3 (43)	27 (15)

DISCUSSION

Non-fragility pelvic and acetabular fractures are the result of high-energy trauma. In our study, 47% of pelvic ring injuries were secondary to road traffic accidents and 40% followed falls from height. The incidence of road traffic accidents in pelvic ring fractures is lower than the incidence observed globally (road traffic accidents are reported as being responsible for 77% of pelvic ring fractures in India, for

Table 3 Associated injuries with pelvic and acetabular fractures

Injury	Pelvic ring fracture only, *n* (%)	Combined pelvic ring + acetabulum fracture, *n* (%)	Acetabulum fracture only, *n* (%)	Iliac wing fracture, *n* (%)	Sacrum body fracture, *n* (%)	Spinopelvic dissociation, *n* (%)	All pelvic & acetabular fractures, *n* (%)
Head injury	33 (35)	2 (18)	9 (20)	1 (8)	2 (29)	1 (14)	48 (27)
Spine fracture	48 (51)	6 (55)	5 (11)	5 (42)	6 (86)	6 (86)	76 (43)
Abdomen injury	24 (26)	2 (18)	3 (7)	5 (42)	1 (14)	3 (43)	38 (22)
Upper limb fracture	24 (26)	2 (18)	6 (14)	4 (33)	1 (14)	1 (14)	38 (22)
Lower limb fracture	30 (32)	3 (25)	16 (36)	2 (17)	1 (14)	3 (43)	55 (31)
Open P&A injury	5 (5)	0 (0)	0 (0)	3 (25)	0 (0)	0 (0)	8 (5)

Table 4 Comparison of associated injuries between pelvic ring and acetabular fractures

Injury	Pelvic ring fracture only, *n* (%)	Acetabulum fracture only, *n* (%)	*P* value
Head injury	33 (35)	9 (20)	0.11
Spine fracture	48 (51)	5 (11)	**< 0.001**
Abdomen injury	24 (26)	3 (7)	**0.01**
Upper limb fracture	24 (26)	6 (14)	0.13
Lower limb fracture	30 (32)	16 (36)	0.7
Open P&A injury	5 (5)	0 (0)	0.18

Table 5 Association between Young-Burgess fracture classification and mechanism of injury

Mechanism	LC, *n* (%)	APC, *n* (%)	VS, *n* (%)	*P* value
Fall	34 (38)	3 (50)	6 (86)	**0.03**
Road traffic accident	52 (58)	1 (17)	1 (14)	**0.01**
Crush injury	4 (4)	2 (33)	0 (0)	0.05

Combined-type (n = 2) omitted from analysis due to insufficient dataset. LC: Lateral compression; APC: Anteroposterior compression; VS: Vertical shear.

example)[6]. Data in the UK from 1989-2001 demonstrated 63% of pelvic ring fractures were attributable to road traffic accidents[7]. The reduced incidence in our study can be explained by the progressive improvement in UK road and vehicle safety, which is illustrated by government figures demonstrating the decline in road traffic accidents causing serious injuries and fatalities[8]. This skew away from road injuries may also represent the local inner-city population, many of whom are socially deprived, with unusually high incidences of interpersonal violence and mental illness. Accordingly, it is notable that attempted suicide contributes to 15% of the high-energy injuries in our study.

59% of acetabular fractures occurred following road traffic accidents and 39% were secondary to falls from height. Again, this is lower than the incidence of acetabular fractures in road traffic accidents observed globally: 66% of acetabular fractures in Qatar were attributable to road traffic accidents and 28% were the results of falls from height[9].

Cyclist *vs* vehicle collisions were the commonest cause of acetabular fractures in road traffic accidents, and were responsible for 11% of pelvic ring fractures. Self-service cycle-hire schemes, cycle-to-work tax incentives and large-scale investment in cycling infrastructure has triggered a surge in cycling popularity in the UK. In Ireland, a 90% increase in cycling-related acetabular and pelvic fracture referrals was observed between 2016 and 2017[10]. There is a paucity of literature analysing pelvic and acetabular fractures in cyclists. Bass hypothesises that cyclists attached to their pedals by straps or clips are likely to fall directly onto the hip which could promote acetabular fractures[11]. Similarly, Cerynik reports a case of a professional cyclist falling on the right side and sustaining a hyperextension injury to

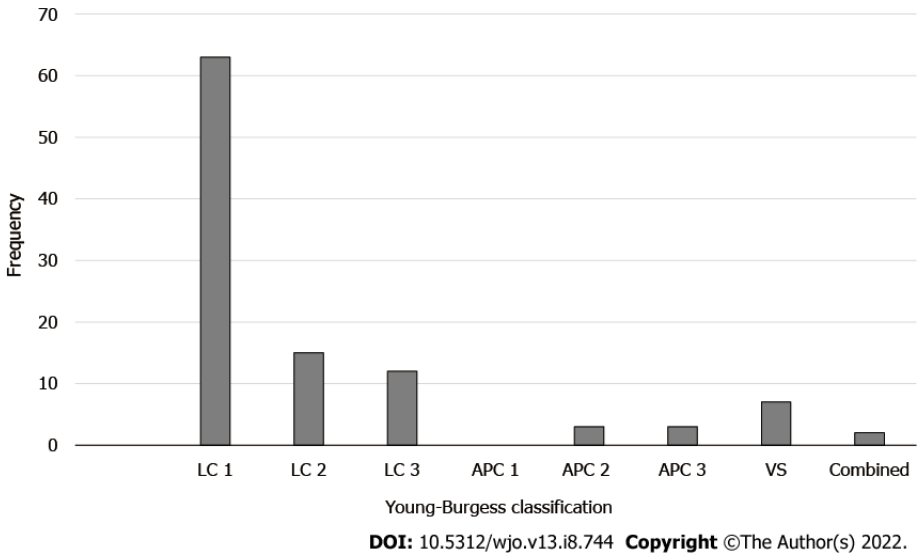

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Figure 1 Distribution of pelvic ring fractures according to Young-Burgess classification.

the left hip which remained clipped in the pedal[12]. Future research should seek to develop understanding of the mechanism of pelvic and acetabular fractures in cyclists and drive cycle safety advancements similar to those witnessed in motor vehicles.

15% of all pelvic and acetabular fractures occurred after a suicide attempt. Analysis of injury patterns demonstrates accidental falls are associated with upper limb injuries secondary to self-protection, whereas suicide attempts are associated with pelvic and acetabular fractures following direct impact or transmitted axial forces *via* the hip joint[13]. De Moore illustrated 54% of patients who attempted suicide by jumping from height were psychotic at the time of the incident – contrasting with 4% of patients who attempted suicide using a firearm[14]. This highlights the importance of dual orthopaedic and psychiatric care in the acute management and rehabilitation of these vulnerable patients. The success of this approach is evident in the literature: in a Swedish study of 12 patients who had attempted suicide by jumping from height, all patients were alive at 4 years with 75% reporting satisfactory quality of life outcomes[15]. We do not have outcome data on those who attempted suicide in our study.

Due to the high-energy mechanisms involved, pelvic and acetabular fractures are often associated with further injuries. In our study, lower limb fractures were observed in 32% of pelvic ring fractures and 36% of acetabular fractures. This is comparable with epidemiological analysis in India demonstrating lower limb fractures in 29% of pelvic ring fractures and 26% of acetabular fractures[6,16]. When comparing pelvic ring and acetabular fractures, there was a significant association between pelvic ring fractures and both spine fractures ($P < 0.001$) and abdominal injury ($P = 0.01$). 5% of our patients after high energy trauma had open injuries. This underlines the importance of the presence of multidisciplinary surgical teams at trauma calls; and supports British Orthopaedic Association Standards for Trauma guidance that all patients suffering high-energy trauma should have an examination of the perineum and rectum documented on arrival[17].

Despite our study solely analysing high-energy pelvic and acetabular fractures, the mortality rate was only 5% with just 1.7% of patients dying within the first 24 h of injury. In Giannoudis' largescale study of UK pelvic ring fractures published in 2007, the 3-mo mortality was 14.2% with a median time to death of 6.2 h[7]. This is likely a reflection of the vast multidisciplinary advancements in acute haemorrhage control – both in a pre- hospital setting and operatively *via* pelvic packing and interventional radiological techniques[18,19].

The Young-Burgess classification is the most widely used classification system for pelvic ring fractures and has been incorporated into Advanced Trauma Life Support guidelines[20]. This characterises pelvic ring injuries mechanistically, correlating with the direction and location of applied force [5]. In our study, there was a statistically significant association between falls and VS fractures ($P = 0.03$), and road traffic accidents and LC fractures ($P = 0.01$). The association between road traffic accidents and LC fractures may partly be explained by analysis demonstrating an increased risk of pelvic fracture following high magnitude side door or door panel intrusion in lateral impact crashes [21]. The need for improved lateral impact vehicle safety is evident, and in 2020 the European New Car Assessment Programme upgraded side mobile barrier testing to promote strengthening around the B-pillar (between the side doors of a car), fitment of side airbags and development of energy absorbing structures in seats and door panels[22].

