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MINIREVIEWS

Developments in diagnosis and treatment of paediatric septic arthritis

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Abstract

Acute septic arthritis in children is an orthopaedic emergency. A delay in diagnosis and inappropriate treatment can result in devastating damage to the joint with lifelong disability as a consequence. The clinical presentation can be a diagnostic challenge, especially in young children. A recent systematic review showed that joint tenderness and fever are important signals of septic arthritis. Ultrasound is helpful in detecting the presence of a joint effusion. Plain radiographs may show bone changes but magnetic resonance imaging is the most reliable imaging study for detecting concomitant osteomyelitis. The diagnosis of acute septic arthritis is highly suggestive when pus is aspirated from the joint, in case of a positive culture or a positive gram stain of the joint fluid, or if there is a white blood-cell count in the joint fluid of more than 50000/mm^3. *Staphylococcus aureus* is the most commonly cultured organism. Recent systematic reviews have identified the most effective drainage techniques, including needle aspiration, arthroscopy and arthrotomy, depending on the affected joint. After the drainage procedure it is important to monitor the clinical and laboratory outcomes. Additional drainage procedures may be necessary in select cases.

Key Words: Septic arthritis; Paediatric; Children; Analysis; Treatment; Drainage

Core Tip: This article provides an up-to-date evidence-based review on the diagnosis and treatment of paediatric septic arthritis. Acute septic arthritis in children is an orthopaedic emergency. It can be a diagnostic challenge, especially in young children. Accurate history, physical exam, laboratory findings and imaging can contribute to the diagnosis of septic arthritis. The following step of joint aspiration with an appropriate treatment must be made in a short time period. Clinical predicting tools and optimal drainage techniques for paediatric septic arthritis were evaluated in recent systematic reviews. After the drainage procedure it is important to monitor the clinical and laboratory outcomes.

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INTRODUCTION

Acute septic arthritis in children is an orthopaedic emergency. Since the clinical presentation can be similar to other joint pathologies, acute septic arthritis is a diagnostic challenge. This is especially true for infants and neonates, in whom refusal to feed, crying and discomfort with limitations of joint movement can be the presenting symptoms. A delay in diagnosis and inappropriate treatment can result in a devastating damage to the joint with lifelong disability as a consequence[1]. According to laboratory evidence, the loss of glycosaminoglycan in cartilage begins within eight hours after the onset of an infection in a joint[2]. An increase in intracapsular pressure in the hip joint, when not promptly decompressed, may lead to compressive ischemia and avascular necrosis of the femoral head[3]. Therefore, it is important to perform an appropriate diagnostic workup and an optimal treatment of this challenging disease. In 2020, a systematic review was published that stated the test characteristics of history, physical examination and laboratory and image investigations in the evaluation for septic arthritis in children presenting with an acute nontraumatic limp[4]. Recently, we published two systematic reviews with a clear overview of the literature on drainage techniques for septic knee and hip arthritis in children[5,6]. In this evidence-based current concept review we therefore provide an update on the diagnostic workup and treatment of paediatric septic arthritis.

BACKGROUND

Epidemiology

The incidence of septic arthritis is two to seven per 100000 children in Europe and three to four per 100000 in the United States of America[7-9]. The highest incident rates are seen among the group of children aged between zero and four years old[9]. Septic arthritis is typically monoarticulair. The most commonly affected joints are the hip (32%-39%) and knee (26%-47%). Other affected joints are ankle (9%-18%), shoulder (2%-12%), elbow (4%-13%) and wrist (1%-2%)[9-14]. Septic arthritis is 1.4 to 1.7 times more common in males than in females[9,10,12].

Bacteriology

Staphylococcus aureus is the most commonly cultured organism. Other common pathogens are *Kingella kingae*, *Streptococcus pyogenes* and *Streptococcus pneumoniae*[10,15,16]. High prevalence of *Salmonella* infection is seen in patients with septic arthritis from Africa[17,18]. The causative pathogens overall can vary depending on the child's age, immunodeficiency, socio-economic factors and vaccination status[9]. *Kingella kingae* is more frequently isolated among children under 36 mo of age in comparison to older children[15]. Before an effective vaccine, *Haemophilus influenzae* type B was a very common cause of septic hip arthritis. This pathogen is now rarely reported in well-immunized populations[19-21]. Some causative organisms are less common, but are seen in specific groups. *Salmonella typhi* can be suspected outside Africa in children with sickle cell disease and has been found in immunoincompetent children [22,23]. *Pseudomonas aeruginosa* is often found after a wound nearby the joint and *Pasteurella canis* is found most often after animal bites[23,24]. *Neisseria gonorrhoeae* should be suspected in sexually active adolescents or in cases of sexual abuse[25].

In 2010, Pääkkönen *et al*[20], showed in septic hip arthritis in children with culture-positive cases that bacteria grew from the synovial fluid only in 34 percent cases, from blood in only 27 percent cases, and from both joint and blood in 39 percent cases.

DIAGNOSIS

Clinical presentation

The classical presentation of septic arthritis in children is a combination of a painful joint with limited range of movement, the inability to bear weight on the involved limb, fever and malaise[3,26-28]. The symptoms can rapidly progress in hours. At physical examination, effusion, erythema, heat, tenderness to palpation and, in the lower extremities, inability to bear weight can be seen. The affected joint is irritable and is most often held in a position of comfort, one that maximizes intracapsular volume. For example, the hip is flexed, abducted, and externally rotated. A characteristic sign is micromotion tenderness[28]. A recent systematic review showed that the presence of joint tenderness and fever increases the risk of septic arthritis[4]. The presence of fever (≥ 38.5°C) has a positive likelihood ratio (LR) of 2.1 to 18.2. The absence of fever had a negative LR of 0.2 to 0.6. Joint tenderness had a positive LR of 11.4 and a negative LR of 0.3[4].

During infancy, the clinical presentation differs from the presentation in older children. Sepsis is often the first notable presentation of septic arthritis in neonates and infants. The symptoms are comprehensive and include irritability, failure to feed or gain weight and muscular spasm. Also, fever, tachycardia, anaemia and the presence of associated infection are occasionally seen. Involvement of the hip joint must be suspected in any infant with sepsis. The following characteristics at physical examination can be present: pain on palpation or passive movement of the hip, lack of active movement of the leg, asymmetrical buttock creases, unilateral oedema or swelling of an extremity, a buttock or the genitalia[29].

Paediatric septic arthritis can occur several weeks after an upper respiratory infection. In infants and neonates, underlying diseases have been recognized as risk factors for septic arthritis, including respiratory distress syndrome, congenital anomalies and extremely low birth weight[30].

Laboratory studies

The initial laboratory testing for a patient with suspected osteoarticular infection should consist of serum samples with complete blood count, Erythrocyte sedimentation rate (ESR), C-reactive protein (CRP) and two blood cultures[31,32]. In 1999, Kocher *et al*[33] identified four predictors that, by combining, had excellent diagnostic performance in differentiating between septic hip arthritis and transient synovitis of the hip in children. These four predictors were a history of fever, non-weight-bearing, an ESR of at least 40 mm/h, and a serum white blood-cell (WBC) count of more than 12000 cells/mm^3. Kocher *et al*[34] concluded that patients with a very high probability of septic arthritis of the hip have three or four positive predictors. They advised that these patients may be good candidates for aspiration in the operating room, given the likelihood that subsequent arthrotomy and drainage will be needed. Patients who have an intermediate probability (two positive predictors) of septic arthritis of the hip may be good candidates for aspiration under ultrasound. Patients who have an extremely low probability (zero or one positive predictors) of septic arthritis of the hip may be appropriate candidates for careful observation without aspiration. After five years, this clinical prediction algorithm was validated in a prospective study[34]. In 2006, Caird *et al*[35] in a prospective study added an elevated CRP level to the Kocher criteria. They stated that a CRP level of more than 2.0 mg/dL (> 20 mg/L) is a strong independent predictor. A recent systematic review showed that the performances of both clinical risk prediction tools are somewhat lower than originally reported. The predicted probability of septic arthritis for the Kocher criteria ranges from 59.1% to 99.6%; this probability remains similar (60% to 98%) when CRP is added[4].

Imaging

Plain radiographs are the next step in the diagnostic workup of paediatric septic arthritis, mainly to rule out bone changes. Additionally, an increased joint space of the affected septic joint may be visualized on radiographs. In case of suspected hip arthritis, an anteroposterior pelvic radiograph allows assessment of the joint space compared to the contralateral hip.

Both ultrasound and magnetic resonance imaging (MRI) are good non-invasive diagnostic tools without radiation exposure in the evaluation of septic arthritis. Ultrasound is an easily implicated diagnostic tool for detecting the presence of a joint effusion[3]. Joint effusion on ultrasound is seen in 91 percent of patients with septic arthritis[36]. However, it cannot distinguish between sterile, purulent, and hemo-rrhagic fluid accumulations[37]. The data from a negative ultrasound in children with less than 24 h of symptoms should be used with caution and must be interpreted along with a careful history and physical examination[38]. An advantage of ultrasound is that no sedation is required in young children. Furthermore, ultrasound is more sensitive in detecting joint effusion and synovial swelling in children with septic arthritis compared to radiography and MRI[4,36]. One drawback of ultrasound is that it can be user-dependent. In addition, it does not necessarily rule out osteomyelitis or nearby intramuscular abscesses.

Although costly, MRI is the most reliable imaging study for detecting bone and periosteal changes in patients with concomitant osteomyelitis[36,39]. Also, MRI can be used to distinguish septic arthritis of the hip from a psoas abscess and help identify adjacent infection sites. However, in young children

sedation in often needed. Although, after the MRI there is a possibility to go straight to the operation room under continuous sedation for a drainage procedure. Recently, an algorithm has been proposed to help identify patients at risk for adjacent infections who would benefit from MRI to identify additional sites of infection. This algorithm contains five variables: older than 3.6 years, CRP > 13.8 mg/L, duration of symptoms > 3 d, platelets < 314 × 10 cells per μL (microliter), and absolute neutrophil count > 8.6 × 10 cells per μL. Patients with three or more risk factors are classified as high risk for having an adjacent infection and would benefit from MRI[40].

Microbiology testing

Synovial fluid analysis by aspiration is an important part of the diagnostic workup when septic arthritis is suspected. Synovial fluid should be sent for white blood cell count, gram stain, culture and antibiotic sensitivity. The diagnosis of acute septic arthritis is highly suggestive when pus is aspirated from the joint, when there is a positive culture of the joint fluid, a positive gram stain of the joint fluid or a WBC count in the joint fluid of > 50000/mm^3. Despite appropriate cultures, a notable proportion remains culture negative. Polymerase chain reaction testing of synovial fluid for *Kingella kingae* (generally seen in children younger than 36 mo of age) and other fastidious pathogens increases detection, particularly in patients who received antibiotics before synovial fluid sampling[41,42].

DIFFERENTIAL DIAGNOSIS

It is important to consider several diseases in the differential diagnosis of septic arthritis[43].

The differentiation between septic hip arthritis and transient synovitis, also known as coxitis fugax, can be difficult because both conditions often present with similarities. Transient synovitis presents as an atraumatic, acutely irritable hip in a child who has progressive symptoms, often sub febrile temperature and refuses to bear weight. Transient synovitis is a self-limiting disorder that is managed nonoperatively and without antibiotics. It typically occurs in children between the ages of three to eight years, with a mean age at presentation of five to six years[44,45]. Most children have symptoms for less than a week at the time of presentation. However, in a retrospective review in 1986, 12 percent of patients had discomfort dating back at least one month[45]. The Kocher criteria can help differentiate between septic arthritis and transient synovitis[33,34]. A transient synovitis is plausible when zero predictors are found.

Juvenile idiopathic arthritis is usually polyarticular and often has gradual onset of symptoms. The first peak is between two to five years of age and the second is between 10 to 14 years of age. Joints are warm and markedly swollen, but not especially painful. The symptoms tend to be worst upon rising in the morning. Joint involvement is generally symmetric and most frequently affected locations are the knees, wrists and ankles. The hip is rarely the initial joint. Children with systematic onset of juvenile idiopathic arthritis and intermittent fever, often have a skin rash[46].

Lyme arthritis needs to be considered in lyme disease endemic areas. About 90 percent of children with Lyme disease present with erythema migrans, which is an early stage of the disease[47]. In six percent an arthritis can present, but arthritis is the most common manifestation of late Lyme disease. Monoarthritis of the knee is most common, but Lyme arthritis may also cause an asymmetric oligoarthritis. The affected joint is usually swollen and may be tender, but the pain is less intense and the range of motion greater as compared to bacterial arthritis. Besides, fever is uncommon[48,49].

In addition to clinical presentation and laboratory studies, plain radiographs should eliminate fracture and other structural diagnoses. For example, in children with pain in the hip or knee joint, plain radiographs are used to exclude slipped capital femoral epiphysis and Legg-Calvé-Perthes disease. Legg-Calvé-Perthes is a syndrome of idiopathic osteonecrosis (avascular necrosis) of the hip. It typically presents as hip pain and/or limp of acute or insidious onset in children between the ages of 3 to 12 years of age, with a peak incidence between five to seven years of age[50]. Stress fractures are rarely seen in children, but they can occur in athletes engaged in endurance sports. Sometimes the radiographs of Legg-Calvé-Perthes and stress fractures are negative and MRI is needed to confirm the diagnosis.

An MRI can also be used when osteomyelitis, pyomyositis, subperiosteal abscess, cellulitis, intramuscular abscess, or tumour are still in the differential diagnosis. MRI is the gold standard imaging technique for osteomyelitis[51]. The tibia and femur are the most commonly affected bones in children with osteomyelitis. A systematic review showed that the clinical features of osteomyelitis include fever (60%), localized pain (70%), reduced range of movement (50%) and reduced weight-bearing (50%)[51]. In contrast to isolated septic arthritis, the child with osteomyelitis usually allows some joint movement and pain-free range of motion with gentle examination. Osteomyelitis can occur next to septic arthritis (Figure 1).

Pyomyositis is a purulent infection of skeletal muscle that arises from haematogenous spread[52]. It commonly manifests as a local abscess but may also present as a diffuse inflammatory or a rapidly progressing myonecrotic process. The quadriceps, gluteal, and iliopsoas muscles are the most commonly affected anatomic sites[53]. It is classically an infection of the tropics (Africa and the South Pacific), although it has been recognized in temperate climates. Trauma has been postulated as a predis-

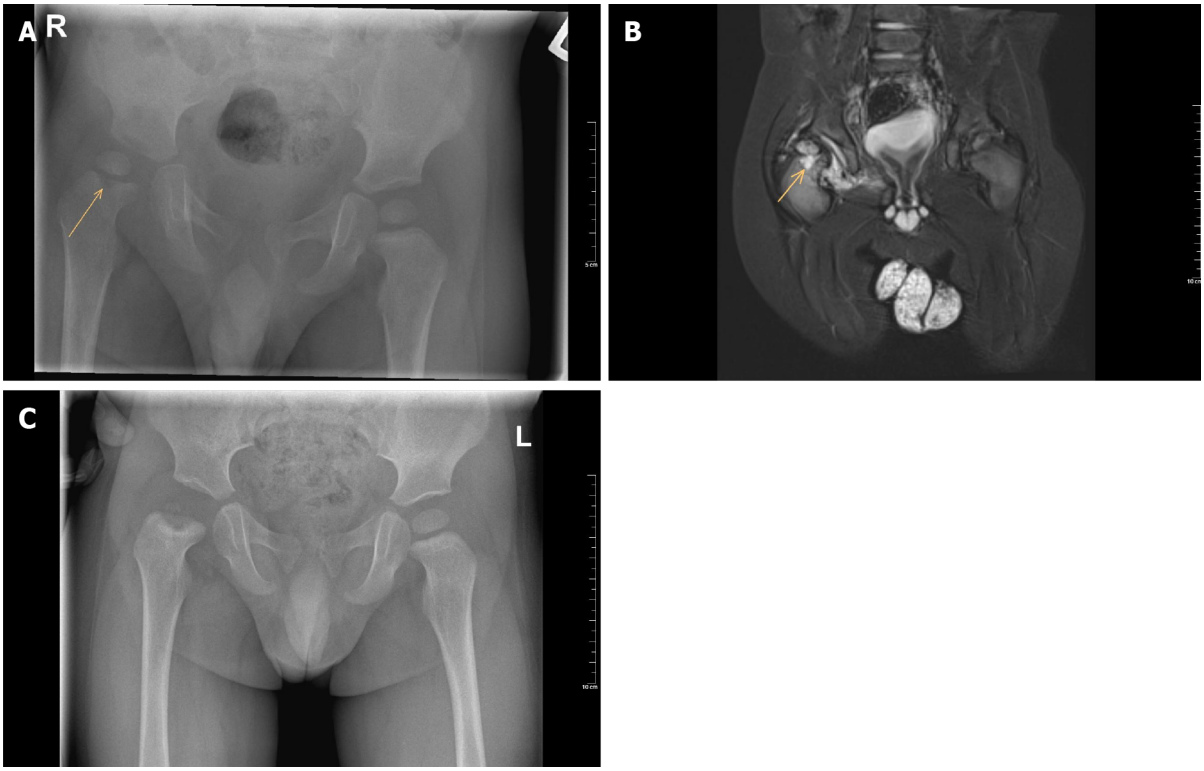

Figure 1 Radiograph images. A: Plain anteroposterior pelvic radiograph of a one-year-old boy with septic hip arthritis showing concomitant osteomyelitis of the proximal femur at the right side (arrow); B: T2 magnetic resonance imaging coronal view confirms joint effusion, suggestive of hip arthritis, and increased signal of the metaphysis, suggestive of osteomyelitis (arrow); C: Plain anteroposterior radiograph of the same boy after six months follow-up, which shows avascular necrosis of the femoral head.

posing factor for pyomyositis. Pyomyositis presents with fever and pain with cramping localized to a single muscle group. On physical examination, exquisite muscle tenderness, oedema, and/or fluctuance of the involved muscle group may be present. MRI is the optimal imaging technique, because it is highly sensitive for muscle inflammation (Figure 2)[53].