The management of pelvic and acetabular fractures consumes considerable hospital resource. The literature has demonstrated pelvic fracture patients have more intensive care admissions (24.5% *vs* 11.7%) and longer inpatient stays (15 *vs* 8 d) than any other high-energy trauma patients[7]. In our

study, intensive care admission was necessary in 43% of patients, with a median total hospital length of stay of 13 d. Furthermore, 48% of patients required pelvic or acetabular surgery, with 38% undergoing additional surgery for other orthopaedic injuries. British Orthopaedic Association Guidelines advise reconstruction of the pelvic ring should occur within 72 h of stabilisation of the patient's physiological state[17], with Willett demonstrating time to surgery is a significant predictor of radiological and functional outcome for both elementary and associated displaced fractures of the acetabulum[23]. Therefore, it is crucial that major trauma centres allocate sufficient bed space and theatre capacity for the dedicated management of pelvic and acetabular fractures.

A principle of NHS funding is that insurance industries have a legal obligation to pay healthcare costs for patients who have been injured in an accident and have successfully claimed personal injury compensation. The tariff for the Injury Cost Recovery Scheme is currently capped at £915 per day with a maximum charge of £54682. Outpatient appointments are not funded by the scheme once the patient has received inpatient treatment[24]. Given the estimated cost of an intensive care bed alone is £1932 per night (which 43% of patients in our cohort required)[25], future research should analyse the direct cost of pelvic and acetabular fractures to help determine whether the current compensation arrangements adequately reimburse major trauma care.

This study has limitations which must be considered when interpreting findings. Patients could only be included if they had undergone computed tomography of the pelvis to allow fracture classification. This meant patients who died in a pre-hospital or very early ED setting, prior to undergoing computed tomography of the pelvis, were excluded from analysis. We acknowledge the inevitable effect of geographical and national variation in terms of making comparisons with other centres around the world. The single centre studied is an inner-city level-1 facility with high rates of interpersonal violence, mental illness and low socioeconomic status, compared with the rest of the UK. Therefore, the distribution of injuries will inevitably reflect this diversity. Comparison between nations is also difficult to control due to cultural, legal and behavioural differences within the population which will also affect injury types and mechanisms - examples include the use of roundabouts in the UK and Europe *vs* stop junctions in the United States. Suicide by gunshot is rare in the UK and Europe but much more common in United States and countries where firearm accessibility is relatively high, which may account for the high proportion of suicide falls from height in our series. Similarly, we recorded no pelvic or acetabular injuries resulting from gunshots, which would be much more common in other centres around the world. Moreover, the authors acknowledge the lack of clinical or radiological follow-up in this study. Ideally, an epidemiological study would be complemented by outcomes data, but this was not available for the cohort studied. Finally, analysis of the distribution of acetabular fractures in accordance with the Letournel and Judet classification system was not included in this study.

CONCLUSION

Pelvic and acetabular fractures most commonly occur in young male patients following high-energy trauma and are associated with concomitant orthopaedic injuries (most commonly spine and lower limb fractures), intensive care admission and long inpatient stays. The vast majority of pelvic ring injuries secondary to road traffic accidents are lateral compression type. Injury prevention research should seek to drive advancements in lateral impact cycle and motor vehicle safety, along with mental health surveillance for those deemed to be potential suicide risks.

ARTICLE HIGHLIGHTS

Research background

To optimise trauma outcomes, the National Health Service introduced the Trauma Network System in 2012 which designated 27 hospitals in England responsible for the specialist management of severely injured patients. To our knowledge, this is the first study to analyse the epidemiology of high-energy pelvic and acetabular trauma over a one-year period at a major trauma centre since introduction of the Trauma Network System.

Research motivation

Non-fragility pelvic and acetabular fractures are the result of high-energy trauma. Despite evolving safety measures, high-energy trauma/suicide remains the leading cause of death under the age of 45 in the United Kingdom. Therefore, it is critical that research explores opportunities for future injury prevention in these high-risk patients.

Research objectives

This study sought to characterise the epidemiology of high-energy pelvic and acetabular trauma, to demonstrate the wide-ranging resources required to care for these patients and explore opportunities

for future injury prevention research.

Research methods

227 consecutive patients at a level-1 trauma centre with pelvic and acetabular fractures were analyzed over a one-year period. Paediatric patients, fragility fractures and patients without computed tomography of the pelvis were excluded leaving 175 patients for inclusion in the study. Statistical analysis was performed using Fisher's exact test for categorical variables.

Research results

72% of pelvic and acetabular fractures occurred in male patients at a median age of 45 years. 15% were the result of a suicide attempt. 48% of patients required pelvic or acetabular surgery, with 38% undergoing further surgery for additional orthopaedic injuries. Vertical shear pelvic ring fractures were associated with falls (P = 0.03) while lateral compression fractures were associated with road traffic accidents (P = 0.01).

Research conclusions

High-energy pelvic and acetabular fractures are associated with concomitant orthopaedic fractures (most commonly spine and lower limb). Most pelvic ring injuries secondary to road traffic accidents are lateral compression type illustrating the need for future research to drive advancements in lateral impact vehicle safety.

Research perspectives

Future research should drive advancements in lateral impact vehicle safety given the statistically significant association between lateral compression fractures and road traffic accidents. Additionally, research should focus on mental health surveillance strategies for patients deemed to be potential suicide risks.

FOOTNOTES

Author contributions: Cuthbert R designed the research study, performed data acquisition, and wrote the manuscript; Walters S, Ferguson D and Karam E designed the research study and performed data acquisition; Ward J, Arshad A, Culpan P and Bates P contributed towards conception of the study and final editing; all authors revised the article critically for important intellectual content, and provided final approval for the paper to be published.

Institutional review board statement: The NHS Research Ethics Committee decision tool excluded need for ethical review as this was a retrospective observational study.

Informed consent statement: Informed consent was not required for the above study as data was collected retrospectively and anonymized.

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ORIGINAL ARTICLE

Retrospective Study

Effect of pelvic fixation on ambulation in children with neuromuscular scoliosis

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Abstract

BACKGROUND

The effect of posterior spinal fusion (PSF) incorporating the pelvis on an ambulatory patient's ability to mobilize after the fusion is not well understood.

AIM

To see whether a posterior spinal fusion with pelvic fixation using iliac or sacral alar iliac screws in ambulatory neuromuscular scoliosis (NMS) patients influences postoperative ambulatory ability.

METHODS

A retrospective review of all patients with NMS that underwent PSF with fixation incorporating the pelvis between January 1, 2012 and February 29, 2019. A total of 118 patients were eligible, including 11 ambulatory patients. The primary outcome was the maintenance of ambulatory status postoperatively. Secondary outcomes included postoperative curve magnitude, pelvic obliquity, and complications, comprising infections, instrumentation failure, and any unplanned returns to the operative room.

RESULTS

The ambulatory function was maintained in all 11 ambulatory NMS patients. One patient had an improvement in functional status with equipment-free ambulation postoperatively. An average postoperative follow-up was 19 mo. The overall complication rate was 19.4% (n = 23) with no significant differences between the groups in infection (P = 0.365), hardware failure (P = 0.505), and reoperation rate (P = 1.0). Ambulatory status did not affect complication rate (P = 0.967).

CONCLUSION

Spinal fusion to the pelvis in ambulatory patients with NMS provides effective deformity correction without the reduction in ambulatory capabilities.

Key Words: Pelvic fixation; Ambulation; Neuromuscular scoliosis; Pediatrics; Posterior spinal fusion; Pelvis

Core Tip: Neuromuscular scoliosis (NMS) represents a medically and surgically complex disorder that can have a profound impact on the patient's quality of life and the ability of their caretakers to provide adequate care. The purpose of this study is to determine whether posterior spinal fusion with pelvic fixation using iliac or sacral-alar iliac screws in ambulatory NMS patients affects postoperative ambulatory ability.

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INTRODUCTION

Neuromuscular scoliosis (NMS) represents a medically and surgically complex disorder that can have a profound impact on the patient's quality of life and the ability of their caretakers to provide adequate care[1,2]. In patients with retained mobility, progression of the neuromuscular disease may result in a loss of their ability to ambulate. Conversely, in non-ambulatory and wheelchair-bound patients, it can lead to difficulty in sitting balance, resulting in hand-dependent sitting, development of decubitus ulcers, and hygiene-related issues[2-4]. The primary goal for patients with NMS is to prevent major curve progression while restoring coronal and sagittal alignment over a balanced pelvis[2,4,5]. To achieve this goal, spinal instrumentation must often be extended into the pelvis. Historically, the fusion of the spine to the pelvis has been taboo, recommended only when pelvic obliquity was > 15 degrees or in low lumbar curves in which the sacrum is affected by the curve[3,6-8]. In 2002, Tsirikos *et al*[4] published their study on cerebral palsy patients who underwent a posterior spinal fusion (PSF) with extension to the pelvis using a unit rod. In their 24 ambulatory patients that underwent PSF to the pelvis, only one patient lost ambulatory function secondary to heterotopic ossification of her hips. This study showed, for the first time, that ambulatory patients who undergo fusion to the pelvis retained mobility after surgery. Recently, a study by Menger *et al*[9] has reported the effects of using PSF with pedicle screws and S2 sacral alar-iliac screws in ambulatory patients with any diagnosis of pediatric scoliosis. Of their 25 patients, only one patient had a decline in postoperative ambulation. However, no study to date has specifically evaluated outcomes in ambulatory children with NMS after a PSF using modern instrumentation. This study aimed to determine whether PSF with pelvic fixation using iliac or sacral-alar iliac (SAI) screws in ambulatory NMS patients influences postoperative ambulatory ability.

MATERIALS AND METHODS

An institutional review board approval was obtained for this study (IRB# 2018-0161). An informed consent exemption was also obtained through a waiver. A retrospective review of all patients with NMS who underwent PSF between January 1, 2012 and February 29, 2019 at a single academic children's hospital was performed, yielding 169 patients. Patients were excluded if their fusion did not extend to the pelvis using iliac or SAI screws, yielding a total of 118 patients for the study. The primary outcome was the maintenance of ambulatory status postoperatively. Secondary outcomes included postoperative curve magnitude, pelvic obliquity, and complications, comprising infections, instrumentation failure,

and any unplanned returns to the operative room (UPRORs). Statistical analysis was performed using IBM SPSS Statistics, Version 26.0 (Armonk, NY). Pearson's Chi-Square and Leven's test for equality were used as appropriate for all categorical data. Significance was set at an alpha level of 0.05.

RESULTS

A total of 118 patients, including 11 ambulatory patients, were enrolled in the study. Detailed demographic and diagnosis data of ambulatory and non-ambulatory patients with NMS are included in Table 1.

No ambulatory patient with NMS became non-ambulatory after PSF with pelvic fixation. In one case, a 19-year-old male that underwent PSF from T1 to the pelvis with SAI screws had an improvement with the ability to ambulate in the clinic free of mobility aids. Table 2 outlines the differences between major curve magnitude (MCM) and pelvic obliquity (PO) for both groups preoperatively and postoperatively and the average change for both parameters.

The major curve magnitude was similar between the groups. However, the preoperative PO was significantly larger in the non-ambulatory *vs* the ambulatory group (15.5 degrees *vs* 7.8 degrees, $P < 0.0001$). Furthermore, when comparing the total change of MCM and PO between the ambulatory and non-ambulatory groups, no significant difference was found (MCM $P = 0.181$; PO $P = 0.143$). SAI screws were used in 114 patients, iliac bolts were used in 2 patients, and iliac screws were used in 2 patients. The type of pelvic fixation used did not affect postoperative ambulatory status ($P = 0.965$), and all ambulatory patients had pelvic fixation consisting of SAI screws.

The total complication rate for all patients enrolled was 19.4% ($n = 23$). The complication profile for the entire patient population and ambulatory and non-ambulatory groups is summarized in Table 3. No statistically significant difference was found in reoperation, injection, or hardware failure rates between the two groups. All patients with hardware failure required revision of spinal fixation. Overall, the patient's ambulatory status did not affect the overall postoperative complication rate ($P = 0.967$).

A small subset of our patients had previous spinal correction surgery, including three ambulatory and ten non-ambulatory patients. Prior surgery performed included the use of vertical expandable prosthetic titanium rib (VEPTR) rods (6), an extension of previous posterior spinal fusion (4), previous staged anterior spinal fusion (2), and the use of growing rods (1). Within this small subgroup, previous surgery did not affect ambulation ($P = 0.209$), postoperative infections ($P = 0.180$), or hardware failure (0.538). Prior surgery significantly affected the need for reoperation ($P = 0.001$), despite no significant difference in infection or hardware failure rates. Prior surgical procedures also significantly affected curve magnitude ($P = 0.044$) and PO ($P = 0.015$).

DISCUSSION

The effect of PSF with pelvic fixation in children with the ability to ambulate has long been an unclarified question. This study focused on the outcomes of patients with NMS who underwent PSF with extension to the pelvis using either SAI or iliac screws. In our study, we found that all patients could ambulate at the same or higher function after PSF with extension to the pelvis. Additionally, we found no significant difference between ambulatory and non-ambulatory groups in complications, UPRORs, hardware failure, or postoperative infections.

To date, this is only the second investigation to report on ambulatory patients with NMS undergoing PSF with fixation to the pelvis using modern pelvic fixation constructs. When comparing our results with the current literature, our findings are consistent. Tsirikos *et al*[4] have evaluated the ambulatory status of 24 NMS patients that underwent PSF incorporating the pelvis using a unit-rod construct. Only one patient in their study lost the ability to ambulate after fusion to the pelvis, and this was secondary to heterotopic ossification of the hips and unrelated to the spinal fusion. Patient- and caregiver-reported outcome questionnaires were also used to assess the postoperative function. Improvements in sitting ability, head and trunk balance, physical appearance, and respiration were noted without any change in ambulatory ability. Furthermore, 12 patients in their study underwent preoperative and postoperative gait analysis. They did not find any significant difference in postoperative gait mechanics in any of these patients. However, patients in their study received a unit rod in contrast to our cohort, where the majority had SAI or iliac screws for pelvic fixation. Menger *et al*[9] have evaluated the effect of PSF with extension to the pelvis in 25 ambulatory children with scoliosis from various diagnoses. Their patients included idiopathic, syndromic, neuromuscular, and congenital scoliosis, of which neuromuscular scoliosis only comprised 28%. They found that all patients retained the ability to ambulate postoperatively, with only one patient noting a decreased ability after fusion. Patient-reported outcomes showed that 25% of the patients noted a change in ambulatory ability while PROMIS T scores completed by most patients fell within one standard deviation of normal, showing only mild ambulatory deficit compared to the normal population. Our study supports these findings, showing no change in ambulation in our patient population.

Table 1 Patient demographics

		Ambulatory	Non-ambulatory	Total	*P* value
Gender					0.405
	Female	4	53	57	
	Male	7	54	61	
Race					
	Black	2	70	72	
	White	8	32	40	
	Hispanic	0	2	2	
	Asian	0	1	1	
	Other	1	2	3	
Age at surgery		16.91 (4.93)	13.32 (3.32)	13.65 (3.63)	0.122
Average follow-up		18.43	18.43	19.14	
Diagnosis					
	Cerebral palsy	5	85	90	
	Post-traumatic spinal cord injury	0	10	10	
	Spina bifida	0	7	7	
	Myopathy	2	0	2	
	Muscular dystrophy	1	2	3	
	Spinal muscular atrophy	0	2	2	
	Alexander's disease	0	1	1	
	Charcot marie tooth	1	0	1	
	Pelizaeus merzbacher disease	0	1	1	
	Lennox gastaut syndrome	1	0	1	
	Geroderma osteodysplasia	1	0	1	

Table 2 Preoperative and postoperative deformity measurements

	Preoperative		Postoperative		Average correction	
	Major curve magnitude	Pelvic obliquity	Major curve magnitude	Pelvic obliquity	Major curve magnitude	Pelvic obliquity
Ambulatory	60.1 (28-110)	7.8 (2-14)	26.9 (12-61)	4.7 (0-15)	33.2	3.1
Non-ambulatory	70 (12-140)	15.5 (0-47)	26.4 (2-81)	8.3 (0-37)	43.6	7.2
P value	0.221	0.000	0.912	0.122		

Mean values with range within parentheses, all values in degrees.

Adult spinal deformity literature provides further insight into the effects of pelvic fixation with PSF. A study by Kondo *et al*[10] has investigated the pre- and postoperative physical function of 30 patients who underwent long spinal fusion from the thoracic spine to the ilium. They found that all patients had significantly improved pain, balance, and 6-minute walking test after PSF. Furthermore, they found that patients with significantly worse preoperative sagittal balance and pelvic tilt had greater improvements in gait speed, gait endurance, and dynamic balance compared to patients with less significant sagittal imbalance or pelvic tilt. Yagi *et al*[11] have investigated the difference between the effect of PSF to the pelvis with iliac screws and the upper instrumented vertebrae in 30 adult female patients. Gait analysis was obtained preoperatively and at 12-18 mo postoperatively, showing an improvement in gait pattern and gait ability. Additionally, Edwards *et al*[12] have investigated the difference in long PSF from the thoracic spine to either L5 or the pelvis in 95 adult patients. Their findings were consistent, showing improved Scoliosis Research Society 24 patient-reported outcomes for both groups and no significant

Table 3 Complication profile between ambulatory and non-ambulatory groups

	Reoperation rate	Infection rate	Hardware failure rate
Overall	18.6	12.7	5.9
Ambulatory	18.2	0	9.1
Non-ambulatory	18.7	14	5.6
P value	0.239	0.365	0.505

All values in percentages.

difference between them. Our findings, although in a vastly different patient population, are consistent with the results of these studies.

Our study had several limitations. First, ambulatory patients with NMS requiring PSF were rare at our institution and only comprised 9.3% of our total patient population. It is possible that a significant difference might be found between ambulators and non-ambulators with NMS with a larger number of patients. Second, gait lab analysis was not available for the included patients, making it difficult to compare the effects of pelvic fixation on postoperative ambulation more objectively. Finally, by not having long-term postoperative follow-up in all patients, it is possible that some patients had a change of ambulatory status unknown to our institution. Despite these limitations, our study is the first in the literature to evaluate the effect of pelvic fixation on postoperative ambulatory status in patients receiving PSF using modern pelvic fixation instrumentation, demonstrating that the postoperative complication profile remains unchanged compared to non-ambulatory controls.

CONCLUSION

In conclusion, we found that it is safe for ambulatory patients with NMS to undergo PSF incorporating the pelvis using modern constructs. Additionally, posterior spinal fusion with extension to the pelvis has no significant effect on complications, UPRORs, hardware failure, or postoperative infections.