TREATMENT AND FOLLOW-UP

Drainage procedures

Paediatric septic arthritis can be treated by arthrocentesis (articular needle aspiration) with or without irrigation, arthroscopy or arthrotomy. All procedures are followed by antibiotics. Each of the drainage techniques have advantages and disadvantages within the different joints. Arthrocentesis, usually ultrasound-guided, has the advantage of a minimally invasive and short procedure. Generally, this can be used as a first procedure in different joints. However, in the very young, arthrocentesis requires an anaesthetic. Arthrocentesis without anaesthesia or sedation can be an anxiety-producing and painful experience. Advantages of arthroscopy include direct visualization of the joint, the ability to perform a complete debridement of the necrotic synovium and a thorough irrigation of the joint with minimal operative morbidity[54,55]. An arthrotomy gives a good overview of the joint and allows a thorough irrigation, but a disadvantage is a larger incision with more scar tissue. The anterior approach is the most mentioned approach for arthrotomy in paediatric septic hip arthritis[6].

Recent systematic reviews showed a clear overview of the literature on drainage techniques for septic knee and hip arthritis in children[5,6]. It was concluded that knee arthroscopy might have a lower risk of additional drainage procedures as compared to arthrocentesis and arthrotomy in paediatric septic knee arthritis[5]. In septic hip arthritis, arthrocentesis and arthroscopic procedures may have a higher risk of additional drainage procedures in comparison with arthrotomy. Nonetheless, arthrotomy in septic hip arthritis might be associated with inferior outcomes on the long term[6]. However, the studies about the optimal drainage procedure of the several joints were diverse and the scientific quality was generally low[5,6].

Antibiotics

Antibiotic coverage should start in suspected cases as soon as cultures and synovial fluid samples are collected and the joint has been drained, unless the patient is septic[26,27]. Most surgeons agree that

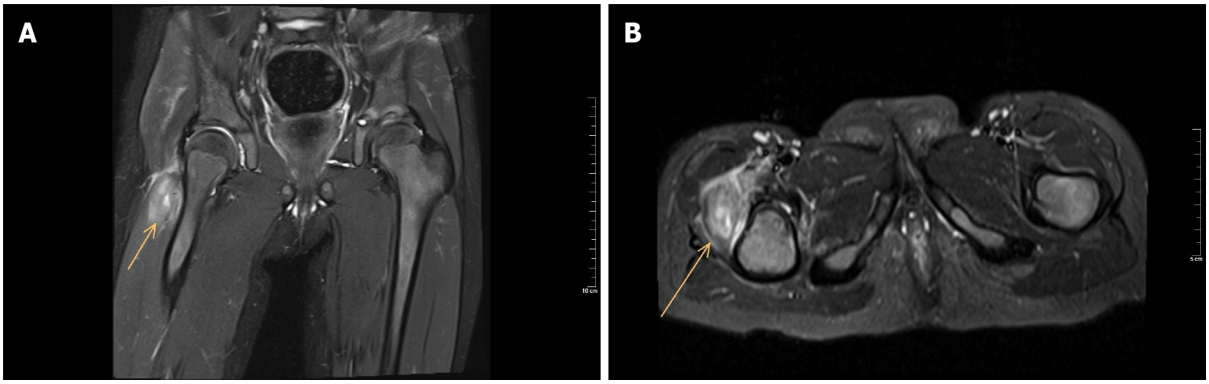

Figure 2 T2 magnetic resonance imaging of a three-year-old girl with pyomyositis of the vastus lateralis at the right side (arrow). There is no excessive fluid in the hip joint space. A: Coronal view; B: Sagittal view.

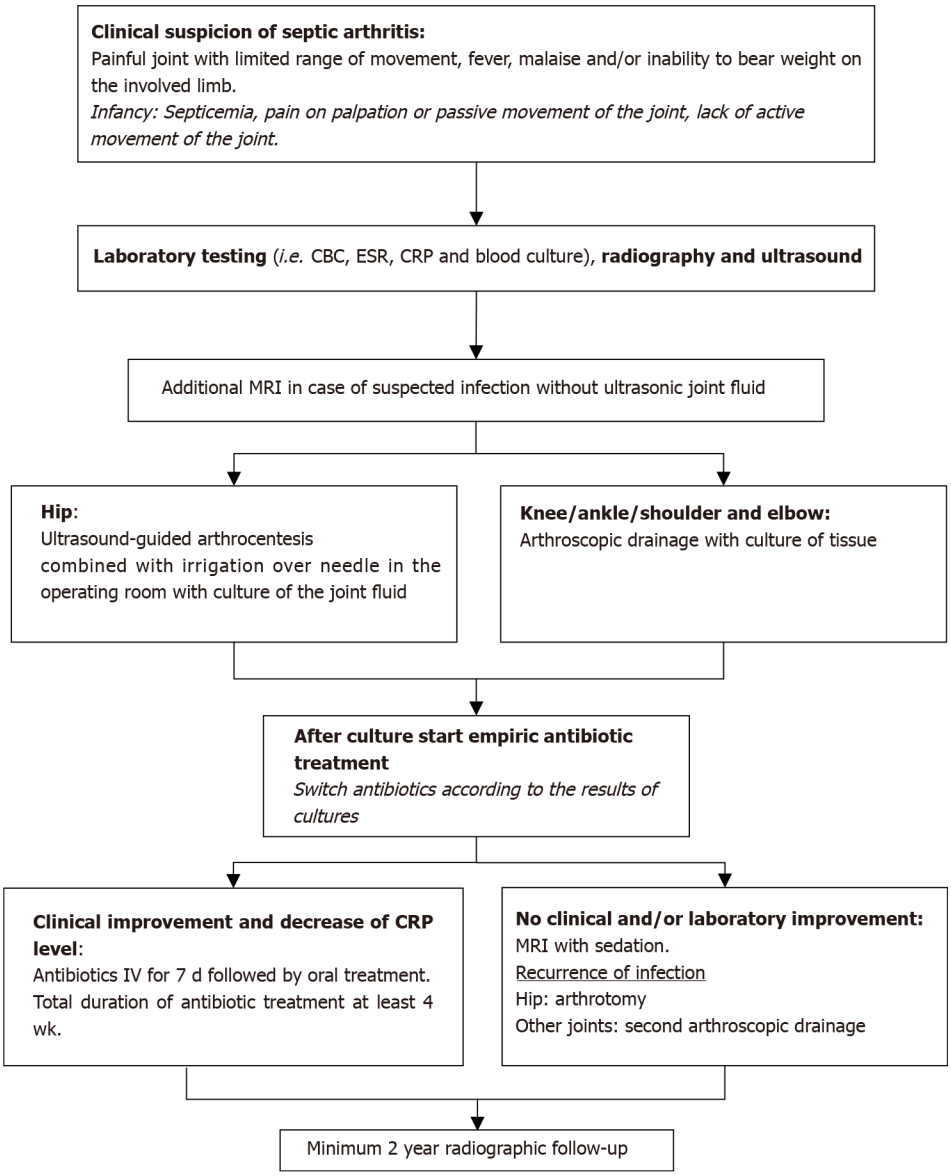

Figure 3 Diagnostic and treatment algorithm for paediatric septic arthritis. CBC: Complete blood count; ESR: Erythrocyte sedimentation rate; CRP: C-reactive protein; WBC: White blood cell; MRI: Magnetic resonance imaging; IV: Intravenous.

preoperative antibiotics should be avoided in the management of paediatric septic arthritis, because MacLean *et al*[56] showed that it leads to additional washouts and complications.

In consultation with the infectious disease team, the patient is transitioned to oral antibiotics after clinical and laboratory improvement, see Figure 3. It has been reported that the treatment with large doses of well-absorbed antimicrobials for 10 d (started intravenously for a few days only) is as effective as a 30 d treatment in children with septic arthritis, provided that the clinical response is good and the CRP level normalizes quickly[10]. However, the ideal duration of treatment has not yet been determined.

Follow-up

After the drainage procedure it is important to monitor the clinical and laboratory outcomes. Peltola *et al* [10] showed in a prospective trial that the CRP level and ESR can increase the first few days after starting the therapy. The highest scores were found on day two and three. A second or third drainage procedure is not exceptional[5,6].

The duration of symptoms between onset and the procedure is negatively associated with the prognosis, especially in infants and neonates with septic hip arthritis[30]. Septic hip arthritis can lead to serious musculoskeletal sequelae, which include: leg length discrepancy, pathologic hip dislocation, a hip joint surface irregularity, coxa magna or avascular necrosis (Figure 1C)[30]. Close follow-up with radiographic observation of at least two years is recommended.

RECOMMENDATIONS FOR FUTURE RESEARCH

There is a need for clinical risk prediction tools of paediatric septic arthritis to be prospectively validated [4]. Furthermore, the current literature about drainage techniques of paediatric septic arthritis is diverse and the quality is generally low[5,6]. Future prospective studies should ideally endeavour larger numbers of patients, define an established diagnosis of acute septic arthritis, report the delay between the first symptoms and the diagnosis, randomize treatment, and provide adequate follow-up time.

CONCLUSION

Paediatric septic arthritis can be a diagnostic challenge, especially in young children. A delay in diagnosis and inappropriate treatment can result in devastating damage to the joint with lifelong disability as a consequence. An accurate history, physical exam, laboratory findings and appropriate imaging can contribute to the diagnosis of septic arthritis. Prompt initiation of appropriate treatment is of paramount importance. After the drainage procedure it is important to monitor the clinical and laboratory outcomes. Based on the available scientific evidence, a diagnostic and treatment algorithm for paediatric septic arthritis is proposed (Figure 3).

FOOTNOTES

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ORIGINAL ARTICLE

Retrospective Cohort Study

All-epiphyseal versus trans-epiphyseal screw fixation for tillaux fractures: Does it matter?

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Abstract

BACKGROUND

Tillaux fractures occur primarily in adolescents due to the pattern of physeal closure and are classified as Salter-Harris type III physeal fractures. Operative management with screw fixation is recommended for more than 2 mm of displacement or more than 1 mm of translation. However, the efficacy and complications of trans-physeal *vs* all-physeal screw fixation have not been investigated extensively.

AIM

To compare the clinical and functional outcomes of trans-physeal (oblique) and all-epiphyseal (parallel) screw fixation in management of Tillaux fractures among pediatric patients.

METHODS

This was an ethics board approved retrospective review of pediatric patients who presented to our tertiary children's care facility with Tillaux fractures. We included patients who had surgical fixation of a Tillaux fracture over a 10 year period. Data analysis included demographics, mode of injury, management protocols, and functional outcomes. The patients were divided into group 1 (oblique fixation) and group 2 (parallel fixation). Baseline patient characteristics and functional outcomes were compared between groups. Statistical tests to evaluate differences included Fisher's Exact or Chi-squared and independent samples t or Mann Whitney tests for categorical and continuous variables, respectively.

RESULTS

A total of 42 patients (28 females and 14 males) were included. There were no

significant differences in body mass index, sex, age, or time to surgery between the groups [IK2]. Sports injuries accounted for 61.9% of the cases, particularly non-contact (57.1%) and skating (28.6%) injuries. Computed Tomography (CT) scan was ordered for 28 patients (66.7%), leading to diagnosis confirmation in 17 patients and change in management plan in 11 patients. [GRC3] Groups 1 and 2 consisted of 17 and 25 patients, respectively. For mid to long-term functional outcomes, there were 14 and 10 patients in groups 1 and 2, respectively. Statistical analysis revealed no significant differences in the functional outcomes, pain scores, or satisfaction between groups. No infections, non-unions, physeal arrest, or post-operative ankle deformities were reported. Two (4.8%) patients had difficulty returning to sports post-surgery due to pain. One was a dancer, and the other patient had pain while running, which led to hardware removal. Both patients had parallel fixation. Hardware removal for groups 1 and 2 were 4 (23.5%) and 5 (20.0%) patients, respectively. The reasons for removal was pain in 2 patients, and parental preference in the remaining.

CONCLUSION

This is the largest reported series of pediatric patients with Tillaux fractures comparing functional outcomes of different methods of screw fixation orientation to the physis, which showed no difference regarding functional outcomes.

Key Words: Tillaux fracture; Orthopedic surgery; Fixation technique; Functional outcomes

Core Tip: Tillaux fractures that require surgery can undergo screw fixation by all-epiphyseal or trans-epiphyseal techniques. This study shows that there were no statistically significant differences between the functional outcomes or complications between the two techniques. Therefore, we suggest using the trans-epiphyseal techniques because it has an easier screw trajectory in surgery, all-epiphyseal screws have been shown to increase pressure in the tibiotalar joint, and the trajectory is trigonometrically a better angle to compress the fracture.

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INTRODUCTION

Tillaux fracture is an avulsion fracture of the anterolateral distal tibial epiphysis that occurs primarily in adolescents due to the pattern of physeal closure, and is classified as a Salter-Harris type III physeal fracture[1]. They occur most commonly in children near skeletal maturity at around ages 12-14 years old during the period of distal tibial physis closure, with supination-external rotation being the typical mechanism of injury. In children, the cartilaginous physes are more susceptible to injury than the surrounding tissues, leading to bone failure prior to the failure of ligamentous attachments. The physis initially closes centrally, then medially, and finally laterally, giving rise to the anterolateral location of the Tillaux fracture[2]. In the Tillaux fracture pattern, this manifests as an avulsion of the distal lateral tibial epiphysis at the site of attachment of the anterior inferior tibiofibular ligament where the physis is still cartilaginous and weaker than the ligament[3].

Ankle fractures account for approximately 5% of all pediatric fractures and 15% of all injuries involving a physis[4]. Tillaux fractures specifically account for 3%-5% of all pediatric ankle fractures[5, 6], and the amount of data in the literature on these fractures is limited. Operative management with screw fixation is recommended for fractures with more than 2 mm of displacement or more than 1 mm of translation[2]. Fixation can be performed by an all-epiphyseal (parallel) or trans-physeal (oblique) screw orientation. Traditional treatment of this injury involved all–epiphyseal screw fixation (parallel to the ankle joint line) because it avoids the open physis, theoretically preventing growth arrest. However, a previous cadaveric study showed that parallel screw fixation can lead to increased joint pressures[7], potentially altering ankle joint biomechanics and increasing the risk of arthritis and complications in the long term[8]. Oblique screws may have an easier to achieve intra-operative trajectory, serve as a better fixation construct as they are relatively more perpendicular to the fracture line, and would not lead to increased pressure in the ankle joint articular cartilage.

To our knowledge, the efficacy (including functional outcomes) and complications of oblique *vs* parallel screw fixation for Tillaux fractures have not yet been investigated in the literature. This study aims to compare the healing and functional outcomes of both fixation techniques. We hypothesized that oblique fixation would result in no differences in bone healing, complications, or functional outcomes compared to parallel fixation.

MATERIALS AND METHODS

This cohort study was conducted at a single-center following institution review board approval. All patients under 18 years old who underwent surgical fixation of Tillaux fractures between January 2010 and March 2020 were included in the study. Patients were excluded if they had underlying conditions interfering with either bone physiology, anatomy, or healing, such as cerebral palsy, osteogenesis imperfecta, *etc.* Patients were stratified into two groups based on the screw fixation technique: Group 1 consisted of patients with oblique (trans-physeal) fixation (Figure 1), and group 2 consisted of patients with parallel to the ankle (all-epiphyseal) fixation (Figure 2). Screw fixation technique was determined by a review of operative notes and post-operative radiographs.

Patients' charts were reviewed for the following data: Age, sex, body mass index (BMI), mechanisms of injury (Sports Contact, Sports Non-Contact, Motor Vehicle Collision [MVC], Non-Sports related Fall, and Other), radiographs and advanced imaging, and time to surgery. Complications such as physeal/growth arrest, deformity of the ankle at follow-up, revisions/hardware removal, and infections were analyzed. Functional outcomes were obtained at a minimum of 1 year post-operatively and included the Oxford Ankle Foot Questionnaire for Children (OxAFQ-C) score, Single Assessment Numeric Evaluation (SANE) score, Visual Analog Scale (VAS) pain scores, and patient satisfaction. Satisfaction was set as a binary variable, with answers categorized as satisfied or dissatisfied.

Statistical analysis

Baseline patient characteristics, complications and functional outcomes were compared between groups. Statistical tests to evaluate differences included Fisher's Exact or Chi-squared and independent samples t or Mann Whitney tests for categorical and continuous variables, respectively. Normality assessments were conducted using the Kolmogorov-Smirnov test for all continuous variables. All statistical analyses were performed and reviewed by BH and IAI trained in these techniques using IBM SPSS Statistics V.27.0 (IBM Corp, Armonk, NY). The *P* value was set at < 0.05 for statistical significance. Results are reported as counts with corresponding percentages or means with standard deviation.

RESULTS

A total of 42 patients (28 females and 14 males) were included in the analysis. There were no significant differences in BMI, sex, age, or time-to-surgery between the groups (Table 1). Sports injuries accounted for 61.9% of all injuries, particularly non-contact (57.1%) and skating (28.6%) (Table 2). However, there were no significant differences between groups. A CT scan was ordered for 28 patients (66.7%), which led to 11 patients (26.2%) changing treatment plan from non-operative treatment to surgery, and the remaining led to the confirmation of surgical management.

Groups 1 and 2 consisted of 17 and 25 patients, respectively. Functional outcomes were available for 14 (82.4%) and 10 (40.0%) patients in groups 1 and 2, respectively. The average follow-up for the long-term outcomes was 3.5 (± 2.8) years. Statistical analysis revealed no statistically significant differences in functional outcomes between groups (Table 3). No infections, non-unions, physeal arrest, or post-operative ankle deformities were reported. Two patients had difficulty returning to sports post-surgery due to pain (1 from each group). One was a dancer, and the other patient had pain while running, which resulted in hardware removal. Hardware removal occurred for 4 and 5 patients in groups 1 and 2, respectively. The reason for removal was the persistence of pain in 2 patients (1 from each group), and parental preference in the remaining.

DISCUSSION

Our study assessed the functional outcomes of Tillaux fracture patients, and compared them based on screw fixation technique (oblique *vs* parallel). The results suggest no differences in the SANE, VAS and Oxford scores, or patient satisfaction. These findings support our hypothesis that there would not be any differences between the two groups.

The radiographic cutoffs for surgical or non-surgical management of Tillaux fractures is generally recognized as more than 2 mm of displacement or greater than 1 mm of translation[9]. Liporace *et al*[10] questioned the efficacy of CT scans in this patient population because the addition of CT scans did not

Table 1 Demographics

Variable	Total Sample (*n* = 42)	Oblique (*n* = 17)	Parallel (*n* = 25)	*P* value
Sex				
Female	28 (66.7)	13 (76.5)	15 (60.0)	0.27
Male	14 (33.3)	4 (23.5)	10 (40.0)	
Age (yr.)	13.5 ± 1.4	13.4 ± 1.7	13.6 ± 1.2	0.43
Body mass index (lbs/m^2)	26.3 ± 6.4	26.2 ± 4.5	26.4 ± 7.3	0.93
Time-to-surgery (d)	7.6 ± 9.6	6.9 ± 4.7	8.0 ± 11.8	0.38

Table 2 Mechanism of injury

Factor	Total sample (*n* = 42)	Oblique (*n* = 17)	Parallel (*n* = 25)	*P* value
Sports	26 (61.9)	11 (64.7)	15 (60.0)	1.00
Skating	12 (28.6)	7 (41.2)	5 (20.0)	0.17
Contact	3 (7.1)	1 (5.9)	2 (8.0)	1.00
Non-contact	24 (57.1)	10 (58.8)	14 (56.6)	0.86
Motor vehicle collision	0	0	0	-
Fall	10 (23.8)	3 (17.6)	7 (28.0)	0.49

Table 3 Functional outcomes

Variable	Oblique (*n* = 14)	Parallel (*n* = 10)	*P* value
SANE score (0-100)	90 ± 18.58	88.5 ± 16.3	0.86
Pain score (0-10)	1.8 ± 1.7	1.7 ± 1.9	0.61
Oxford score (0-100)			
Physical scale score	76.2 ± 20.6	82.5 ± 20.95	0.70
School and play scale score	91.5 ± 14.6	93.8 ± 13.5	0.67
Emotional scale score	91.5 ± 14.6	96.9 ± 7.9	0.36
Satisfaction			
Satisfied	13 (92.9)	10 (100)	1.00
Dissatisfied	1 (7.1)	0	

significantly change the impression of the amount of displacement per case. However, it did influence the decision to operate as seen in our cohort, as 40% of the patients who underwent CT scans were changed to surgical management.

During surgery, the fracture can be fixed with a screw in oblique or parallel orientation relative to the tibiotalar joint. The oblique fixation technique involves placing a screw directly through the Tillaux fragment and ending in the metaphysis, which violates the physis[6,11,12]. Lintecum *et al*[13] described a parallel fixation technique that involves placing a screw parallel to the tibiotalar joint, through the Tillaux fragment, and into the distal epiphysis. The rationale of this technique was to avoid interrupting the physis and subsequently, growth potential. However, Crawford *et al*[14] found that growth interruption rarely occurred in patients who underwent surgical fixation. Another case series has found that obliquely oriented screws did not lead to leg length discrepancy[15]. This is most likely due to imminent physeal closure and the fact that there is little remaining linear growth potential. Further, parallel screws are not ideal because they lead to increased pressure in the joint, fixation is not perpendicular to the physeal fracture line, and the all-epiphyseal trajectory is more challenging to achieve with fear of penetrating the articular cartilage due to proximity.

Charlton *et al*[7] showed in cadavers that parallel screw fixation led to a statistically significant increase of forces in the tibiotalar joint following fixation and that the increase in force disappeared following removal of the screw. Theoretically, increased joint pressures can lead to altered joint

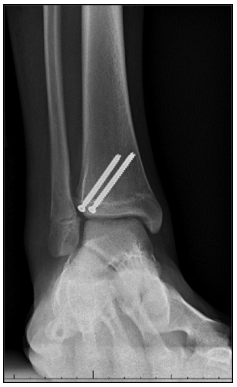

Figure 1 Oblique fixation of tillaux fracture.

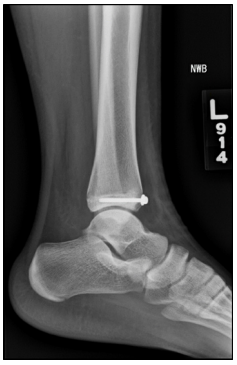

Figure 2 Parallel fixation of tillaux fracture.

biomechanics and associated complications such as arthritis over time. However, there are no long-term studies following surgical fixation of Tillaux fractures to prove this.

In normal ankle fractures, hardware removal is a controversial topic and generally left up to surgeon preference[16]. Some studies have shown negative outcomes with leaving in the screws[17], and Jung *et al* showed that functional outcomes and pain improve with removal[18]. The negative outcomes of parallel screw fixation could be avoided if an oblique screw trajectory led to less post-operative pain, decreased joint pressures and associated complications, and similar functional outcomes compared to parallel screw fixation. As the Tillaux fragment is avulsed from the anterolateral corner of the distal tibia, a parallel screw does not sit perpendicular to the fracture (Figure 1), which could lead to worse fixation compared to an oblique screw which could instead be placed perpendicular to the fracture line.

Multiple small studies have examined the functional outcomes of surgically treated Tillaux fractures and have found excellent outcomes[2,19-23]. These studies often consisted of a mixture of fixation techniques and did not compare between them. In a study of 7 patients treated with screw fixation (1 patient and 6 patients *via* open and closed reduction internal fixation, respectively), 6 had full and immediate recovery without complication with a mean Foot and Ankle score of 96.71 out of 100. One patient had pain and joint stiffness in the post-operative period with resolution following conservative management[21]. A study of 23 children with 2-5 mm of displacement following Tillaux fracture reported a mean Foot and Ankle Ability Measure of 91.2% following both open and closed reduction with no difference in outcomes between the two types of management[20]. Another study of 13 adolescent patients with Tillaux fractures treated with a 4 mm partially threaded cancellous screw directed horizontally into the epiphysis *via* anterolateral approach found radiographical evidence of fracture union in all cases (100%) and a mean Foot and Ankle Score of 97[6]. Another study of 6 children treated with screw fixation found that patients regained complete and painless ankle mobility after a follow-up of 5-7 months[19]. These studies show excellent outcomes but do not compare the two fixation techniques. The fact that most patients have excellent outcomes regardless of the fixation type was the basis of our hypothesis that the oblique screw is most likely an equivalent, if not better, option.

Pilla *et al*[15] demonstrated that oblique compression screw fixation in 10 patients with an average final follow-up of 15 months resulted in equal leg lengths and no angulation, joint stiffness, or limitations of activities. This study serves to disprove the notion that placing the screw across the physis will have adverse functional and leg length outcomes. Combined with our results of equal functional outcomes, it is evident that patients would only benefit from oblique screws due to previously mentioned reasons as opposed to negative outcomes. However, there is still no data on whether oblique

screws lead to increased joint pressures as do parallel screws. There is additionally no data on long-term complications, such as post-operative pain or arthritis, between groups. Our findings of equivalent functional outcomes between screw placement groups validates the need to obtain more information on long-term complications of oblique screw fixation in order to properly evaluate whether this method is equivalent or superior to parallel screw fixation.

Approximately 62% of the Tillaux fracture patients in our cohort were related to sports injuries, with 46% of these sports injuries resulting from skating accidents. We speculate that high and hard booted skates (hockey and roller) may provide a fulcrum at the level of the ankle that leads to increased risk of supination-external rotation type injuries, which is the most common mechanism leading to Tillaux fractures. One study that analyzed injuries sustained while rollerblading found that the ankle was involved in 10% (3rd most) of injuries[24]. All ankle injuries sustained involved a rotational mechanism, and supination-external rotation injuries were associated with high top skates. Thus, an activity that leads to extreme rotation about the ankle and/or a supination-external rotation moment increases the risk of a Tillaux fracture, especially in the appropriate age group[24]. Participation in skating sports and activities (street or ice hockey, roller-blading, roller-skating, *etc*.) is likely associated with an increased risk of Tillaux fracture compared to other sports.

Limitations of the study

The limitations of this study are that the patient numbers are relatively small which could lead to the study being underpowered. However, due to the rarity of the injury, our numbers are the largest reported in the literature for this type of comparison. The assignment of patients and perioperative complications were all based on a retrospective review of patient records, which leaves the opportunity for error and misinterpretation. While the type of surgical fixation performed was determined by individual surgeon preference, there was no standardized criteria for assigning patients to undergo either parallel or oblique fixation. [GRC1] In addition, we were only able to contact 57% of the patients for functional outcomes, but these limitations are shared among similar studies on this topic. Despite these limitations, this study is one of the largest studies on Tillaux fractures with mid to long-term outcomes. To our knowledge, it is the only study that has compared functional outcomes based on screw orientation techniques.

CONCLUSION

In comparing functional outcomes of different methods of screw fixation orientation to the physis, we concluded that there were no differences with a mean follow-up of 3.5 years. This suggests that the oblique fixation is equivalent to parallel fixation; however, more rigorous longitudinal[GRC1] studies are needed to assess long-term complications of oblique screw fixation to further prove superiority.

ARTICLE HIGHLIGHTS

Research background

Operative management of Tillaux fractures in adolescent patients is recommended for more than 2 mm of displacement or more than 1 mm of translation with screw fixation.

Research motivation

The efficacy, superiority and complications of trans-physeal *vs* all-physeal screw fixation have not been investigated in literature yet.

Research objectives

To compare outcomes of trans-physeal and all-epiphyseal screw fixation in management of Tillaux fractures in young patients.

Research methods

The patients were divided into group 1 (oblique screw fixation) and group 2 (parallel screw fixation). Patient characteristics and functional outcomes were compared between groups.

Research results

A total of 42 patients (28 females and 14 males) were divided into Groups 1 and 2, which consisted of 17 and 25 patients, respectively. Statistical analysis revealed no significant differences in the functional outcomes, pain scores, or satisfaction between groups.

Research conclusions

In young patients with Tillaux fractures, comparing functional outcomes of different methods of screw fixation orientation to the physis, showed no difference regarding functional outcomes.

Research perspectives

Based on our findings, oblique screws, which provide better compression of the Tillaux fracture, are recommended over parallel screws, which create more joint forces and require a more difficult screw trajectory.

FOOTNOTES

Author contributions: All the authors contributed appropriately and equally in the execution of the study and drafting of manuscript.

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ORIGINAL ARTICLE

Retrospective Study

Femoroacetabular offset restoration in total hip arthroplasty; Digital templating a short stem *vs* a conventional stem

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Abstract

BACKGROUND

Failure in restoring individual anatomy could be a reason for persistent functional limitations post total hip arthroplasty. Femoroacetabular offset (FAO) plays an important role in anatomic restoration, as loss of offset ≥ 5 mm is associated with altered gait and decreased functional outcome. Preoperative assessment by use of digital templating has shown to be a reliable method for sizing the components in total hip arthroplasty, and can show if anatomic restoration is achieved. In recent years, short stems are growing in popularity as it could allow better restoration due to more variety in placement.

AIM

To assess whether restoration of the FAO differs between a short or a conventional stem by use of digital templating. Additionally, association of the preoperative offset and caput-colllum-diaphyseal angle (CCD-angle) within restoration of both stems was investigated, and the reliability of measurements was assessed.

METHODS

A total of 100 standardized hip radiographs were used for digital templating. Restoration of FAO was classified into "restored" or "not restored", when a < 5 mm or ≥ 5 mm difference from baseline value presented, respectively. Differences between the two stems concerning proportions of correct restoration of the FAO were analyzed by use of McNemar tests. To assess association between CCD-angle and preoperative FAO with absolute FAO restoration, multi-level analysis was performed by use of a linear mixed model to account for paired measurements. Through determination of the optimal point under the curve in operating curve-analysis, bootstrapping of thousand sets was performed to determine the optimal cutoff point of the preoperative FAO for restoration within

the limits of 5 mm. Three observers participated for inter-observer reliability, with two observers measuring the radiographs twice for intra-observer reliability.

RESULTS

The mean preoperative FAO was 79.7 mm (range 62.5-113 mm), with a mean CCD-angle of 128.6° (range 114.5°-145°). The conventional stem could only restore the FAO in 72 of the cases, whereas the short stem restored the FAO in all cases. CCD-angle was not a predictor, but the preoperative FAO was. A cut-off point of 81.25 mm (95% confidence interval of 80.75-84.75 mm) in preoperative FAO was found where the conventional stem was unable to restore the FAO. Reliability of measurements was excellent, with an intra-observer reliability of 0.99 and inter-observer reliability in baseline measurements higher than 0.9 between the three observers.

CONCLUSION

In preoperative planning of FAO restoration in total hip arthroplasty, digital templating shows that short stems with a curve following the medial calcar are potentially better at restoring the FAO compared to conventional stems if the preoperative offset is ≥ 80.0 mm.

Key Words: Offset; Anatomic offset restoration; Total hip arthroplasty; Short hip stem; Conventional hip stem

Core Tip: This is a retrospective study, consisting of digital templating a short stem and conventional stem in the same X-ray of the hip to see if there is a difference in restoring the femoroacetabular offset. We found that in a larger femoroacetabular offset (> 80 mm) the short stem could provide better restoration when compared to a conventional stem.