ARTICLE HIGHLIGHTS

Research background

Ambulatory patients with neuromuscular scoliosis are a rare subset of patients in which treatment does not compromise their ability to ambulate.

Research motivation

Insufficient research has been done to support the effects of posterior spinal fusion incorporating the pelvis on the ability to ambulate in ambulatory patients with neuromuscular scoliosis.

Research objectives

To report the effect of posterior spinal fusion incorporating the pelvis on the ability to ambulate after fusion in patients with neuromuscular scoliosis.

Research methods

This is a retrospective analysis of patient function outcomes after undergoing posterior spinal fusion incorporating the pelvis over a seven-year period at our children's hospital.

Research results

Of the eleven patients fitting this criterion, no patient lost their ability to ambulate after undergoing posterior spinal fusion incorporating the pelvis.

Research conclusions

According to our findings, there is no effect on the ambulatory function of neuromuscular patients after posterior spinal fusion incorporating the pelvis.

Research perspectives

Although more evidence is needed, the experience at our institution would support that posterior spinal

fusion incorporating the pelvis does not affect the patients' ability to mobilize in ambulatory neuromuscular scoliosis patients.

FOOTNOTES

Author contributions: Drake LC performed study design, x-ray measurements, statistical analysis, and manuscript preparation; Sukkarieh H contributed to study design and manuscript preparation; McDonald TC contributed to study design and manuscript preparation; Bhanat E contributed to statistical analysis and manuscript preparation; Quince E contributed to x-ray measurements and statistical analysis; Atkins M contributed to x-ray measurements and statistical analysis; Wright P contributed to study design and manuscript preparation; Brooks JT contributed to study design, statistical analysis, and manuscript preparation

Institutional review board statement: The study was reviewed and approved by the University of Mississippi Medical Center Institutional Review Board [Approval No. 2018-01610].

Informed consent statement: Patients were not required to give informed consent to the study because the analysis used anonymous clinical data that were obtained after each patient agreed to treatment by written consent.

Conflict-of-interest statement: Brooks JT is a paid consultant of Depuy-Synthes, A Johnson & Johnson Company; paid consultant of OrthoPediatrics; and a paid presenter or speaker of Medtronic Spine. The remaining authors declare no conflicts of interest.

Data sharing statement: Statistical code and dataset are available from the corresponding author at jaysson.brooks@tsrh.org. Participants did not give informed consent for data sharing.

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ORIGINAL ARTICLE

Prospective Study

Quantitative alpha-defensin testing: Is synovial fluid dilution important?

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Abstract

BACKGROUND

Alpha-defensin has been widely studied for the diagnosis of periprosthetic joint infection (PJI). However, there is a lack of detailed information regarding the proper laboratory technique of the enzyme-linked immunosorbent assay (ELISA) method, such as sample dilution.

AIM

To assess the influence of dilution in the synovial fluid during ELISA for the diagnosis of knee PJI; and determine which dilution presents a better performance.

METHODS

Forty samples of synovial fluid from arthroplasty knees were included, 17 in the infected group and 23 in the aseptic group, according to Musculoskeletal Infection Society criteria. Initially, five synovial fluid samples from each group were assessed for quantitative analysis of alpha-defensin using ELISA. Different dilution ratios (1:10, 1:100, 1:500, 1:1000 and 1:5000) were tested based on the predetermined cutoff value of 5.2 mg/L. The dilutions that performed better were used to compare the results of all samples.

RESULTS

For infected cases, a gradual increase in the dilution of synovial fluid samples led to an equivalent increase in alpha-defensin level. The same was not observed in the aseptic cases. Both 1:1000 and 1:5000 dilutions presented satisfactory results to differentiate infected and aseptic cases. Further analyses were performed using 1:1000 and 1:5000 for all 40 samples. The 1:1000 dilution resulted in a sensitivity of 88.2% (95%CI, 66%-98%) and specificity of 95.7% (95%CI, 79%-99%), whereas the 1:5000 dilution presented a sensitivity of 94.1% (95%CI, 73%-99%) and a specificity of 100% (95%CI, 86%-100%).

CONCLUSION

The synovial fluid dilution had an important influence on the alpha-defensin ELISA results. Dilutions of 1:5000 showed the best performance for the diagnosis of knee PJI. The results of this study set the basis for a more reliable and reproducible alpha-defensin ELISA during the investigation of PJI, contributing to the expansion of this technique in different treatment centers worldwide.

Key Words: Alpha-defensin; Enzyme-linked immunosorbent assay; Periprosthetic joint infection; Laboratory findings

Core Tip: Alpha-defensin is an antimicrobial peptide widely studied in patients with periprosthetic joint infection. Indeed, the analysis of alpha-defensin concentration in the synovial fluid by enzyme-linked immunosorbent assay (ELISA) has been gaining ground. However, there is a lack of information regarding the detailed technique for synovial fluid ELISA, particularly in regard to its dilution. Therefore, this study analyzed the influence of dilution in synovial fluid samples for the alpha-defensin ELISA method. We presume that this novel information may be helpful to make ELISA more reproducible and widely accessible for different treatment centers worldwide.

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INTRODUCTION

Periprosthetic joint infection (PJI) is an increasingly common and devastating complication that can lead to significant morbidity and mortality[1,2]. Since neither clinical examination nor laboratory tests are always trustworthy, the diagnosis of PJI remains a challenge[3]. Indeed, there is no gold-standard method for its diagnosis[4]. Therefore, several groups around the world have attempted to refine the diagnostic criteria of PJI[2,5,6]. The criteria score proposed (and later updated) by the Musculoskeletal Infection Society (MSIS) is the one most used by orthopedic surgeons[2].

Regarding the different strategies to improve the diagnosis of PJI, the use of biomarkers has been extensively studied in recent years[1,7,8]. Alpha-defensin has gained attention as one of the most reliable markers[9,10]. Defensins are antimicrobial peptides that act as part of the host's innate immune response against pathogen invasion and are produced in increased numbers during septic inflammation [11,12]. Thus, synovial-fluid alpha-defensin has shown excellent results in diagnosing PJI[13,14]. Two different modalities are available to measure synovial alpha-defensin: The qualitative alpha-defensin lateral flow test and the quantitative enzyme-linked immunosorbent assay (ELISA)[15]. Particularly, the ELISA method has presented the best results, so it was included as a criterion in the new International Consensus on Orthopedic Infections 2018 consensus[6].

Despite the importance and the many studies about alpha-defensin in synovial fluid[15,16], there is a lack of detailed information regarding the ELISA technique[13]. In fact, some crucial information about the reproducibility of the test and the standardization of specific cutoff values are unclear. Dilution of the synovial fluid sample is necessary for the test, but the ideal ratios are not known.

Therefore, this study aimed to evaluate the potential influence of dilution on the quantitative alpha-defensin ELISA test for the diagnosis of PJI in the synovial fluid of patients undergoing total knee arthroplasty (TKA). We hypothesized that changes in the dilution of the joint fluid would influence the

test performance for the diagnosis of PJI.

MATERIALS AND METHODS

The study was approved by the local ethics committee (No. 71039317.3.0000.0068). All the included patients signed the consent form.

Between January 2017 and December 2018, this study enrolled patients with primary TKA and any suspicious signs or symptoms of chronic infection, as follows: more than three months of persistent knee pain, effusion or local heat, presence of a draining sinus, early failure of the prosthesis (less than 5 years), fever and malaise. Patients who had used antibiotic therapy for at least four weeks before the evaluation or had an insufficient volume of synovial fluid during knee aspiration were excluded. Forty-five patients were assessed for recruitment. Of these, five did not have enough synovial fluid and were excluded from the study. The other 40 patients were included. They were divided into two groups: infected and noninfected (aseptic painful). Seventeen (42.5%) patients were considered to have infection, and 23 (57.5%) patients were classified as having aseptic painful TKA. Positive infection was confirmed if the MSIS criteria for PJI were fulfilled[17], as follows: presence of a draining sinus communicating with the joint or at least two positive cultures of the same microorganism, or if three out of the following five criteria were present: elevated serum C-reactive protein and erythrocyte sedimentation rate, elevated synovial white blood cell count, elevated percentage of synovial polymorphonuclear leukocytes (PMNs), positive histological analysis of periprosthetic tissue and a single positive culture of synovial fluid or periprosthetic tissue. For chronic PJI, synovial cell count and differential cutoff values were 3.000 cells/μL, 80% PMN.

Synovial fluid was collected from each patient. Using a sterile technique, the lateral suprapatellar approach was performed, and a 20-mL syringe with a 21-gauge needle was used to aspirate the joint fluid. A minimum of 0.5 mL was aspirated and stored in a tube with ethylenediaminetetraacetic acid (EDTA). The tubes were transported to the laboratory within one hour after aspiration at room temperature. Previous studies have estimated the stability of alpha-defensin levels in synovial fluid for a minimum of 48 h at room temperature[13]. The fluid was centrifuged for ten minutes at 2000 rpm according to our laboratory standardization, and the supernatant was frozen at -80°C until use[13].