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INTRODUCTION

In recent years, failure of anatomical restoration has gained more attention as a reason for persistent complaints after total hip arthroplasty (THA). Despite considerable improvement, up to 22% of the patients experience functional limitations in daily life[1-4]. Since there has been an increase of young and active patients receiving THA, who have higher expectations of their functional outcome[4,5], excellent results are needed. Nowadays, there is more focus on anatomical restoration as related to clinical outcome[6]. An important part of accurate anatomical reconstruction is a restored femoroacetabular offset (FAO). A loss of ≥ 5 mm between the preoperative offset and postoperative offset is associated with altered gait and decreased functional outcome[7,8]. Restoration of offset improves hip stability, range-of-motion, abductor function and reduced wear[9-13].

Conventional stems are the most common choice for elective THA, due to the amount of experience in placement of these stems and good long-term results. However, individual anatomy can hinder proper femoral offset restoration as the diaphyseal anchorage of this type of stem limits placement options. Short hip stems were designed for preservation of proximal bone stock, but it seems that anatomical restoration is also achievable with short stems. As there are many different designs, short stems can be classified based on osteotomy or anchoring principle. Metadiaphyseal anchoring short stems allow for excellent restoration of individual anatomy[6,14,15], as the placement of these curved short stems can be angled in the desired position to follow the natural curvature of the medial calcar. Due to this feature, it mimics the physiological load transfer on the proximal femur[16,17].

For correct placement of the hip stem, digital 2d-templating is common clinical practice and is a reliable method to estimate the correct size of hip stems prior to surgery[18-21]. It provides information on the level of osteotomy, insight on the probable size of components, and whether anatomical restoration can be achieved.

The primary aim of this study was therefore to see if the FAO could be restored by use of preoperative digital 2d-templating with a short metadiaphyseal anchoring stem and a conventional stem, within a wide range of anatomical hip variations. The secondary aim was to examine the

association of secondary measurements required for digital templating, such as the caput-colllum-diaphyseal angle (CCD-angle) and preoperative offset, with offset restoration. Additionally, the intra- and inter-observer reliability of the measurements by use of digital 2d-templating was investigated, as there is limited data on this particular subject and its reliability[21,22].

MATERIALS AND METHODS

Patients

One hundred standardized preoperative hip measurement radiographs of patients were included, with primary or secondary osteoarthritis as indication for THA. The radiographs were randomly chosen from two ongoing cohorts, the Optimys trial (Mathys Ltd, Bettlach, Switzerland) and the CBH trial (Mathys Ltd, Bettlach, Switzerland). Fifty radiographs were randomly selected from either cohort, creating a variability in coxa norma, vara and valga. If preoperative measurement radiographs were missing, containing a magnification marker for determination of the amount of magnification used, these radiographs were excluded. Approval for inclusion has been attained from the medical ethics review committee, under registry numbers NL47055.048.13 and NL48211.048.14.

Radiological evaluation

Standardised preoperative hip radiographs with magnification marker were used for 2D-digital templating. An internal rotation angle of 20° was used to produce the full profile of the femoral neck on anteroposterior radiography[23,24]. Computer-assisted measurements and 2d-templating were performed by use of Orthoview (Materialise NV, Leuven, Belgium)[25,26].

Pre-templating FAO was measured by first determining the femoral offset, defined as the distance of the longitudinal axis of the femur to the center of rotation. The longitudinal axis was determined from a 4-point box in the intramedullary cavity of the femur. The acetabular offset was determined next, defined as the distance from the center of rotation to the lateral edge of the pelvic teardrop[6,23,24,27-29]. The CCD-angle was used to identify the difference in hip-anatomy, *i.e.*, to identify if patients had a coxa vara (< 120°), coxa norma (120°-135°) or coxa valga (> 135°).

Digital templating of the short and conventional stem was then performed, with the cup as fixed factor in both images. The variables were measured again after templating, with femoral offset now being defined as the distance from the longitudinal axis of the femur to the center of rotation of the prosthetic head. The post-templating acetabular offset was defined as the distance from the center of rotation of the cup to the lateral edge of the pelvic teardrop (Figure 1).

Radiological measurements and templating were performed independently by three observers. To assess intra- and inter-observer reliability, the measurements were performed twice by a medical student (Verboom T) and by a resident in orthopaedic surgery (de Waard S), and once by an experienced orthopaedic hip surgeon (Haverkamp D).

Implants

Implants used for templating in this study were the CBH as the conventional stem and the Optimys as the short stem. In both cases the RM Pressfit Vitamys (Mathys Ltd, Bettlach, Switzerland) cup was used. The CBH is a widely used conventional press fit hip stem with a diaphyseal anchorage. Since the CBH hip stem follows the longitudinal femoral axis, femoral offset can only be increased (after determining the correct stem size) by choosing a larger head size and/or a lateral neck.

The Optimys is a short press fit hip stem, which anchors in the metadiaphyse. The shape of the Optimys follows the curvature of the medial calcar and can be placed into varus or valgus position, allowing to increase or decrease the femoral offset as needed. Also, extra femoral offset can be given with head size and a lateral neck.

Statistical analysis

Patient characteristics and outcome variables are described as means with ranges or frequencies with accompanying percentages. Restoration of FAO was dichotomized into "restored" when < 5 mm from baseline or "not restored" when ≥ 5 mm from baseline[7,30]. Differences between the short stem and the conventional stem concerning the proportions of correct restoration of the offset were analyzed by use of McNemar tests. To assess the association between absolute offset restoration and both CCD-angle and preoperative offset, multi-level analyses were performed by use of linear mixed model to account for paired measurements for both hip stems. In case of effect modification of stem type, linear regression analyses were performed for each stem separately. A P value < 0.05 was considered statistically significant.

For the determinants that were significantly associated with offset restoration (CCD-angle or preoperative offset), an operating curve (ROC) -analysis was performed to determine the optimal cutoff point of this independent variable for restoration within the limits of 5 mm. To provide a 95 % confidence interval (CI), bootstrapping procedure was performed. By using a 1000 bootstrap samples

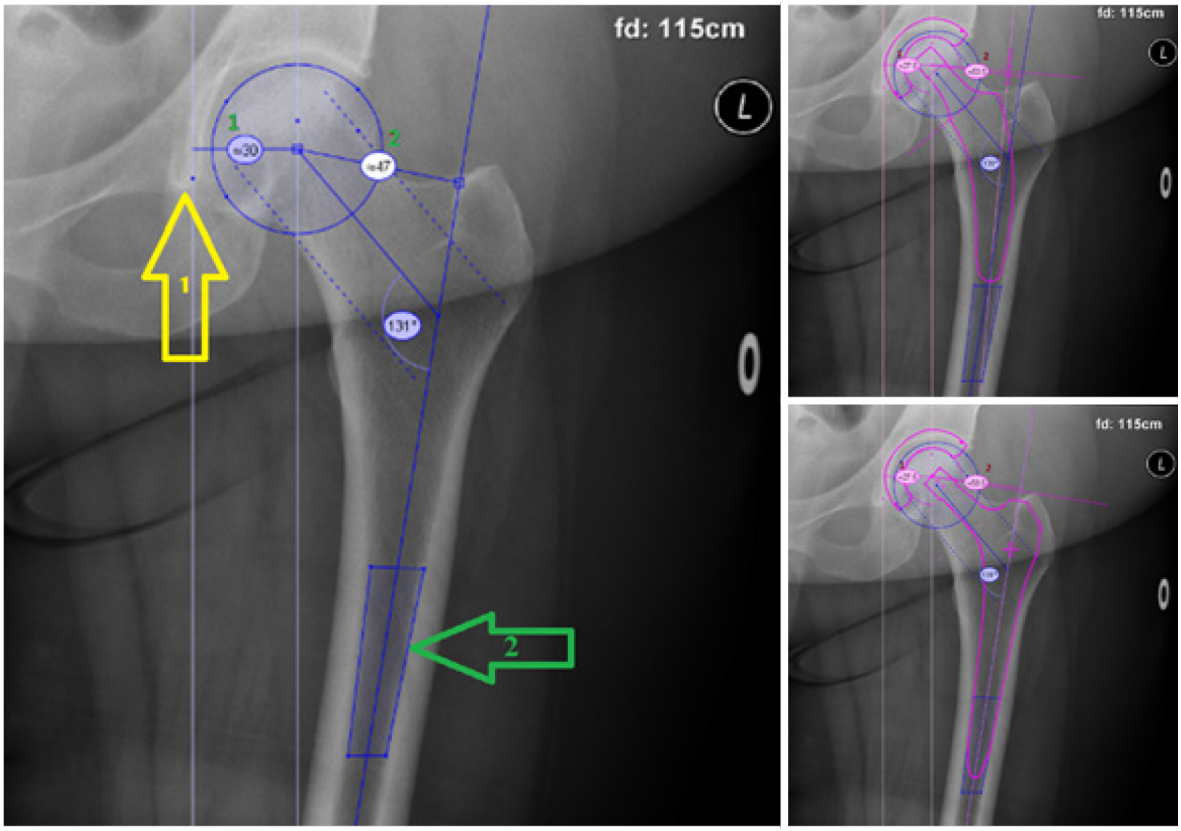

Figure 1 Measurements in digital templating before and after hip stem placement. Arrow 1: Teardrop. Arrow 2: Femoral axis determination box. Line 1: acetabular offset. Line 2: femoral offset.

and calculating their respective cut-off values, the Standard Error was obtained to acquire the 95 %CI of the optimal cut-off point. Accompanying area under the curve (AUC) was calculated as measure of accuracy.

Additionally, to assess inter-observer and intra-observer reliability, intra-class correlation coefficients ($ICC_{2,1}$) were calculated. Statistical analysis was performed using IBM SPSS Statistics, version 24.0 (Armonk, NY: IBM Corp.).

Sample size

A pilot study was performed where 20 radiographs were randomly chosen and evaluated, in which 30% of conventional stems had more than 5 mm loss in FAO. Based on a 10% difference with the short stem being clinically relevant, a sample of 89 radiographs was required to identify superiority of the short stem in FAO restoration when compared to the conventional stem, with an a = 0.05 and a power of 90%. A total of 100 radiographs were included in this study.

RESULTS

Patient characteristics

Radiographs in a total of 100 patients were included, 72 were female. A mean age of 67 years was found, with a mean BMI of 27. Almost all patients were diagnosed with primary coxarthrosis. The mean preoperative FAO was 80mm, with a CCD-angle of 128.6° (Table 1).

Restoring FAO

The short stem reached a post-templating difference of < 5 mm in FAO in all cases (100%) for both student and resident, whereas the conventional stem only achieved this in 76% and 72% of the radiographs for student and resident, respectively. The difference in FAO restoration was significant (P < 0.001), in benefit of the short stem compared to the conventional stem. A varus hip showed a failure rate of 14.3% (n = 4/24) of the non-restored hips, while a valgus hip showed no failure at all (Figure 2).

Significant interactions (P < 0.001 for all analyses) were observed between the stems and the determinants (CCD-angle and preoperative FAO), therefore analyses of the stem types were performed separately. Significant association of the CCD-angle and pre-templating FAO with the FAO restoration

Table 1 Patient and radiological characteristics

Patient characteristic	(*n* = 100)
Female, %	72
Age, mean (range)	66.7 (41-90)
BMI, mean (range)	27.3 (18.7-42.8)
Right hip, %	54
Indication, %	
Primary coxarthrosis	98
Perthes coxarthrosis	1
Posttraumatic coxarthrosis	1
Femoral offset (mm), mean (range)	47 (30.5-67)
Acetabular offset (mm), mean (range)	32.5 (22.5-47.5)
Femoro-acetabular offset (mm), mean (range)	80 (62-113)
CCD-angle (°)	128.6 (114.5-146)

CCD angle: Caput-colllum-diaphyseal angle; CI: Confidence interval.

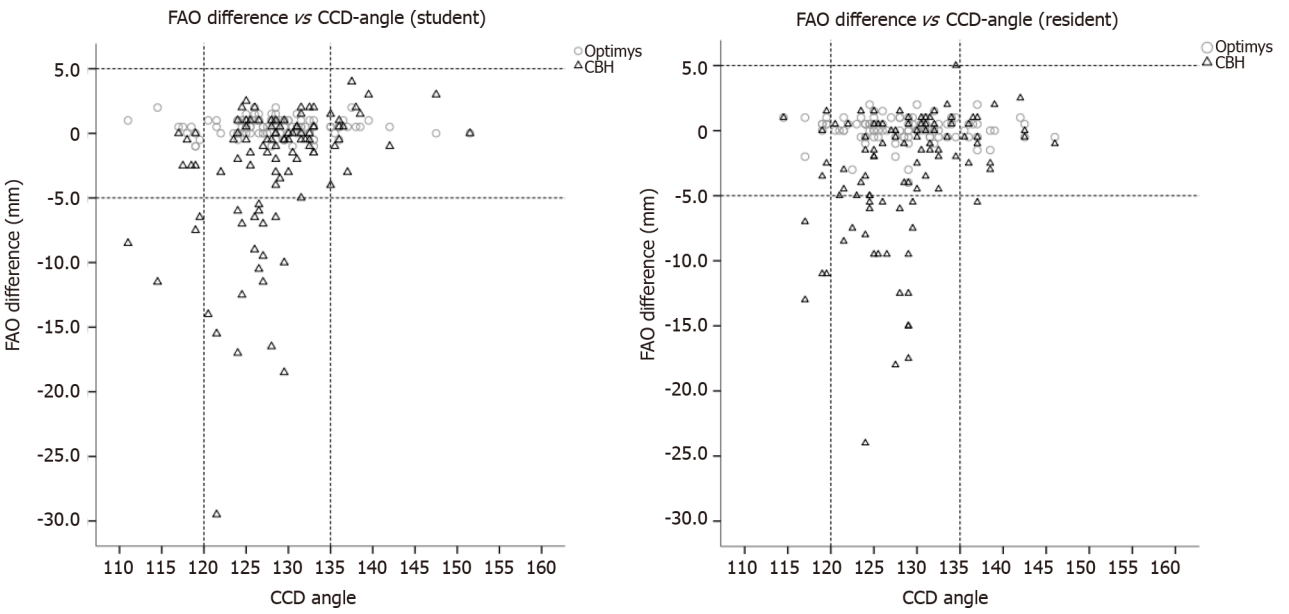

Figure 2 Femoroacetabular offset difference *vs* caput-colllum-diaphyseal angle for student and resident. Reference lines for varus (< 120°) and valgus (> 135°) angles. CCD: Caput-colllum-diaphyseal angle; FAO: Femoroacetabular offset.

was only observed for the conventional stem, with the highest explained variance for the pre-templating FAO of 68% (Table 2).

An FAO of more than 81.25 mm showed a failure in 79% of the templated conventional stems with the resident, compared to the student with a failure rate of 76% above 80.5 mm. A negative trend-line in FAO restoration is seen as the pre-templating FAO increases by both student and resident (Figure 3). For a correct cut-off point for failure in the conventional stem, bootstrapping was performed for a ROC-analysis for the pre-templating FAO with a restoration within 5 mm. The CCD-angle was not used for bootstrapping, as the AUC was smaller than 0.5. After bootstrapping the measurements of the resident, the optimal threshold of the pre-templating FAO was 81.25 mm (95%CI: 80.75-84.75), above which the conventional stem could not restore the FAO (Figure 1), with a sensitivity of 0.96, specificity of 0.79, and an AUC of 0.94.

Post-templating femoral and acetabular offset

The results of the post-templating measurements are shown in Table 3. The short stem restored the

Table 2 Determinants correlated with offset restoration

	β coefficient (95%CI)	R^2	*P* value
Student			
CCD-angle (short stem)	-0.01 (-0.03, -0.02)	0.002	0.62
CCD-angle (conventional stem)	0.34 (0.18, 0.50)	0.15	< 0.001
Pre-templating FAO (short stem)	-0.004 (-0.02, 0.01)	0.002	0.62
Pre-templating FAO (conventional stem)	-0.45 (-0.53, -0.38)	0.63	< 0.001
Resident			
CCD-angle (short stem)	-0.01 (-0.04, 0.02)	0.004	0.55
CCD-angle (conventional stem)	-0.25 (-0.10, 0.41)	0.09	0.002
Pre-templating FAO (short stem)	-0.02 (-0.04, 0.00)	0.03	0.05
Pre-templating FAO (conventional stem)	-0.44 (-0.50, -0.38)	0.68	0.000

FAO: Femoroacetabular offset; CCD angle: Caput-colllum-diaphyseal angle; CI: Confidence interval.

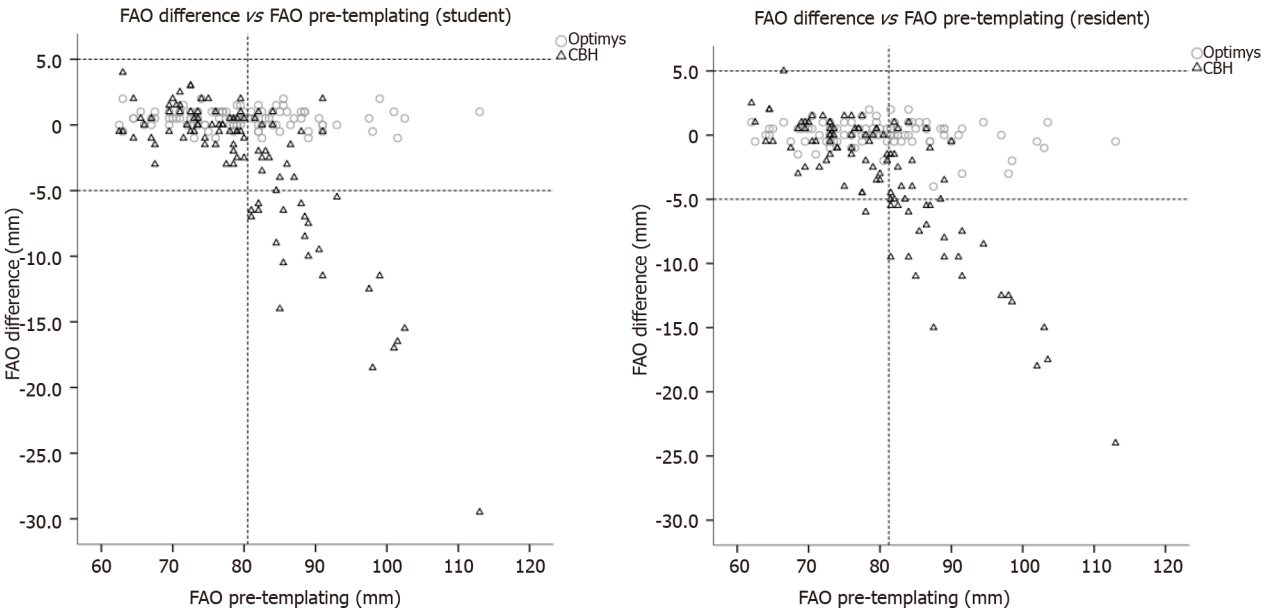

Figure 3 Femoroacetabular offset difference *vs* femoroacetabular offset pre-templating for student and resident. Reference line at cutoff point of 80.5 mm pre-templating Femoroacetabular offset (FAO) for the student, reference line at cutoff point of 81.25 mm pre-templating FAO for the resident. FAO: Femoroacetabular offset.

femoral offset in all cases, whereas the conventional stem restored the femoral offset in 91% of the cases. There was a mean decrease of acetabular offset of -4 mm.

Intra-observer reliability and inter-observer reliability

The intra-reliability of the student and the resident was both 0.99 for the pre-templating FAO. All other reliability scores were > 0.9 for both the student and the resident. Compared to the hip surgeon in pre-templating FAO, the inter-observer reliability was 0.93 and 0.95, between the student *vs* hip surgeon and resident *vs* hip surgeon respectively (Tables 4 and 5).

DISCUSSION

The goal of this study was to determine whether a metadiaphyseal anchoring short stem potentially facilitated a better restoration of FAO in digital templating compared to a conventional hip stem. The FAO was taken as primary measurement and not the femoral offset, as the acetabular offset can decrease postoperative due to medial placement of the acetabular component[31]. Therefore, the

Table 3 Post-templating measurements of radiographs (*n* = 100)

	Short stem	Conventional stem
Post-templating measurements		
Femoral offset (mm), mean (range)	51.5 (3679)	48 (3757.5)
Acetabular offset (mm), mean (range)	28.5 (23.535.5)	28.5 (23.535.5)
Femoro-acetabular offset (mm), mean (range)	80 (62112.5)	76.5 (63.589.5)
Difference pre- and post-templating		
Femoral offset (mm), mean (range)	4 (-2.513)	1 (-11.511)
Acetabular offset (mm), mean (range)	-4 (-142.5)	-4 (-142.5)
Femoro-acetabular offset (mm), mean (range)	0 (-42)	-3 (-245)
Restoration of femoral offset, %	100	91
Restoration of femoro-acetabular offset, %	100	72

Table 4 Intra-observer reliability

	Student	Resident
Pre-templating FAO	0.99	0.99
Post-templating FAO short stem	0.98	0.98
Post-templating FAO conventional stem	0.92	0.93
CCD-angle	0.93	0.94

FAO: Femoroacetabular offset; CCD angle: Caput-colllum-diaphyseal angle.

Table 5 Inter-observer reliability

	Student *vs* Resident	Student *vs* Hip surgeon	Resident *vs* Hip surgeon
Pre-templating FAO	0.98	0.93	0.95
Pre-templating FO	0.97	0.93	0.94
Pre-templating AO	0.97	0.91	0.92
Post-templating FAO short stem	0.97	0.93	0.95
Post-templating FAO conventional stem	0.90	0.84	0.86
CCD-angle	0.87	0.81	0.76

FAO: Femoroacetabular offset; CCD angle: Caput-colllum-diaphyseal angle.

femoral offset must increase additionally to compensate for the loss in acetabular offset or the cup must be placed more lateral. How the acetabular component is placed varies per orthopedic surgeon. However, the acetabular cup used in this study showed an average decrease of 3.7 mm in acetabular offset in literature[32,33]. In this study there was a decrease in acetabular offset of 4 mm, which is comparable to the other studies. The FAO restoration rate within 5 mm limits for the short stem was achieved in all cases, whereas the conventional stem achieved a restoration rate of 72% (resident) and 76% (student) during digital templating. The pre-templating FAO was associated with failure in FAO restoration when using the conventional stem, as pre-templating FAO values > 81 mm had a non-restoration rate of 60% in this group. The cutoff value was determined to use for a future reference standard, as it could provide a cutoff point if clinical relevance is shown. The cutoff point of 80 mm for pre-templating FAO was chosen conservatively, at the found cutoff value (81.25 mm), because of the rapid decrease in restoration rate beyond these points, to account for variance in the general population. The CCD-angle was not clinically relevant for FAO restoration, nor was the pre-templating FAO clinically relevant for the short stem. While it was expected that varus hips would comprise the majority of hips where a conventional stem would prove insufficient in FAO restoration, this was only observed

in 14% (n = 4/24) of the cases. While it stands to reason that a varus angle would increase femoral offset, a varus hip is not the primary reason for failure of FAO restoration. There was no difference in FAO restoration between both stems in valgus hips. Since there is no prior data on this specific subject, these results cannot be compared to other studies.

The short stem used in this study is a metadiaphyseal anchoring stem, with a curved design. It is to be expected that other similar designs are capable to restore the FAO in the same manner, which has previously been shown with the Nanos stem (Smith and Nephew, Marl, Germany)[15]. During surgery, the resection of the femoral neck determines for a large part the placement of the hip stem. In varus hips, a smaller part of the femoral neck will be resected for optimal placement as compared to valgus hips. Thus, a short stem thus can be neck preserving or trochanter sparing, depending on the anatomy of the patient. This is the main reason why the FAO can be restored within the 5 mm limit. Metaphyseal stems are not comparable to our outcomes, due to stem design differences.

Conventional hip stems are anchored in the diaphysis, where placement variability is limited and increasing femoral offset is only facilitated by using a larger head size or a lateral neck. Due to this rigidity in placement options, the results of this study can be interpreted for all conventional hip stems. Conventional stems can be placed into a varus position using smaller stem size, resulting in an increased femoral offset. However, long term survival could be compromised due to increased stress on the tip of the prosthesis. Therefore, this manner of placement is not recommended. In the results between the experienced hip surgeon and resident and medical student, the ICC values were lower for the conventional stem than expected. However, the hip surgeon was inclined to sooner place the conventional stem into a varus position, restoring the FAO better than the resident and medical student.

The high level of inter- and intra-observer reliability is indicative of high accuracy and reproducibility of the measurements. This reliability has also been shown in other templating studies[21,29,34,35], along with a high predictive value for prosthesis placement[6,21]. The found cutoff point may, after further clinical research, be a reason to introduce digital 2d-templating as a tool for stem type selection in combination with clinical considerations. Also, this study shows that preoperative templating can be performed reliably by medical students and orthopedic residents, after a learning curve.

There were some limitations to this study. Firstly, 2d-templating was used to measure 3-dimensional distances, which may cause underestimation of femoral offset and modification of CCD-angles[28,34]. However, radiographic 2d-templating is the method of choice for the majority of hip surgeons due to cost, radiation load, availability and has been shown to be similar in reliability and accuracy to 3d-templating with use of computed tomography[36]. The CCD-angle modification from 2d-templating may have been disadvantageous to the assessment of the CCD-angle as a predicting factor for FAO restoration. Secondly, other characteristics of the femoral canal were not examined in this study. The Dorr classification could help decide on type of femoral stem chosen for the surgery[37]. A Dorr type A with a large offset would be very difficult for a conventional stem to restore the offset, whereas a Dorr type C could lead to inadequate fixation of a short stem.

Another limitation is the fact that no postoperative measurements were done, which means that the results cannot be directly translated to clinical practice. However, the short stem was able to restore the FAO postoperative in the study of Kutzner *et al*[6] and recent studies showed that preoperative digital 2d-templating assured a satisfying restoration of the individual anatomy in short stems[22,26,38].

An advantage in usage of conventional stems over short stems is that there are many available studies with long-term outcomes, while these are only limited for short stems. It may also be preferable to use conventional stems in patients with suboptimal bone quality, as there is a lower load per hip stem surface unit due to the larger diaphyseal anchoring area. Theoretically, short stems could lose initial press-fit in softer bone with a higher chance on subsidence, increasing the risk of implant instability or periprosthetic fractures. Especially in older patients, the advantage of short stems, *i.e.*, preservation of proximal bone stock, is less important and not worth the risk for potentially increasing the risk of complications. Another topic is the costs of hip stems. Conventional stems are less expensive than short stems, which is also relevant once all clinical factors have been properly considered.

The advantage in FAO restoration in this study may contribute to the use of short stems in a broadened patient group with hips with a large offset. Clinical trials will have to show whether the improved restoration in FAO will grant the expected improved functional. Other reasons to choose conventional stems over short stems still may have priority over the advantage found in this study.

CONCLUSION

In preoperative planning of FAO restoration in THA, digital templating shows that short stems with a curve following the medial calcar are potentially better at restoring the FAO compared to conventional stems if the preoperative offset is ≥ 80.0 mm.

ARTICLE HIGHLIGHTS

Research background

The following steps that are necessary to take are the postoperative measurements of the short stem to see if the offset can be restored. Also, a pilot study with gait measurements in a case-matched study of patients with either a short or conventional stem will help to define if there is a difference.

Research motivation

If the native offset was > 80 mm, the short stem was better at restoring FAO than the conventional stem in digital templating. This could indicate that there is a specific patient population that could benefit if a short stem with a curve is chosen as femoral stem instead of the conventional stem.

Research objectives

A FAO more than 80mm showed a large failure rate in restoration in the conventional stems, whereas the short stem could restore the offset in all cases. The reliability of all measurements were good between in both inter- as intra-reliability, with no difference in experience.

Research methods

Digital templating in a standardized X-ray of the hip were used from two ongoing cohorts, varying in hip anatomy. Orthoview was used as digital templating program. Pre-templating FAO was measured, as well as post-templating FAO measurements in the short and conventional stem. The results were divided into restored (< 5 mm difference in offset) or not-restored (> 5 mm difference in offset).

Research results

Primary objective was the femoroacetabular offset restoration in all types of hip anatomy between a short and conventional hip stem, where the acetabular component is used as a fixed parameter. Second objectives were the reliability of the measurements.

Research conclusions

As digital templating is a reliable tool for measuring component sizes in total hip arthroplasty, this is used as measurement to see if there is a difference between a short and conventional hip stem in a wide range of hip anatomy.

Research perspectives

Short stems are gaining popularity, as one of the possible advantages is the restoration of offset. Offset restoration improves functional outcome. This could benefit the younger patient population, as they have higher expectations of their total hip arthroplasty in their more active lifestyle.

FOOTNOTES

Author contributions: de Waard S, Verboom T, Bech NH, Kerkhoffs GM, Haverkamp D drafted the manuscript; de Waard S and Haverkamp D did the measurements; Sierevelt I performed the statistical analysis, de Waard S assisted with data analysis; Sierevelt I, Haverkamp D participated in study design; Kerkhoffs GM and Haverkamp D participated in oversight of the study.

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ORIGINAL ARTICLE

Clinical Trials Study

Periprosthetic joint infections in femoral neck fracture patients treated with hemiarthroplasty – should we use antibiotic-loaded bone cement?

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Abstract

BACKGROUND

Hemiarthroplasty is the most common treatment in elderly patients with displaced intra-capsular femoral neck fracture (FNF). Prosthetic joint infection (PJI) is one of the most feared and frequent complications post-surgery because of the frail health status of these patients and the need for fast track surgery. Therefore, priorities should lie in effective preventive strategies to mitigate this burden.

AIM

To determine how much the implementation of the routine use of antibiotic-loaded bone cement (ALBC) as a relatively easy-to-apply amendment to the surgical practice reduces the infection rate in our hemiarthroplasty cohort.

METHODS

We retrospectively assessed all demographic, health status and treatment-related

data of our FNF patients undergoing cemented hemiarthroplasty in the period from 2011 to 2017; 241 patients were further analyzed after exclusion of patients with cancer-related sequelae and those who died before the end of the 1-year observation period. The PJI rate as diagnosed on basis of the Musculoskeletal Infection Society (MSIS) criteria 2011 was determined for each included patient and compared in function of the bone cement used for hip stem fixation. Patients were split into a group receiving a plain bone cement in the period from January 2011 to June 2013 (non-ALBC group) and into a group receiving an ALBC in the period July 2013 to December 2017 (ALBC group). Data analysis was performed with statistical software. We further calculated the cost-efficacy of the implementation of routine use of ALBC in the second group balancing the in-hospital infection related treatment costs with the extra costs of use of ALBC.

RESULTS

In total 241 FNF patients who received cemented hemiarthroplasty in the period from January 2011 to January 2017 were eligible for inclusion in this retrospective study. There were 8 PJI cases identified in the ALBC group among n = 94 patients, whereas 28 PJI cases were observed in the non-ALBC group among n = 147 patients. The statistical analysis showed an infection risk reduction of 55.3% (in particular due to the avoidance of chronic delayed infections) in the ALBC group (95%CI: 6.2%-78.7%; P = 0.0025). The cost-evaluation analysis demonstrated a considerable cost saving of 3.500 € per patient, related to the implementation of routine use of ALBC in this group.

CONCLUSION

Use of ALBC is a potent infection preventive factor in FNF patients receiving cemented hemiarthroplasties. It was further found to be highly cost-effective.

Key Words: prosthetic joint infection; Femoral neck fracture patients; Hemiarthroplasty; Antibiotic-loaded bone cement; Prophylaxis; Cost-efficacy

Core Tip: Routine use of antibiotic-loaded bone cement in cemented hemiarthroplasties of femoral neck fracture patients has the potential of reducing the infection risk to a significant degree. This measure should be considered on top of the implementation of strict protocols of special pre-, peri- and postoperative orthogeriatric care

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INTRODUCTION

Prosthetic joint infection (PJI) is a rare but very dreadful complication of arthroplasty. The incidence is typically in the range of 1%-2% after primary elective joint replacement[1], but easily surpasses 5% in the elderly population of femoral neck fracture (FNF) patients undergoing hemi- or total hip arthroplasty[2]. This high infection rate reflects the fragile health conditions of such patients being on an emergency surgery track and their often suboptimal pre-, peri- and postoperative care. It is expected that the FNF patient numbers will grow significantly in our ageing societies causing high socioeconomic costs and a high burden of morbidity and mortality[3]. In order to mitigate the high risk of complications occurring in this patient cohort, it is therefore mandatory to consider amendments to the routine surgical protocols. This also includes more potent preventive strategies for infections.