Determination of synovial alpha-defensin concentrations

Reagents from the commercially available ELISA test kit (Hycult Biotech®, Uden, The Netherlands) were used according to the manufacturer's instructions. However, as anticipated, there was no manufacturer recommendation for synovial fluid dilution. In this study, ten samples (five from each group) were randomly selected and diluted in the buffer included in the kit at 1:10, 1:100, 1:500, 1:1000 and 1:5000. All dilutions were tested in duplicate. The reactions were read at 450 nanometers in an ELISA SpectraMax 190 reader (Molecular Devices, San Jose, United States) in accordance with the package insert instructions. The results of spectrophotometry were obtained in optical density (OD) units. The OD values were plotted on the vertical axis, and the corresponding concentrations were plotted on the horizontal axis (logarithmic scale). The concentration was multiplied by the dilution factor to obtain the actual alpha-defensin value in mg/L. A cutoff value of 5.2 mg/L was used since the same value was used as the cutoff in previous studies[13,18].

Initially, ten out of 40 cases were selected to define which dilutions would provide the best performance. After detecting which dilutions performed better, we expanded the analysis to all other cases. All samples were tested with the selected dilution ratio, following the same procedures as described above except for the serial dilution.

Statistical analysis

Statistical analysis was performed using GraphPad Prism version 8 (GraphPad Software, La Jolla, CA). The results of the alpha-defensin synovial fluid are expressed as mean and range. Differences between the two groups were compared using the Mann–Whitney test. To assess the performance of the test using 1:1000 and 1:5000 dilutions, the sensitivity, specificity, positive predictive value and negative predictive value were evaluated through the Wilson-Brown method. The 95% confidence interval (95%CI) was also calculated. $P < 0.05$ was considered to be statistically significant.

RESULTS

Table 1 shows the demographic and laboratory results of the included patients. Regarding the initial assessment, five samples from each group were tested using different dilutions. In the infected group, a gradual increase in synovial fluid dilution resulted in an equivalent elevation of alpha-defensin levels. The same response was not observed in the aseptic group (Figure 1). In addition, the best diagnostic performance of the test was obtained at 1:1000 and 1:5000 dilutions. Table 2 summarizes these findings.

Table 1 Demographics and laboratory results of the included patients

	Total	Aseptic cases	Infected cases
Sex			
Male	9	4	5
Female	31	19	12
Age (range)	67.57 (47-85)	67.65 (47-85)	67.47 (51-84)
Laterality			
Right knee	21	13	8
Left knee	19	10	9
Inflammatory disease			
RA	8	5	3
Gout	2	0	2
Major Criteria			
Sinus Tract	4	0	4
2 positive cultures	2	0	2
Minor criteria			
CRP and ESR +	9	0	9
WBC count	15	1	14
PMN%	14	0	14
Hystological +	5	0	5
1 culture	12	1	11

RA: Rheumatoid arthritis; CRP: C-reactive protein; ESR: Erythrocyte sedimentation rate; WBC: White blood cells; PMN: Polymorphonuclear neutrophils.

Table 2 Mean and range in mg/L of the initial 10 cases (5 from infected and 5 from aseptic group) in several dilutions

	Dil. 1:10, mean (range)	Dil. 1:100, mean (range)	Dil. 1:500, mean (range)	Dil. 1:1000, mean (range)	Dil. 1:5000, mean (range)
Infected cases	0.04 (0.03-0.05)	0.52 (0.40-0.76)	2.92 (1.68-4.45)	6.68 (3.62-9.62)	32.67 (12.65-50.18)
Aseptic cases	0.01 (0-0.03)	0.09 (0.02-0.30)	0.21 (0.12-0.55)	0.3 (0.24-0.48)	1.43 (1.4-1.49)
P	0.016	0.008	0.008	0.008	0.008

Mann-Whitney test.

We next evaluated all of the remaining samples using these dilution ratios. The results of the alpha-defensin tests including all patients are displayed in Table 3 and Figure 2. At a dilution of 1:1000, statistical analysis indicated a sensitivity of 88.2% (95%CI, 66%-98%), a specificity of 95.7% (95%CI, 79%-99%), a positive predictive value of 93.8% (95%CI, 72%-99%) and a negative predictive value of 91.7% (95%CI, 74%-99%). In this situation, one false positive and two false negatives were found.

At the 1:5000 dilution, a sensitivity of 94.1% (95%CI, 73%-99%), a specificity of 100% (95%CI, 86%-100%), a positive predictive value of 100% (95%CI, 81%-100%) and a negative predictive value of 95.8% (95%CI, 80%-99%) were observed. Only one false-negative result was identified within the infected group. This misdiagnosed case presented with a draining sinus and had positive intraoperative cultures.

DISCUSSION

To the best of our knowledge, there is a lack of studies detailing and testing the influence of different

Table 3 Mean and range of synovial fluid alpha-defensin values (in mg/dL) of all patients

	Number of cases	Dilution of 1:1000	Dilution of 1:5000
Infected cases	17 (42.5%)	6.60 (0.26-9.62)	24.10 (5.72-50.18)
Aseptic cases	23 (57.5%)	0.74 (0.24-8.54)	1.50 (1.22-4.66)
P		< 0.001	< 0.001

Mann-Whitney test.

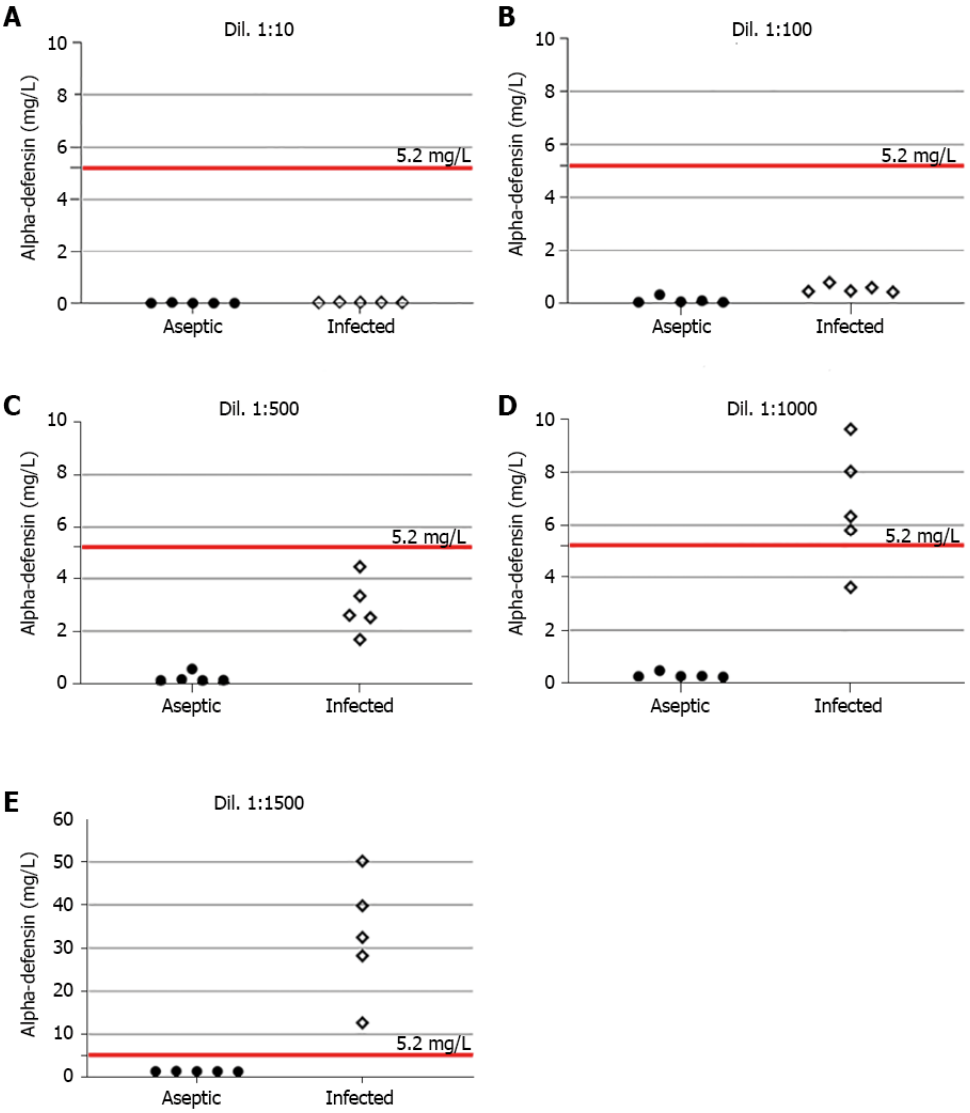

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Figure 1 Results of alpha-defensin concentration (mg/L) according to each dilution. A: 1:10; B: 1:100; C: 1:500; D: 1: 1000; and E: 1:5000. Noteworthy, for infected cases a gradual increase in the sample dilution resulted in an increasing level of alpha-defensin. The same was not observed in the aseptic cases. In addition, both 1:1000 and 1:5000 dilutions presented favorable results to differentiate infected and aseptic cases.

dilutions on the synovial fluid alpha-defensin ELISA test for the diagnosis of TKA infection. The novel results of this laboratory study support our hypothesis that the right synovial fluid dilution is crucial for a high diagnostic accuracy of the alpha-defensin ELISA test. Here, we found positive results using dilutions of 1:1000 and 1:5000, the best results occurring with a 1:5000 dilution ratio.

As mentioned above, in one of the first studies of synovial fluid alpha-defensin, a cutoff value of 5.2 mg/L of alpha-defensin was defined as the threshold for the diagnosis of PJI[19]. However, the dilutions applied to obtain this cutoff value were not described, making it hard to replicate the methods, even using the same alpha-defensin ELISA kit. In our study, using a 5.2 mg/L cutoff, the most effective dilution to distinguish between infection and noninfection was 1:5000. Using this dilution ratio, only

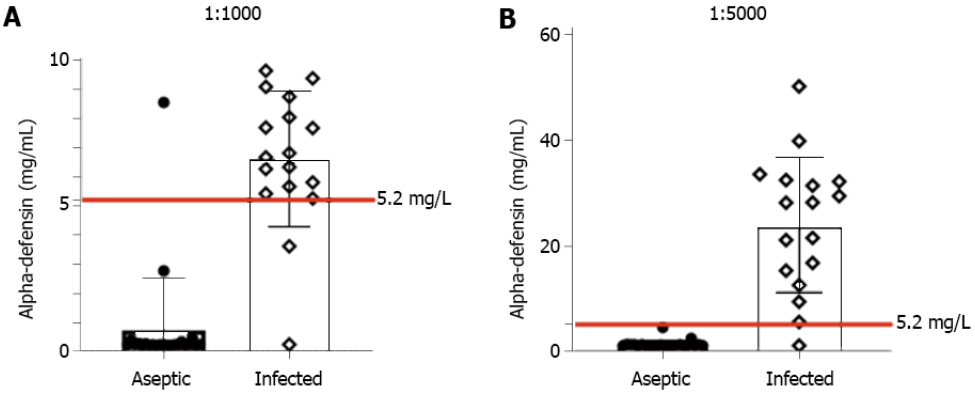

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Figure 2 Results of synovial fluid alpha-defensin values of all patients using 1:1000 and 1:5000 dilution. A: 1:1000 dilution; B: 1:5000 dilution. As observed, there was one case of false negative in the infected group.

one false-negative result was found. Similar to other patients[10,13], this patient presented with a drainage sinus, though our patient had positive intraoperative cultures, which was not seen in that other series. We also showed that although a dilution of 1:1000 had satisfactory results for detecting infected cases, it had lower sensitivity and specificity.

Another interesting consideration relates to the prozone phenomenon. The prozone phenomenon, also known as the hook effect, is a false-negative response that occurs in immunological tests as a consequence of an excess of either antigen or antibody[20]. In an alpha-defensin test, if the amount of antigen (*i.e.*, alpha-defensin) is greater than the amount of antibody, the secondary antibody (*i.e.*, peroxidase) will not bind properly, and the test will present a false result. This could be the reason for some false-negative values during the alpha-defensin assay. In this study, we did not directly assess the influence of dilution on the prozone phenomenon, but since lower dilutions are more likely to exhibit the prozone effect, the latest dilutions may be helpful to overcome this phenomenon[21], potentially allowing a more precise differentiation between TKA infection and asepsis.

Some limitations of our study must be considered. The small sample size may underpower the study. However, the consistent findings with different dilutions and the excellent results using a 1:5000 dilution reduced the need to increase the sample size. In addition, despite the exciting progressive improvement in the test performance with serial dilutions, we did not demonstrate the actual reason why it occurs. Further studies are necessary to answer this question. Even so, we describe in detail the analysis of synovial fluid alpha-defensin by ELISA, including the best dilutions for the most accurate diagnosis of knee PJI. Moreover, the information provided herein may ensure the reproducibility of the test across the laboratories, with more precise data.

CONCLUSION

Changes in synovial fluid dilution for ELISA had an important influence on the determination of alpha-defensin levels. Based on the cutoff value of 5.2 mg/L, dilutions of both 1:1000 and 1:5000 were adequate to support the diagnosis of TKA infection. The 1:5000 dilution showed the best performance in separating the infection and the aseptic cases, making it the most reliable dilution during knee PJI investigation. Therefore, the results of this study lay the foundation for a more reliable and reproducible alpha-defensin ELISA during the investigation of PJI, contributing to the expansion of this technique to different treatment centers worldwide.

ARTICLE HIGHLIGHTS

Research background

Periprosthetic joint infection (PJI) is a serious complication post-surgery that is associated with substantial morbidity and financial burden to the healthcare system. The alpha-defensin quantitative enzyme-linked immunosorbent assay (ELISA) is one of the most useful methods to investigate PJI.

Research motivation

Although the alpha-defensin ELISA is currently the most reliable test to diagnose PJI, there is a lack of detailed information regarding its proper laboratory technique, including the best sample dilution.

Research objectives

This study aimed to assess the influence of dilution in the synovial fluid during ELISA for the diagnosis of knee PJI and determine which dilution presents a better performance.

Research methods

In this prospective study, 40 cases of total knee arthroplasty were evaluated: 17 classified as PJI and 23 classified as aseptic knees. Initially, 5 synovial fluid samples from each group were assessed by ELISA using different dilution ratios (1:10, 1:100, 1:500, 1:1000 and 1:5000). The dilutions had better performance were used to compare the results of all samples.

Research results

For infected cases, a gradual increase in the synovial fluid dilution led to an equivalent increase in alpha-defensin level, which was not seem in the aseptic cases. Both 1:1000 and 1:5000 dilutions presented satisfactory results to differentiate infected and aseptic cases. Further analyses were performed using 1:1000 and 1:5000 for all 40 samples. The 1:1000 dilution resulted in a sensitivity of 88.2% (95%CI, 66%-98%) and specificity of 95.7% (95%CI, 79%-99%), whereas the 1:5000 dilution presented a sensitivity of 94.1% (95%CI, 73%-99%) and a specificity of 100% (95%CI, 86%-100%).

Research conclusions

Synovial fluid dilution appears to influence the alpha-defensin ELISA results. Dilutions of 1:5000 showed the best performance for the diagnosis of knee PJI.

Research perspectives

The results of this current study may set the basis for more reliable and reproducible alpha-defensin ELISA during PJI investigation, contributing to the expansion of this technique in different treatment centers worldwide.

FOOTNOTES

Author contributions: Abdo RCT collected the samples; Leite CBG wrote the article; Abdo RCT, Leite CBG, Lima ALLM and Bonfa E contributed to the data analysis; Abdo RCT, Gobbi RG, Lima ALLM, Bonfa E, Pécora JR and Demange MK contributed to the intellectual concept and design of the study; Pasoto SG performed the laboratory tests and contributed to the strategy for alpha-defensin analysis according to its dilution; Leon EP conducted the laboratory tests; Gobbi RG reviewed the article.

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CASE REPORT

Bilateral hip heterotopic ossification with sciatic nerve compression on a paediatric patient–An individualized surgical approach: A case report

João Pedro Gouveia Nóbrega, Pedro Jordão, Joana Arcângelo

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Abstract

BACKGROUND

Neurogenic heterotopic ossification is an acquired serious complication described in patients with central nervous system disorders and defined by bone formation in non-osseous tissue.

CASE SUMMARY

We present an unusual case of a 13-yr-old boy presenting with hip pain and severe gait impairment 5 mo after the diagnosis of hemiplegia following a spontaneous intracerebral haemorrhage. Computed tomography revealed bilateral heterotopic ossification of both the paretic and the non-paretic limbs, with entrapment of the sciatic nerve. The choice of surgical or nonsurgical management of such patients depends on the timing of diagnosis, the symptoms, and the extent of maturation of the ossified lesions. Surgical resection remains the only treatment with proven, evidence-based effectiveness. The choice of surgical approach largely depends on the location of the ossified lesions.

CONCLUSION

We believe the plane of dissection presented is a satisfactory option for resection of a posteromedial mass and sciatic nerve release.

Key Words: Hip; Heterotopic ossification; Pediatrics; Orthopedics; Ressection surgery; Case report

Core Tip: Rare case of a post-stroke bilateral neurogenic heterotopic ossification of the hip with sciatic nerve entrapment in a paediatric patient with an individualised surgical approach for resection and release of the sciatic nerve.

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INTRODUCTION

Neurogenic heterotopic ossification (NHO) is a process of ectopic bone deposition in non-skeletal tissue in the setting of an event involving the central nervous system, such as a stroke, cerebral anoxia, or cranial or medullary injury. Its severity and clinical presentation vary depending on the extension of the ossified lesion and the compromise of adjacent neurovascular structures. The etiopathogenesis of NHO is unclear, but existing evidence supports the involvement of neuronal control mechanisms[1] and conversion of mesenchymal progenitor cells to osteoblast lineages[2] with the participation of prostaglandin E2 and osteoblast stimulating factors[3]. In this report, we introduce a case of a paediatric patient who, following a haemorrhagic stroke, developed bilateral hip NHO with entrapment of the sciatic nerve and with the unusual involvement of both the paretic and nonparetic limbs. We describe our surgical approach and resection strategy.

CASE PRESENTATION

Chief complaints

A 13-yr-old boy with sickle cell trait presented with hip pain and limited range of motion.

History of present illness

The patient had a 5-mo history of painful bilateral hip stiffness that progressively impaired his gait. Extensive bilateral heterotopic ossification was seen on pelvic radiographs (Figure 1).

History of past illness

The patient had an history of right fronto-temporal haemorrhagic stroke because of an arteriovenous malformation, complicated with a right chronic subdural haemorrhage resulting in right facial nerve palsy with dyspraxia and left hemiplegia that has persisted since then.

Personal and family history

There is no personal and family history.