The prophylactic use of antibiotic-loaded bone cement (ALBC) is a frequent surgical practice in cemented hip and knee joint replacement aiming at reducing the risk of procedure related infections. The idea behind delivering antibiotics directly into the joint compartment was originally pioneered by Buchholz and Engelbrecht in 1969. They reported high initial peak concentrations of the antibiotic eluted in situ from bone cement which was found to exceed 100-1000 fold the minimum inhibitory concentration (MIC) of the pathogen in the first days without exposing the patient to major risks of side effects[4,5]. Systemically applied antibiotics, by contrast, often do not reach effective concentration

levels in the osteoarticular compartment as a consequence of reduced blood flow in inflamed tissue and limited bone penetration of many antibiotics[6]. Indeed, by implementing this additional prevention measure Buchholz achieved an impressive reduction in deep infections in both, primary and revision hip replacements[7]. Subsequently, the Scandinavian registries and – most recently - the National Joint Registry of UK have demonstrated that the additional use of ALBC to perioperative systemic prophylaxis reduces the revision risk in cemented joint replacement[8-10]. It can be further speculated that this effect might vary if specific cement brands were compared due to brand-specific differences in antibiotic elution as a function of their special polymer contents and porosities[11,12]. Although one would expect from these experiences in elective procedures that hemiarthroplasty patients might benefit equally or even more from additional local antibiotic prophylaxis, data in this patient group are still sparse. To the best of our knowledge there is also no cost evaluation available in fracture patients which calculated the treatment costs of hemiarthroplasty related infections against the extra costs of ALBC use instead of plain cement.

In view of the very high numbers of PJI cases which we observed in the past in our hemiarthroplasty patients we decided to assess the infection preventive effect of the implementation of routine ALBC use for our cemented hemiarthroplasties. By comparing the infection rate before and after this surgical protocol modification we wanted to address the following questions in form of a retrospective clinical study: (1) *(Primary endpoint of the study)* Does the implementation of ALBC instead of plain cement as standard for hip stem fixation reduce the infection rates in this frail patient cohort? (2) Do we observe the highest protective effect, if we switch to an ALBC brand which has been described as a superior antibiotic eluting polymer matrix[13,14]? (3) What is the influence of individual patient risk factors and parameters on the occurrence and course of PJI cases; and (4) *(Secondary endpoint of the study)* Is the implementation of routine use of ALBC cost-effective?

For this purpose we retrospectively analyzed the patients and compared the PJI rate in those hemiarthroplasty procedures which had been cemented in the period from 2011 to 2013 with the plain bone cement Cemex with the PJI rate of those procedures which had been cemented in the subsequent period 2013 to 2017 with the gentamicin loaded bone cement Palacos R+G.

MATERIALS AND METHODS

This study (study approval number 35/17 NoEPA by Hospital Ethical Committee) analyzed all hip fracture patients treated at the University Hospital Central de la Defensa Gómez Ulla in Madrid, Spain, in the period from 2011 to 2017. Patient data and clinical histories were available on paper or in electronic form in the hospital IT program Balmis® (Hewlett Packard, Spain). In total 427 patients with diagnosis of hip fractures were reported. Of these 72 were excluded because of osteosynthesis treatment, 114 patients were further excluded because of periprosthetic or oncologic fractures or because of premature death before completing the 1-year observation period. Finally, 241 patients with intracapsular neck of femur fractures who went on to have cemented hemiarthroplasty either with a mono- or with a bipolar prosthesis in this period were found eligible for study inclusion. All interventions were performed by the same team of surgeons and the same surgical access route to the femur (direct lateral or Hardinge access route). The preoperative parental antibiotic prophylaxis was administered in the following way: either administration of 2 g of cefazolin, initiated 60 min before incision, or administration of 1 g of vancomycin, respectively, in case of contraindications or allergy against cephalosporins. In total 3 additional shots of 1 g of cefazolin, each one in an interval of 8 h, or 1 g of vancomycin, each one in an interval of 12 h, respectively, were administered postoperatively.

The hemiarthroplasty prosthesis used in all patients of this study was the brand Multifit Integrated System® with monopolar Ellittica® head or the bipolar prosthesis head SBA® (both Samobiomedical, Italy). The bone cement used for stem fixation in the period from January 2011 until June 2013 was the antibiotic-free brand Cemex (Tecres Spa, Italy) of high viscosity, mixed under atmospheric conditions and retrogradely injected with aid of a gun. The bone cement subsequently used in the period from July 2013 until the end of the study in December 2017 was the 0.5 g gentamicin containing high viscous cement Palacos R+G (Heraeus-Medical, Germany), prepared in a vacuum-mixing system and retrogradely injected under pressure with aid of a gun.

The following patient data were collected from the files: age, sex, type of intracapsular femur fracture according to the Garden classification, type of trauma (low or high energy impact), form of arrival to the emergency department at the hospital (self-walking, in vehicle of relatives, by ambulance or transfer from another health institution). Presence of risk factors for infections were recorded including inflammatory arthropathies, degree of immunosuppression, diabetes mellitus, previous articular infection, malnutrition, hemophilia and presence of tumors. The health status of all patients was assessed using the American Society of Anesthesiologists (ASA) score, the degree of mobility was assessed according to the Functional Ambulation Category (FAC) score and the Barthel Functional (BF) index for activities of daily living was used to evaluate the level of functional independence. The diagnosis of acute or delayed periprosthetic infections within the observation period of 1 year was done on basis of the MSIS criteria 2011[15] (see Table 1). All data were collected in a Microsoft Excel® speadsheet in strict

Table 1 Criteria for diagnosis of periprosthetic joint infection according to the Musculoskeletal Infection Society Workgroup[15]

PJI exists when
(1) There is a sinus tract communicating with the prosthesis; or (2) A pathogen is isolated by culture from at least two separate tissue or fluid samples obtained from the affected prosthetic joint; or (3) Four of the following six criteria exist: (a) Elevated serum erythrocyte sedimentation rate (ESR) and serum C-reactive protein (CRP) concentration; (b) Elevated synovial leukocyte count; (c) Elevated synovial neutrophil percentage (PMN%); (d) Presence of purulence in the affected joint; (e) Isolation of a microorganism in one culture of periprosthetic tissue or fluid; or (f) Greater than five neutrophils per high-power field in five high-power fields observed from histologic analysis of periprosthetic tissue at 9400 magnification.

PJI: Periprosthetic joint infection.

anonymous form and analyzed using the statistical software package of SPSS®, version 15 (SPSS Inc., Chicago, IL, United States).

We further performed a cost-evaluation in which we compared across both study arms the overall product related costs as well as the costs related to the surgical interventions and to the days of in-hospital care according to the 2014 updated DRG (diagnosis related groups) based hospital reimbursement regulation DEF/2277/2014 for medical services and products in institutions of the Ministry of Defense of Spain. These costs include in detail: (1) Routine and special diagnostic and therapeutic examinations prior to the surgical procedure; (2) All expenses related to complications during the pre-, peri- and post-operative phase; (3) All expenses of surgical reinterventions, if required, because of bad surgical practice and within a period of 2 mo from day of hospital discharge; (4) All medication during the treatment including blood supply and hemoderivates; (5) Nutritional assistance including parenteral or enteral products; (6) Expenses related to the medical team (specialized doctors, nurses and auxillary staff); (7) Expenses for use of theatre and anesthesia; (8) Expenses for all required medical consumables and pre- and postoperative controls including the early ambulatory phase; (9) Expenses related to the days in an individual or shared hospital room; (10) Expenses within the intensive care unit, if required; and (11) Expenses for revision-related procedures after hospital discharge.

RESULTS

In total 241 patients with intracapsular neck of femur fractures who went on to receive cemented hemiarthroplasty in the period from January 2011 to December 2017 were eligible for inclusion in this retrospective study. They were stratified into 2 study groups according to the bone cement used for the fixation of the hip stem, 94 patients received the gentamicin-loaded bone cement (ALBC group) and 147 patients received the plain cement without any added antibiotic (non-ALBC group). The demographic and health status related data for all patients were analyzed in detail and compared between both groups with focus on risk factors for infections (see Table 2). There were 38 patients (25.9%) in the non-ALBC group who had one or several risk factors including inflammatory arthropathies, malnutrition, immunosuppression, diabetes, prior articular infection, tumors or hemophilia. The percentage of risk for infection patients was higher in the ALBC group with 39.4% (n = 47). Use of oral anticoagulants (acenocumarol) was also assessed and compared between the groups (6.8% in the non-ALBC group *vs* 8.5% in the ALBC group, data not shown). The predominant overall ASA status of the patients in both groups was 3 (52.9%) and the predominant FAC mobility score was 4. Distribution of sex and average of patient age were comparable in both groups.

Primary endpoint

The overall incidence of PJI was compared between both groups. The number of infection cases was found to be with 8 cases among 94 patients (8.5%) significantly lower in the ALBC group as opposed to 28 infections among 147 patients in the non-ALBC group (19%) within the observation period of 1 year (see Figure 1A). From the total number of 8 infections occurring in the ALBC group, 4 cases were classified as acute (evolution of symptoms before 3 mo) and 4 cases as chronic delayed (evolution of symptoms after three months). In the non-ALBC group, 8 infections were of acute nature while 20 were delayed (see Figure 1B). This means in the statistical analysis that the use of the gentamicin-loaded bone cement Palacos R+G instead of the plain cement Cemex led to an overall reduction of the infection risk of 55.3% (95%CI: 6.2%-78.7%; P = 0.0025). The number needed to treat was 1.8.

Secondary endpoint

The implementation of routine use of the antibiotic-loaded bone cement Palacos R+G instead of the plain cement Cemex resulted in additional treatment costs. In order to justify these extra costs, we calculated the cost-benefit ratio of this new measure on basis of our routine hemiarthroplasty cost figures and the additional treatment expenses related to the management of the infection cases. The

Table 2 Basic clinical data of included patients in study according to the study arms

Items	Plain cement group (*n* = 147), *n* (%)	ALBC group (*n* = 94), *n* (%)	Both groups, (*n* = 241), *n* (%)
Sex			
Male	42 (28.6)	29 (30.9)	71 (29.5)
Female	105 (71.4)	65 (69.1)	170 (70.5)
Age			
< 80	27 (18.4)	25 (26.6)	52 (21.6)
> 80	120 (81.6)	69 (73.4)	189 (78.4)
Garden classification			
I	4 (2.7)	10 (10.6)	14 (5.8)
II	19 (12.9)	8 (8.5)	27 (11.2)
III	47 (32.0)	35 (37.2)	82 (34.0)
IV	77 (52.4)	41 (43.6)	118 (49.0)
Type of trauma			
High energy	1 (0.7)	0 (0)	1 (0.4)
Low energy	146 (99.3)	94 (100)	240 (99.6)
Arrival at hospital			
Walking	2 (1.4)	5 (5.3)	7 (2.9)
Transferral by relatives	1 (0.7)	1 (1.1)	2 (0.8)
Ambulance	95 (64.6)	75 (79.8)	170 (70.5)
Transferral from other centres	49 (33.3)	13 (13.8)	62 (25.7)
Risk factors for infections			
Yes	38 (25.9)	37 (39.4)	75 (31.1)
No	109 (74.1)	57 (60.6)	166 (68.9)

Presentation of femur neck fracture patient characteristics in each group with focus on sex, age, Garden classification of hip fractures, type of trauma, mode of arrival at hospital and risk factors for infection (focus on: presence of inflammatory arthropathies, degree of immunosuppression, presence of diabetes mellitus, previous articular infection, malnutrition, hemophilia and presence of tumors). ALBC: Antibiotic-loaded bone cement.

documented in-hospital costs for the implantation of a primary cemented hemiprosthesis in our institution are 12.665 €. In case of complications these costs increase significantly to 24.205 € for treatment of acute infections or to 35.746 € for the treatment of chronic delayed infections, reflecting in particular length of stay in the hospital and additional surgical intervention costs. The added costs for each patient receiving ALBC instead of plain cement (+20 € per package of 40 g) were subsequently put in relation to the number of avoided infections in the ALBC group. Based on the above shown numbers of infections occurring in each group with their subsequent treatment costs for both, acute and chronic cases, we calculated an average treatment cost of 14.127 € per patient in the ALBC group and of 17.632 € per patient in the non-ALBC group. These figures represent a cost saving of approximately 3.505 € for each patient after switching to the ALBC Palacos R+G.

DISCUSSION

The occurrence of PJI in the cohort of FNF patients treated with hemiarthroplasty is much more frequent and an even more catastrophic complication than in elective hip replacement patients. The high infection rates reflect the general frailty of the patients presenting at an advanced age, with an acute trauma event and with a high burden of comorbidities[16]. Further risk factors for infections have to be added to this including the operative conditions (junior surgeon, uncemented stems, duration of surgery) and the post-operative management regimen (length of hospitalization, hematoma, prolonged wound drainage and urinary catheterizations) as shown in a recent literature review[17]. The surgical and antibiotic treatment of the infection cases together with the extended immobility period further

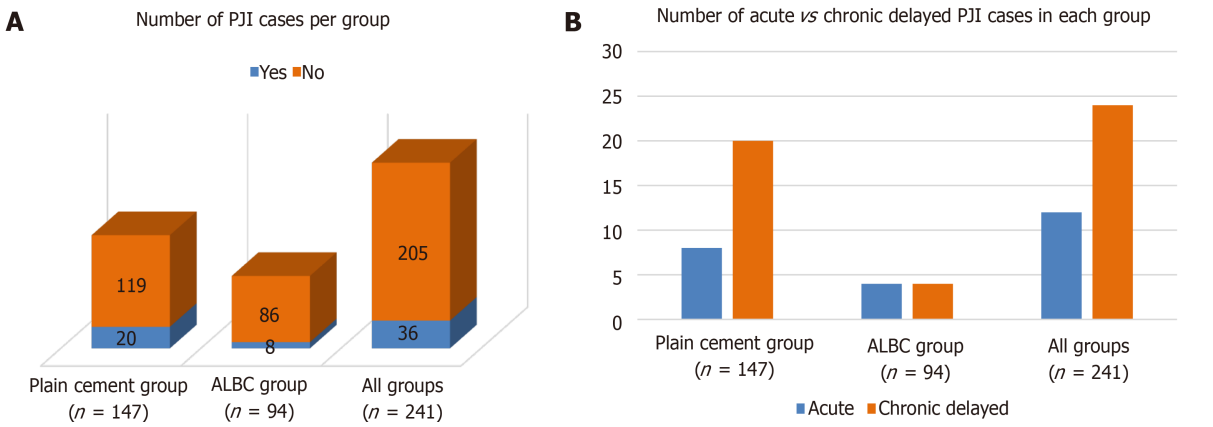

Figure 1 Graphical presentation. A: The number of periprosthetic joint infection (PJI) cases (blue color) *vs* non-infection cases (orange color) in each group within the observation period of 1 yr; B: The number of acute (blue color) *vs* chronic delayed PJI cases (orange color) in each group within the observation period of 1 yr. Staphylococci were the most frequent pathogens (*S. aureus* with higher prevalence in acute infections, coagulase-negative staphylococci with higher prevalence in chronic delayed infections – data not shown). PJI: Periprosthetic joint infection; ALBC: Antibiotic-loaded bone cement.

weakens the organism leading to 1-year mortality rates in the range of 40% to 50%[18,19].

Staphylococcus is the most commonly found microorganism in acute and chronic infections. While the prevalence of *S. aureus* as culprit of PJI is gradually decreasing, coagulase-negative Staphylococci are being found more and more in acute and particularly chronic infections[20]. These bacteria are either directly inoculated through contaminated implants during surgery or postoperatively through contiguous spread from slow healing wounds or through hematogeneous dissemination from more remote bacteremias. Among the anti-straphylococcal weapons available the bactericidal antibiotic gentamicin has still largely retained its antimicrobial efficacy – at least if it is present at high concentrations. Such high peak levels can be expected after initial release of the antibiotic from a well eluting bone cement. Indeed, the analysis of major European arthroplasty registries has shown that the combination of systemic perioperative and local antibiotic prophylaxis *via* gentamicin-loaded bone cement lowers the overall revision risk and protects the implants from early infections[8-10] In a similar way Sanz-Ruiz *et al*[21] recently observed an impressive reduction in their PJI rate (-57% for all cemented primary prostheses and -72.6% for cemented hip replacements) after switching from plain cement to ALBC. Interestingly, the PJI incidence in all their uncemented procedures did not change in the entire observation period, thus suggesting that the outcome was, in fact, due to the change of the bone cement category[21].

One might speculate that the particularly frail population of FNF patients treated with cemented hemiarthroplasty would equally or benefit even more from the presence of an additional antimicrobial "frontline" in situ. However, this hypothesis has not been systematically evaluated in our country. Our present study provides evidence that the implementation of the routine use of ALBC instead of plain cement is a powerful anti-infective measure in this patient cohort. We show here that the number of PJI cases could be significantly reduced by 55% if stems were cemented with ALBC. This effect was even more remarkable in light of the higher percentage of patients with well described risk factors for infections in the ALBC group compared to the non-ALBC group.

We are aware that this finding may not only reflect the switch from an unloaded to an antibiotic-loaded cement category, but may also depend on individual cement brand characteristics. This fits to prior observations showing that the ALBC brand PALACOS R+G has a superior antibiotic elution behaviour compared to other bone cement brands[13,14].

The PJI rate in our hemiarthroplasty patients was found to be much higher than described in the literature, probably reflecting "real world" experiences in our hospital until recently. This refers to the absence of a special orthogeriatric optimization protocol prior and post-surgery as well as to the absence of a routine follow-up of possible complications. Patients were transferred back to their residences or homes and followed by a general practitioner without further hospital consultations in the orthopedic unit where the surgery had been performed. This led to practices where patients with infections were re-admitted to our hospital in an already chronic state, with strong wound dehiscence or even fistula formation and oral antibiotic therapy already initiated. The lessons which we learned from these observations have now triggered the implementation of new protocols. We now routinely improve the pre-operative control of our FNF patients (focus on nutritional status, glycemic control, treatment of urinary tract infections *etc.*), we strictly avoid intraoperative hypothermia and implement postoperative follow-up consultations in the hospital with early diagnosis of possible infection cases. By following these new protocols in combination with the use of ALBC we hope to further decrease the PJI incidence in our FNF patients.

Inspired by recent observations that the antibiotic combinations gentamicin and clindamycin or gentamicin and vancomycin in bone cement exert a stronger and more sustained growth inhibition on many bacteria compared to the gentamicin mono-cement[22,23], we will soon start to test the hypothesis of an even more efficient local antibiotic prophylaxis with dual ALBC in our FNF patients. We therefore want to repeat the here described clinical study comparing in the future PJI incidence between a group receiving the single ALBC Palacos R+G *vs* the PJI rate in a group receiving the dual ALBC Copal G+C (containing 1 g of gentamicin and 1 g of clindamycin). Indeed, Sanz-Ruiz *et al*[24] have recently provided some proof of concept by showing that the routine use of Copal G+C decreased the number of PJI cases in procedures associated with a higher infection risk (aseptic knee revision procedures). The observed risk reduction in the Copal G+C group was 53% compared to the Palacos R+G group. Similarly, Sprowson *et al*[25] also reported a lower infection rate in their highly standardized hemiarthroplasty patient cohorts in the United Kingdom, if allocated to the dual ALBC group. However, it has to be pointed out that the United Kingdom in contrast to many other countries follows a high standard of care for fracture patients by imposing orthogeriatric guidelines on the basis of regular assessments of their national fracture database[26]. Therefore, clinical treatment experiences in the United Kingdom may not be fully transferable to countries with less rigorous orthogeriatric care standards.

Routine use of ALBC is still associated with concerns regarding possible systemic side effects and the risk of resistance development. While caution with high dose ALBC (exceeding concentrations of 3.6 g antibiotic per 40 g of cement – *e.g.*, in spacers during staged septic treatment) appears justified for patients with pre-existing acute kidney injuries[27], there is no evidence for such concerns with low dose ALBC. In fact, we did not observe a higher rate of complications attributed to the use of ALBC in our FNF patients nor a higher rate of *Clostridium difficile* infections. Because of the local mode of antibiotic action there is also no proof so far that ALBC use triggers clinically relevant antibiotic resistance development[28].

Most health systems have come under progressive economic pressure. It is therefore of interest to conclude from our simple cost-benefit evaluations that the relatively easily applicable measure of routine ALBC use in hemiarthroplasty patients has such a cost saving potential in our institution. We could show that approximately 3.500 € could be saved for each patient in the ALBC group. Although this figure will vary from country to country and even from hospital to hospital depending on the price differences between the cements and the hospital-specific PJI treatment costs, we believe that they can provide an indication of what can be achieved.

Our study has several limitations. These refer in the first instance to the retrospective nature of the study and to the limited and not equally balanced number of patients in each study arm. We can also not exclude a cement material related effect because of choosing the plain cement brand from one manufacturer and the ALBC brand from another. However, we would rule out a major patient, procedure and surgical skill related bias between both groups, since patient characteristics, prosthesis use and duration of surgeries as well as the pool of operating surgeons were comparable in the observation periods.

CONCLUSION

The present pilot study has demonstrated that in the absence of good clinical protocols for the frail cohort of FNF patients the relatively easy-to-apply implementation of routine use of ALBC significantly reduces the high number of PJI cases in cemented hemiarthroplasty. This measure was found to be highly cost-effective and leads to considerable savings of treatment costs. The study also brings to attention how important it is to implement orthogeriatric guidelines in a hospital in order to achieve a better pre-, peri- and postoperative care of FNF patients.

Further studies are needed to truly elucidate the effect of ALBC – even loaded with two antibiotics - on a larger scale in FNF patients. Based on our experiences so far we strongly recommend the use of ALBC for cemented arthroplasty in FNF patients.

ARTICLE HIGHLIGHTS

Research background

Use of antibiotic-loaded bone cement (ALBC) for fixation of cemented hip stems in the context of hemiarthroplasties may establish an additional antimicrobial "frontline" in the vulnerable joint compartment.

Research motivation

Given the high periprosthetic joint infection (PJI) rates in this frail patient group of femur neck fracture (FNF), it appears mandatory to consider further effective and easy-to-apply infection preventive measures.

Research objectives

The aim of this study was to compare the PJI rate between patients receiving cemented hip stems with plain cement (non-ALBC group) and patients receiving cemented hip stems with gentamicin-loaded bone cement (ALBC group) in one of the biggest Military hospitals in Spain. The treatment costs of PJI cases in each group were subsequently put in relation to the extra costs related to the routine use of ALBC instead of plain cement.

Research methods

In total 241 FNF patients who went on to receive cemented hemiarthroplasty during the period from January 2011 to December 2017 were eligible for inclusion in this retrospective study. Patients were stratified into 2 study groups according to the bone cement used for the fixation of the hip stem. The number of PJI cases were analyzed and compared between both groups. Infections were further differentiated between early or chronic delayed infections by the onset of symptoms. Treatment costs in each group were compared with the extra costs related to the use of gentamicin-loaded bone cement in the ALBC group.

Research results

Use of ALBC in our hospital setting and in the absence of strict guidelines regulating pre-, peri- and postoperative care of FNF patients has been found to reduce the infection rate by 55%. Despite the extra costs of ALBC use instead of plain cement, this change of surgical practice led to savings of approximately 3500 € per patient.

Research conclusions

Use of ALBC was found to be a potent infection prevention factor in FNF patients receiving cemented hemiarthroplasties. It was further found to be highly cost-effective.

Research perspectives

Further studies validating the generalizability of our findings under different pre-, peri- and postoperative conditions of FNF patient care are warranted. This does also include the use of dual ALBC to further reduce the still high infection rates.

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FOOTNOTES

Author contributions: Crego-Vita D has been the supervisor and principal investigator in this IIT; Aedo-Martin D, García-Canas R, Espigares-Correa A and Sánchez-Pérez C performed the patient consultations, the pre- and postoperative diagnosis and the surgeries; and Berberich C made substantial contributions to the interpretation and discussion of the study and drafted the manuscript.

Institutional review board statement: The first author and principal investigator of the study who submitted the study proposal to the ethics committee received the ethical clearance of this study from the ethical review board of the hospital (see separate certificate).

Informed consent statement: Because of the retrospective nature of the here presented clinical study signed informed consent form is not needed. However, the ethics committee of the Hospital Central de la Defensa Gómez Ulla (Military Hospital Gómez Ulla) has given permission to conduct this study (see certificate).

Conflict-of-interest statement: All authors of this study declare that there is no conflict of interest.

Data sharing statement: No additional data are available.

CONSORT 2010 statement: The authors have read the CONSORT 2010 statement, and the manuscript was prepared and revised according to the CONSORT 2010 statement.

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Bone mineral density in fracture neck of femur patients: What's the significance?

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Abstract

BACKGROUND

The National Institute for Health and Care Excellence (NICE) guidelines have advised further research is required into investigating the added prognostic value of bone mineral density (BMD) in the assessment of fracture risk with the Fracture Risk Assessment Tool (FRAX) score.

AIM

To investigate the significance of BMD in fracture neck of femur patients and compare it to the outcome of the FRAX score.

METHODS

Inclusion criteria for this study were all patients who underwent dual-energy X-ray absorptiometry (DXA) scan following fracture neck of femur between 2015 and 2017. Analysis of BMD, FRAX scores and patient demographic data was undertaken.

RESULTS

A total of 69 patients were included in the study, mean age 74.1 years. There was no significant difference between mean BMD of the femoral neck in males (0.65) as compared to females (0.61) (P = 0.364). Analyses showed no significant correlation between BMD and menopause age (r_s = -0.28, P = 0.090). A significant difference was seen of the femoral neck BMD between the different fracture pattern types (P = 0.026). A stronger correlation was observed between BMD of femoral neck and FRAX major score (r_s = -0.64, P < 0.001) than with BMD of lumbar spine and FRAX major score (r_s = -0.37, P = 0.003).

CONCLUSION

This study demonstrated that BMD of the femoral neck measured by DXA scan is of added prognostic value when assessing patients for risk of fracture neck of femur in combination with the FRAX predictive scoring system.

Key Words: Fracture neck of femur; Bone mineral density; Fracture Risk Assessment Tool score; Fragility fracture; Osteoporosis

Core Tip: The results in this study place more emphasis on bone mineral density (BMD) when assessing fracture risk, in comparison to key factors incorporated into the Fracture Risk Assessment Tool (FRAX) predictive score. Menopause age and female gender had an indeterminate influence on BMD, as well as World Health Organization classification of osteoporosis. Body mass index had a significant influence on BMD. Osteoporosis was more common in patients with extra-capsular hip fracture patterns. This study shows that BMD is significant in assessing risk of fracture neck of femur in comparison to the FRAX predictive score.

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INTRODUCTION

The National Institute for Health and Care Excellence (NICE) define osteoporosis as a disease characterised by low bone mass and structural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture[1]. Fractures secondary to osteoporosis may be referred to as fragility fractures; which are described as those resultant from a mechanical force that would not ordinarily be associated with a fracture[2]; further described by the World Health Organization (WHO) where a fracture occurs from forces equal to or less than a fall from a standing height[1].

Osteoporosis may be viewed as primary or secondary. Primary being characterised by age and sex hormone related progressive mineral loss[3]. Secondary osteoporosis occurs as a result of different pathologies and use of specific medication[4].

Osteoporosis is a disease that develops silently, only manifesting on occurrence of a fracture. It is for this reason that the increase in osteoporosis related pathology has been entitled by some as the "silent epidemic"[4]. The WHO considers osteoporosis to be only second to cardiovascular diseases as a crucial healthcare issue[5].

Prevalence of osteoporosis is known to increase with age, from 2% at age 50 years to 25% at age 80 years[1]. There are known to be over three million United Kingdom residents with osteoporosis at present[6], with this figure expected to continue to rise. Subsequently, the burden on healthcare services as a result of osteoporosis is only likely to rise with the ongoing increase in the world population. In the United Kingdom alone; projections suggest that the incidence of fragility fractures is likely to increase by 21% by the year 2020 (230000 per annum), with a resultant overall annual cost upwards of £2.1 billion [6]. In Europe it is estimated that direct costs resulting from osteoporotic fractures to have an overall cost of €76.7 billion[7].

Despite the above figures, it is almost impossible to truly predict the economic burden of osteoporosis and osteoporotic fractures. The consequences are not only that of economic cost to the healthcare system, but also of associated morbidity, impairment, reduced quality of life and mortality. It is therefore paramount that resources and research into fracture prediction and prevention continues, to ensure that efficient allocation of resources may continue in an already stretched healthcare system.

The International Osteoporosis Foundation and the WHO state that fracture risk should be advised as a short-term absolute risk[8]. A period of ten years is agreed upon as this comprises the probable duration of treatment as well as the benefits that may continue once treatment is ceased[4]. There are several different predicting tools used to identify risk of fragility fracture. The fracture risk assessment tool (FRAX®) is a predictive algorithm developed by the University of Sheffield that takes into account clinical risk factors, with or without the addition of bone mineral density (BMD)[9,10]. The FRAX tool provides a 10-year probability of hip or major osteoporotic fracture by means of a percentage likelihood [11]. The clinical risk factors utilised as part of the FRAX predictive tool are displayed in Table 1.

Table 1 Osteoporosis risk factors utilised in Fracture Risk Assessment Tool predictive tool for osteoporotic fractures[29]

Clinical risk factors
Age
Gender
Weight
Height
Previous fracture
Parent fractured hip
Current smoking
Glucocorticoid use
Rheumatoid arthritis
Secondary osteoporosis risk factors — Type I diabetes mellitus, osteogenesis imperfecta, hyperthyroidism, hypogonadism, premature menopause, chronic malnutrition or malabsorption, chronic liver failure
Alcohol — 3 or more units per day
Bone mineral density

BMD is defined as grams per centimetre squared (g/cm^2)[12]. This is measured by means of dual-energy X-ray absorptiometry (DXA) scan. A value of BMD (g/cm^2) is therefore given for the area of bone scanned (most commonly proximal femur and lumbar spine)[12]. Alternatively, the value may be converted to a value in comparison (standard deviation) with the peak bone mass of a Caucasian female aged 30 (T-score), or for the peak bone mass adjusted for age, gender and race (*z*-score)[12]. It is the T-score that is used by the WHO as an objective means of defining osteoporosis in an individual as per DXA scan result; with Osteoporosis being defined as T-score less than or equal to -2.5 (Table 2)[13].

Currently in the United Kingdom it is common practice for the FRAX tool to be used by a primary care physician to give 10-year probability of major osteoporotic fracture. NICE guidelines currently advise if the value is significant, then preventative management is to be initiated immediately, however if the risk is moderate, a DXA scan is advised to further quantify the probability.

A number of recent publications have focused on re-assessment of the importance of clinical risk factors associated with the progression to osteoporosis, including BMD. Trajanoska *et al*[14] conducted a meta-analysis of genome-wide association studies and a two-sample mendelian randomisation approach to assess the role of fifteen clinical risk factors on osteoporotic fracture risk. It was deduced that among clinical risk factors for fracture that were assessed, only BMD was shown to have a major causal effect on fracture. This mendelian randomisation study provides evidence against a causal effect of several proposed clinical risk factors for fractures (*e.g.*, diabetes, glucose, rheumatoid arthritis, and vitamin D)[14].

Findings from the Foundation of the National Institutes of Health (FNIH) Bone Quality Project, a meta-analysis of twenty-two trials, have shown that a twenty-four percent change in BMD, as per DXA measurement, is responsible for a large proportion of the fracture risk reduction across a range of osteoporosis treatment options[15]. The regression analysis conducted as part of the study displayed percentage difference in increase in BMD (change in BMD with treatment minus the change in BMD with placebo) at the hip, femoral neck, and lumbar spine was significantly associated with relative risk reduction of having a fracture[15]. This, in turn, supports the notion that the BMD, as measured per DXA scan, be utilised as a surrogate biomarker in the measurement of disease progression and management of osteoporosis.

As part of recent guidelines, NICE have recommended research to be focused on the added prognostic value of BMD in the assessment of fracture risk with FRAX[1]. NICE state that there is currently not sufficient research, in primary or secondary care, evaluating if the addition of BMD to FRAX improves the accuracy of the predicted fracture risk[1]. More specifically, NICE advise further research is required to ensure that the addition of BMD results in the correct re-classification of risk, *i.e.*, high to low risk and vice versa[1].

The authors hypothesise an increased significance of BMD in comparison to the individual components of the FRAX score. The aim of this study was to investigate the significance of BMD in fracture neck of femur patients and compare it to the outcome of the FRAX score.

Table 2 World Health Organisation classification of osteoporosis[29]

Terminology	T-score definition
Normal	T ≥ -1.0
Osteopenia	-2.5 < T < -1.0
Osteoporosis	T ≤ -2.5
Severe osteoporosis	T ≤ -2.5 in the presence of one or more fragility fracture

MATERIALS AND METHODS

Patients

This retrospective observational cohort study which did not require ethics committee approval. All patients had sustained a fracture neck of femur and managed as appropriate under the admitting on-call consultant orthopaedic surgeon between 2015 to 2017.

All patients underwent a DXA scan following completion of management of the fractured neck of femur. DXA images were taken of the contralateral femoral neck and the lumbar spine (L2, L3, L4), in line with published protocols[5,10,11]. Patients with contralateral hip prosthesis in-situ and with lumbar spine instrumentation were excluded from the study. FRAX scores were calculated for all the patients included in the study.