Physical examination

Motor examination revealed left spastic hemiparesis (0/5) with hyperreflexia and right side upper limb motor function of 4+/5 and 3/5 on the ipsilateral lower limb. The patient presented with painful, generalized and progressive limited passive range of motion of both hips, and soon was completely bedridden.

Laboratory examinations

There is no laboratory examinations.

Imaging examinations

A computed tomography (CT) scan documented extensive calcification occupying the ischial-femoral space, with bilateral involvement of the posterior muscles of the thigh, mainly the external obturator, gemellus inferior and the proximal aspect of the biceps femoris. A 2.5 cm extension and oedema resulted in osseous incarceration of the proximal aspect of the sciatic nerve that was more evident on the right side (Figures 2 and 3).

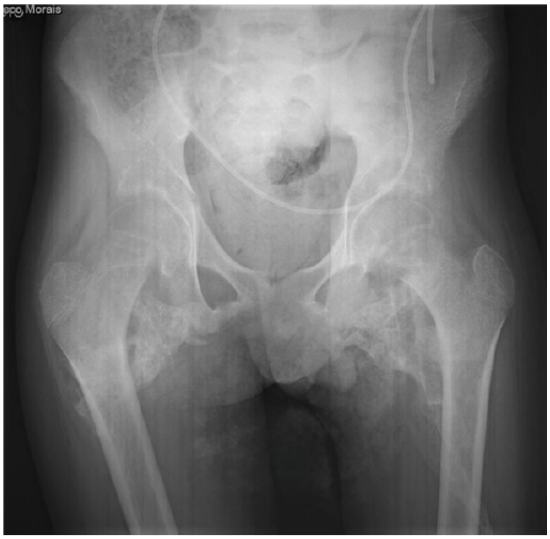

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Figure 1 Antero-posterior pelvic radiograph showing extensive bilateral heterotopic ossification.

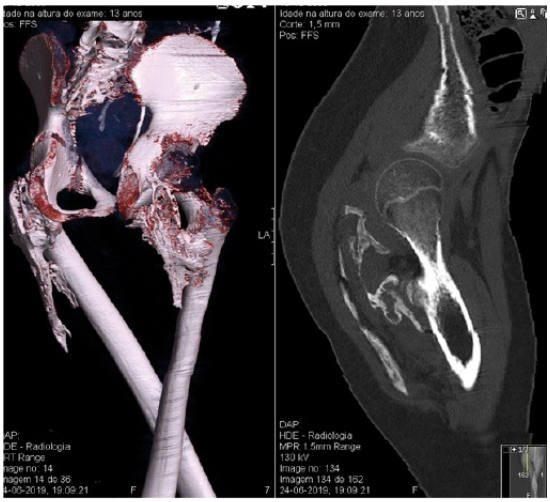

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Figure 2 Computed tomography showing a bilateral bony bridge between the ischium and postero-medial proximal femur that limits hip range of motion.

FINAL DIAGNOSIS

The patient was diagnosed with posteromedial bilateral heterotopic ossification with entrapment of both proximal aspects of the sciatic nerve.

TREATMENT

Surgical resection of the ossified lesion and release of the sciatic nerve were performed, starting with the right hip. A modified posterior thigh approach that was developed by the senior author was used for both hips. The procedure was performed with the patient in a ventral position and began with a "lazy S" incision made in the centre of the gluteal region (Figure 4A). The gluteus maximus was detached from its distal insertion point on the proximal femur and retracted proximally, a manoeuvre intended to preserve gluteus vascularization from the superior gluteal artery. The sciatic nerve was then identified at both extremities of the ossification and subsequently released (Figure 4B and C). Note that a fibrous capsule that had formed between the nerve and the bone facilitated the dissection, which was performed with Kerrison forceps and meticulous haemostasis.

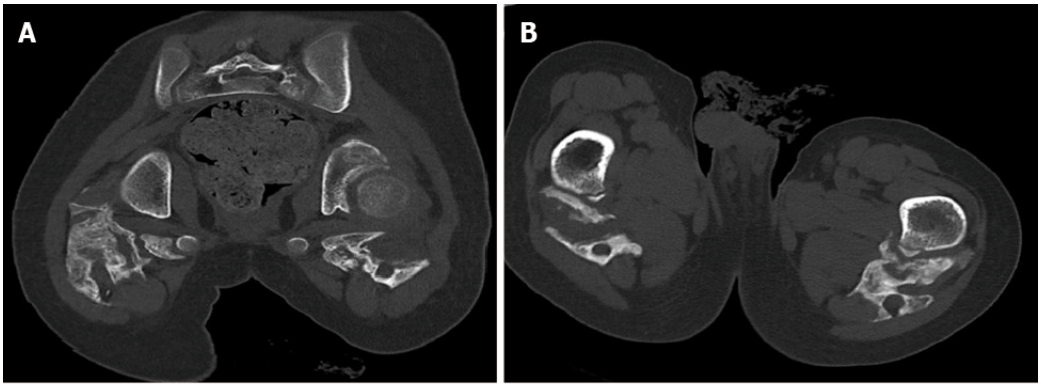

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Figure 3 Computed tomography and axial view. A: A proximal section showing ossification of the gluteal and posterior thigh musculature; B: A distal section showing ossification around the sciatic nerve.

OUTCOME AND FOLLOW-UP

Resection was performed on the left hip 6 wk later, and radiographic evaluation revealed a limited NHO relapse on the right hip (Figure 5A). Postoperatively, the patient began partial weight-bearing walking and participation in a rehabilitation program. After 1-yr of follow-up, there was no further development of the NHO lesions on radiographic evaluations and the patient had experienced a significant clinical improvement, being able to resume walking (Figure 5B).

DISCUSSION

NHO is not often encountered in the paediatric population, and that has resulted in the use of diagnostic and treatment methods based on experience and evidence obtained in adults. To our knowledge, this is the first published case of a post-stroke bilateral NHO of the hip with sciatic nerve entrapment in a paediatric patient. Management of these patients is complex and requires multidisciplinary intervention. Even though there is a lack of evidence to support their effectiveness, and there are some conflicting viewpoints, conservative measures remain the first approach in the early stages of NHO. Pharmacological therapy with bisphosphonates and indomethacin has demonstrated efficacy in the early inflammatory phase of NHO, reducing disease progression. Non-steroidal anti-inflammatory drugs, particularly indomethacin, reduce the incidence of NHO in patients with spinal cord injury[4] but increase the risk of haemorrhagic complications that could be serious in patients with sickle cell trait, such as ours.

Furthermore, peri-articular radiation is considered another valid early-stage therapeutic modality that has been found to be more effective than non-steroidal anti-inflammatory drugs[5]. It is considered useful for inactivating the high mitotic rate of the pluripotent osteoprogenitor cells recruited by the inflammatory cascade and their differentiation into osteoblasts and chondrocytes[6]. Low-dose radiation therapy administered preoperatively or less than 72 h postoperatively represents an effective treatment [7], not only in reducing the size of NHO lesions[8] but also the risk of recurrence[9], with minimal side effects[10].

Another conservative treatment applied is physical therapy, but whether it plays a significant role in the mitigation of NHO lesions remains unclear. It has been suggested that forced manipulation of the extremity can induce HO formation by increasing inflammation[11], whereas lack of movement can cause HO formation and progression to ankylosis. Cautious use of a gentle range of motion is considered the best approach. In this case, we believe that recurrence of the HO on the right hip was promoted by the immobilization incurred while the patient waited for surgery of his left hip. It was only after both hips were operated and freed of ossification, and mobilization was resumed that the HO on the right side stopped progressing. Besides that, postoperative low-dose radiation therapy could have also contributed to minimization of the high risk for recurrence of HO lesions after resection on the right hip.

For this particular case, the patient presented with severe pain, gait impairment and the presence of signs of neurological compromise. It is generally agreed in the orthopaedic community[12] that fully matured hip HO limits the use and efficacy of conservative treatment modalities as curative options. Therefore, surgical intervention remains the mainstay for treatment of mature HO lesions.

First of all, surgical intervention should not aim for a complete resection, as this could incur an increased risk of haemorrhage and infection. A "functional" resection that increases mobility and alleviates pain is preferable. Furthermore, the location of the heterotopic ossification on the hip, which

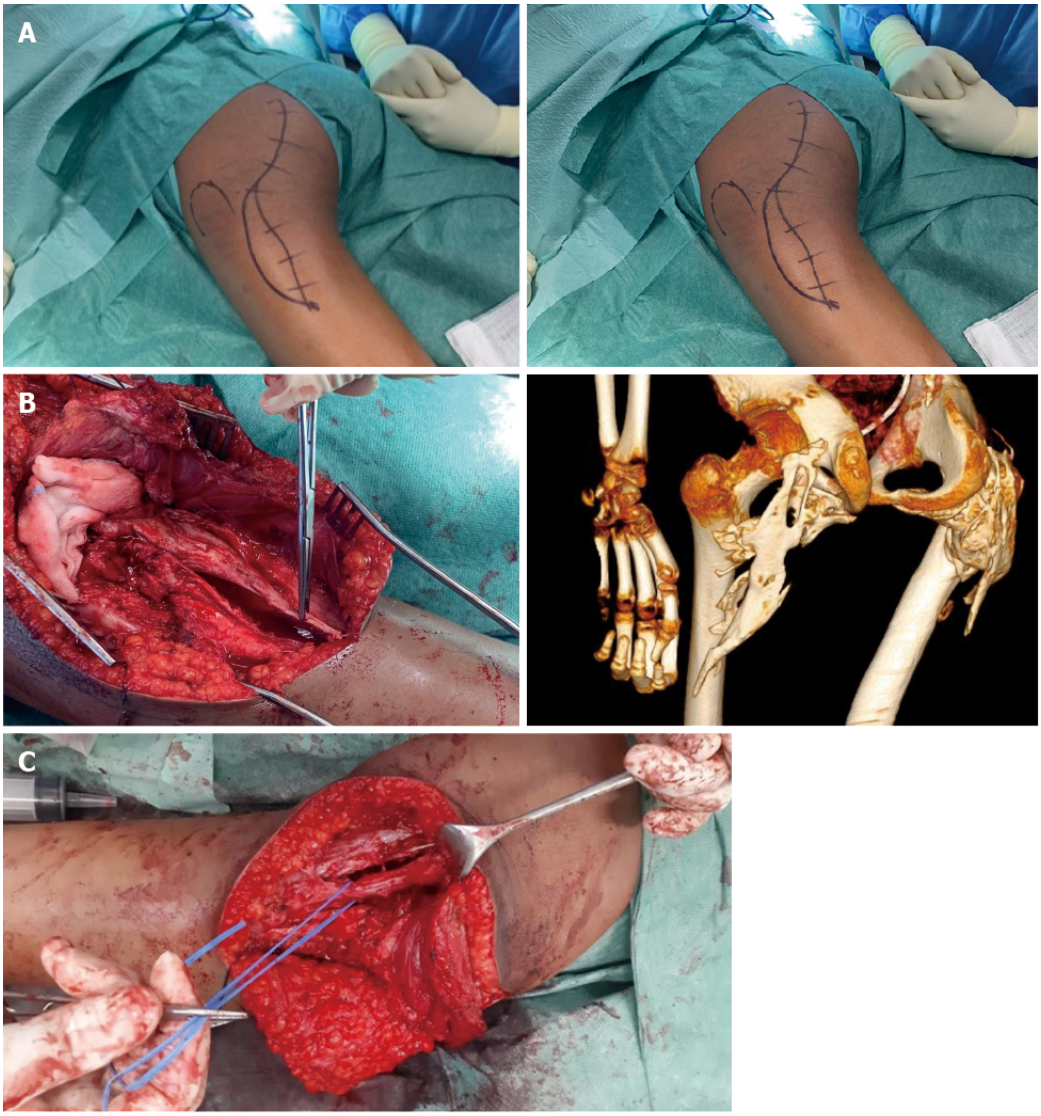

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Figure 4 Intraoperative views. A: Lazy "S" incision in the gluteal region; B: Resection of ossified lesions; C: Release of the sciatic nerve path.

will guide the choice of surgical approach, is largely determined by certain aetiologies; for example, posterior lesions, like in our case, are typically associated with cerebral anoxia.

In our case, the heterotopic calcification had an extension below the plane of the greater gluteus muscle, from the trochanteric region to the ischiatic region. Traditional approaches (such as the postero-lateral Gibson approach) do not allow for a clear exposition of this space. The transgluteal approach has the disadvantage of muscle denervation, and proximal disinsertion of the greater gluteus muscle may jeopardize its vascularization (gluteal artery, branch of the internal iliac artery). Thus, through an S-shaped incision that allows a wide area of exposure, the distal tendinous release of the greater gluteus muscle and the progressive disinsertion of this muscle exposes the entire plane of the rotators and hamstrings (where the major HO lesion lies) without compromising innervation and vascularization.

Controversy persists in the timing of surgery. It is accepted that HO lesions should not be surgically treated until bone maturation is complete with presence of defined cortical margins, which often appear around 6 mo after the beginning of ossification. Some authors suggest waiting 18 mo[8,13]. A recent study suggests that the risk of recurrence is independent of the time to surgery. Early surgery was found to prevent the development of joint ankylosis, and subsequent induction of epiphyseal osteoporosis, progressive cartilage loss, loss of function, joint stiffness, and bone demineralization with increased risk of fracture.

CONCLUSION

A posterior approach of the gluteal region with gluteus maximus distal disinsertion from proximal

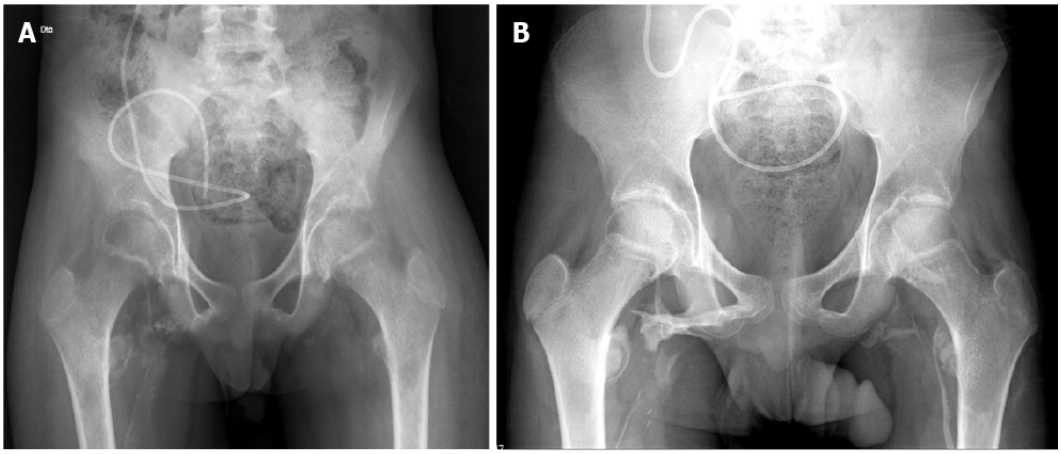

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Figure 5 Radiograph. A: Radiograph obtained immediately after left hip resection, note the regrowth of ossification on the right hip, which was treated first; B: Radiograph at 1 yr after surgery shows limited regrowth of heterotypic ossification on the right hip with signs of cortical maturation.

femur and proximal retraction with a meticulous sciatic nerve release are favorable therapeutic options for severe posterior heterotopic ossifications. This case illustrates the practical difficulties of managing such patients and reinforces the need for specific guidelines not only for treatment and timing but also for the use of adjuvant therapy in the paediatric population, for which the literature is sparse.

FOOTNOTES

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LETTER TO THE EDITOR

Rates of readmission and reoperation after operative management of midshaft clavicle fractures in adolescents

Mohamed Kamal Mesregah

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Abstract

The present letter to the editor is a commentary on the study titled "Rates of readmission and reoperation after operative management of midshaft clavicle fractures in adolescents". There is a debate over whether surgical treatment of clavicle shaft fractures improves clinical outcomes in adolescents. The readmission and reoperation rates following surgery should be identified.

Key Words: Readmission; Reoperation; Clavicle fractures; Operative fixation; ORIF; Adolescents

Core Tip: Most mid-shaft clavicular fractures in adolescents have been typically treated nonoperatively with satisfactory outcomes. There is a major controversy over whether surgical treatment of clavicle shaft fractures in adolescents improves clinical outcomes in the same way it does in adults. There is a need to conduct multiple prospective randomized studies or large comparative database studies to better assess the operative management.

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TO THE EDITOR

I read with great interest the retrospective study on the national rates of readmission

and reoperation after open reduction internal fixation (ORIF) of midshaft clavicle fractures in adolescents by Carrillo *et al*[1], published in your esteemed journal in December 2021 issue.

I agree with the authors that there is a need to identify the national readmission and reoperation rates following ORIF of midshaft clavicle fractures in adolescents. Most clavicular fractures in adolescents have been typically treated nonoperatively, especially those affecting the mid-shaft of the clavicle[2,3]. In adolescents, there remains a major controversy over whether surgical treatment of clavicle shaft fractures improves the clinical outcomes in the same way it does in adults[4].

For the purpose of Carrillo *et al*[1] study, the authors utilized the Healthcare Cost and Utilization Project State Inpatient Database (SID) for the years 2005-2012 in Florida and 2005-2009 in California. This database includes inpatient discharge records from community hospitals in those states.

For identification of patient cohort, the authors used two codes. The first code is CPT 23515 code, which by definition refers to (Open treatment of clavicular fracture, includes internal fixation when performed). However, the other code used by the authors is ICD-9 CM 79.39 code, which refers to (open reduction of fracture with internal fixation, other specified bone), which means that this code is not specific at all to the clavicular fractures. Therefore, I am afraid the authors included in the study adolescent patients with fractures in other body bones, other than clavicular fractures.

Moreover, the authors identified only 334 clavicle fractures in adolescents managed operatively. This number is considered low to determine readmission and reoperation rates in large database studies such as SID. The authors should at least have used SID for years up to 2020 in both states.

The authors also reported that 11 (3.3%) patients were readmitted within 90 d of surgery. However, this low rate is not clinically important as those 11 patients may have been admitted for other reasons unrelated to the index surgery.

Nonoperative care is the successful historical treatment and the current safest treatment for midshaft clavicular fractures in adolescents. Operative care is overused in adolescents for clavicle fractures. To better assess the operative management, there is a need to conduct multiple prospective randomized studies or large comparative database studies.

FOOTNOTES

Author contributions: Mesregah MK revised the literature, collected data, wrote and revised the manuscript.

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