Fracture pattern classification

Neck of femur fractures were classified as intra-capsular or extra-capsular. Extra-capsular fractures were defined as those at the inter-trochanteric line (fracture line passes through the greater trochanter to the lesser trochanter) or distal to this as assessed on plain radiograph imaging (antero-posterior pelvis and lateral hip). Fractures proximal to the inter-trochanteric line were classified as intra-capsular fractures. This is a validated radiographic classification system of fracture neck of femur pattern[16].

Proposed outcome

The authors aim to investigate the association between BMD and the components of the FRAX score within the cohort.

Statistical analysis

All continuous data variables displayed a skewed distribution (verified by both plotted histograms and the Shapiro-Wilks test). The appropriate non-parametric statistical test was used in their analyses. This includes Mann Whitney *U* test and Kruskall-Wallis *H* test used in the appropriate manner. The Chi-squared test was used for the categorical data analysis of the fracture neck of femur pattern type and the Spearman Rank test was used for the correlation analyses. The level of statistical significance was set at $P < 0.05$. Statistical analysis was performed using SPSS for Windows version 25.0 (IBM Corp., Armonk, New York, United States).

RESULTS

Table 3 displays the demographic data of the study cohort. A total of 69 patients were included in the cohort, all undergoing DXA scan following fracture neck of femur and undergoing a complete FRAX score assessment.

Table 4 shows the fracture neck of femur classification pattern. Table 5 shows the details of the surgical management.

The mean FRAX score for a major osteoporotic fracture amongst the study cohort was 19.87% (SD 11.01%); this score representing the percentage probability of occurrence of fracture of the distal radius, proximal humerus, lumbar spine or neck of femur over a ten-year period (Table 6). In addition, the mean FRAX score for fracture neck of femur amongst the study cohort was 7.75% (SD 8.09%); representing the ten-year percentage probability of fracture neck of femur only (Table 6). BMD of the femoral neck and lumbar spine where used to calculate the corresponding T-score and *z*-score. Table 2 shows the WHO classification of Osteoporosis when interpreting T-score values. None of the patients included in this study fitted the classification grade of osteoporosis as all of them had fragility fractures and so by definition were classified as severe osteoporosis when the T-score ≤ -2.5.

Table 7 shows that there was no statistically significant difference for either BMD of femoral neck or lumbar spine between males and females.

Table 3 Patient demographic data

Patient demographic	
Number of patients (*n*)	69
Age yr (mean, range)	74.1 (61-98)
Height cm (mean, range)	161.9 (141-190)
Weight kg (mean, range)	67.7 (31-150)
BMI (mean, range)	25.7 (16-63)
Gender (male:female)	25:44
Menopause age (mean, range)	46.6 (32-56)
Laterality (left:right)	27:42

BMI: Body mass index.

Table 4 Pattern of fracture neck of femur

	***n* (%)**
Intra-capsular fracture	36 (52.2)
Extra-capsular fracture	33 (47.8)

Table 5 Surgical management of fracture neck of femur

	***n* (%)**
Total hip replacement	24 (34.8)
Hemi-arthroplasty	10 (14.5)
Dynamic hip screw	31 (45.0)
Intra-medullary nail	4 (5.7)

Table 6 Dual-energy X-ray absorptiometry scan results

Dual-energy X-ray absorptiometry scan	
FRAX major (mean ± SD)	19.87 ± 11.01
FRAX hip (mean ± SD)	7.75 ± 8.09
BMD hip (mean ± SD)	0.62 ± 0.13
T-score hip (mean ± SD)	-2.20 ± 1.05
z-score hip (mean ± SD)	-0.60 ± 0.97
BMD spine (mean ± SD)	0.88 ± 0.30
T-score spine (mean ± SD)	-1.36 ± 1.65
z-score spine (mean ± SD)	0.37 ± 1.72

BMD: Bone mineral density; FRAX: Fracture Risk Assessment Tool.

Figure 1 illustrates the scatter plot graph showing no significant correlation between the menopause age of female patients and the BMD of either the femoral neck or lumbar spine.

Tables 8 and 9 show no statistically significant difference between the mean menopause age of female patients and the WHO classification of the femoral neck BMD and the lumbar spine BMD respectively.

Figure 2 shows a significant direct correlation between body mass index (BMI) and BMD for both femoral neck ($r_s = 0.58$; $P < 0.001$) and lumbar spine ($r_s = 0.43$; $P < 0.001$).

Table 7 Comparison of mean bone mineral density femoral neck and lumbar spine in males and females

	Male (*n* = 25)	Female (*n* = 44)	*P* value[1]
BMD femoral neck	0.65	0.61	0.364
BMD lumbar spine	1.01	0.85	0.135

[1]Mann Whitney *U* test. BMD: Bone mineral density.

Table 8 Analysis between World Health Organization classification of femoral neck bone mineral density and mean menopause age of female patients (*n* = 39)

	n	Menopause age (mean ± SD)	*P* value[1]
Normal	5	45.0 ± 7.4	0.086
Osteopenia	16	44.8 ± 5.1	
Severe osteoporosis	18	48.4 ± 5.1	

[1]Kruskal-Wallis *H* test.

Table 9 Analysis between World Health Organization classification of lumbar spine bone mineral density and mean menopause age of female patients (*n* = 40)

	n	Menopause age (mean ± SD)	*P* value[1]
Normal	15	47.2 ± 5.7	0.835
Osteopenia	15	46.1 ± 5.3	
Severe osteoporosis	10	46.3 ± 6.1	

[1]Kruskal-Wallis *H* test.

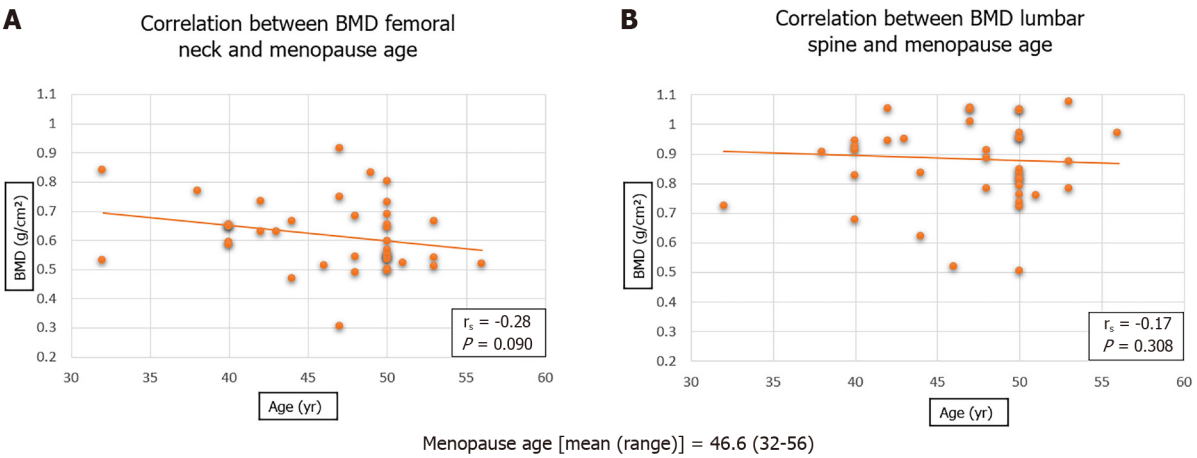

Figure 1 Scatter plot graphs of bone mineral density of femoral neck and lumbar spine with menopause age of female patients (*n* = 44) (Spearman Rank Correlation analysis). A: Femoral neck; B: Lumbar spine. BMD: Bone mineral density.

Table 10 shows a statistically significant difference (P = 0.026) between the pattern of fracture neck of femur and the WHO Classification of femoral neck BMD. Patients with extra-capsular fractures where more likely to have severe osteoporosis than those with intra-capsular fractures.

Figure 3 illustrates a statistically significant inverse correlation between the femoral neck BMD and the lumbar spine BMD with the FRAX major score (percentage likelihood of major osteoporotic fracture in the next ten years). The correlation was stronger with the femoral neck BMD (r_s = -0.64; P < 0.001) than that of the lumbar spine BMD (r_s = -0.37; P < 0.001).

Table 10 Analysis between World Health Organization classification of femoral neck bone mineral density and the pattern of fracture neck of femur (*n* = 62)

	Intra-capsular (*n*)	Extra-capsular (*n*)	*P* value[1]
Normal	6	2	0.026
Osteopenia	17	7	
Severe osteoporosis	10	20	

[1]Chi-Squared test.

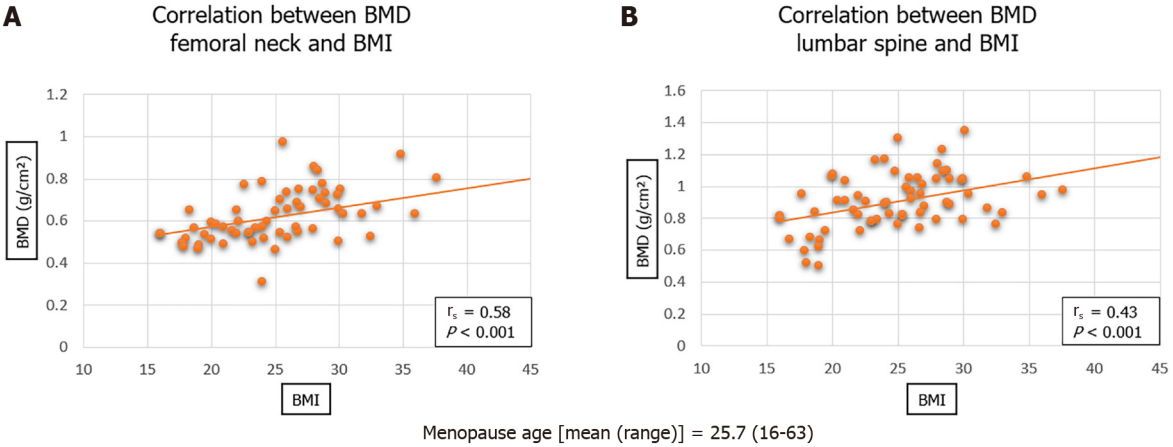

Figure 2 Scatter plot graphs of bone mineral density of femoral neck and lumbar spine with body mass index (*n* = 69) (Spearman Rank Correlation analysis). A: Femoral neck; B: Lumbar spine. BMD: Bone mineral density; BMI: Body mass index.

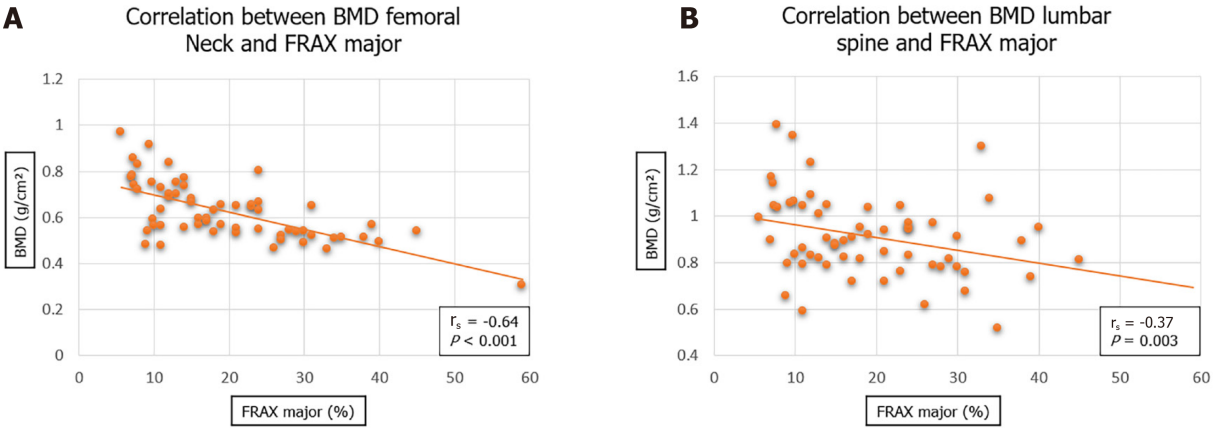

Figure 3 Scatter plot graphs of bone mineral density of femoral neck and lumbar spine with Fracture Risk Assessment Tool major score (*n* = 69) (Spearman Rank Correlation analysis). A: Femoral neck; B: Lumbar spine. BMD: Bone mineral density; FRAX: Fracture Risk Assessment Tool.

DISCUSSION

The main findings of this study were that BMD had a significant correlation with the FRAX score and also with BMI. Neither female gender or early menopause age had a significant influence on BMD. Osteoporosis was more common in patients with extra-capsular hip fracture patterns.

The aetiological factors associated with development of both primary and secondary osteoporosis have been looked at in numerous studies. With the incidence of osteoporosis continuing to rise[17], it is important that new research continues to advance and build upon previous findings.

The clinical risk factors associated with development of osteoporosis have long been agreed upon, with emerging contributory risk factors to secondary osteoporosis being a constant subject of further research[18]. However, the significance of the contribution of certain clinical risk factors to the pathophysiology of the development of primary osteoporosis is less understood. This study aimed to

investigate the significance of BMD in fracture neck of femur patients and compare it to the outcome of the FRAX score.

This study addressed a relatively unique cohort, all patients had sustained a major osteoporotic fracture (*i.e.*, fracture neck of femur). This allowed for research into arguably the most at risk group of individuals in the community. This contrasts to previous literature, whereby major osteoporotic fracture is used as an end-point on patient follow-up[10].

Local clinical guidelines allow for the discretion of the referring clinician with regards to whether DXA scan is appropriate following surgical management and rehabilitation of fracture neck of femur patients. In general, this would be all patients under the age of 75, as well as those patients felt to be independent in all aspects of daily living. This ensures that those included in this cohort will potentially benefit from preventative medical treatments to avert further major osteoporotic fractures. In addition, this ensures that 10-year percentage probability of major osteoporotic fracture data generated is relevant for the cohort.

The majority of patients with intra-capsular fracture neck of femur were managed with total hip arthroplasty, as opposed to hemi-arthroplasty, as displayed in Table 5. This reflects the relatively low mean age of the patients in the cohort. Current National Institute for Health and Care Excellence (NICE) guidelines advise that fracture neck of femur patients be managed surgically by total hip replacement if they are independently mobile and independent in activities of daily living[18]. This, in turn, portrays that the cohort in this study represents a group of individuals who are expected to continue with an independent lifestyle after surgical management, and therefore it is important that further fracture prevention is prioritised by all members of the healthcare team. Osteoporosis was more common in patients with extra-capsular hip fracture patterns in this study. Dynamic hip screw (DHS) is a common internal fixation device used for this fracture pattern. The biomechanical pull-out strength of locking plates is superior to that of conventional plates particularly in osteoporotic bone. It may be more prudent to use DHS implants which have locking plates for screw fixation in the surgical management of patients with an extra-capsular fracture configuration.

The significant (inverse) relationship between femoral neck BMD and lumbar spine BMD with the FRAX score (10-year percentage probability of major osteoporotic fracture) is in agreement with previous literature[17,20]. This supports the ongoing understanding that measures to increase BMD will result in reduced incidence in major osteoporotic fractures[15,21].

The correlation between BMD (both femoral neck and lumbar spine) and BMI is also in agreement with previous literature[22]. This is likely to be explained by a combination of factors, including nutritional status, mechanical load and hormones. It has previously been hypothesised that increased weight, and subsequently increased mechanical load, results in decreased osteoclast activity and increased osteoblast activity, increasing bone strength and bone mineral content[23]. This supports current emphasis on nutritional status of fracture neck of femur patients, not only in aiding rehabilitation, but also in prevention of further fracture.

BMD was noted to have a significant influence on the fracture pattern at the neck of femur. This is also in agreement with previous literature[16], whereby extra-capsular fracture patterns are associated with a lower BMD. However, it is important to emphasis that literature has shown there to be other factors that will have an influence on fracture pattern at the neck of femur[24], most notably intertrochanteric outer diameter and buckling ratio.

Gender difference has long been known to have an influence on both osteoporosis fracture risk and BMD. This is variable is included in the FRAX questionnaire[25]. Interestingly, there was no significant difference between males and females for BMD within the cohort studied. It is important to note that it is not the intention to disprove the influence of gender on BMD, and ultimately osteoporosis. However, it may be argued that the effect of gender is not in isolation, and that other factors that affect BMD (nutrition, mechanical force, genetic predisposition, ethnicity, *etc.*) may outweigh gender's overall role.

It was shown that menopause age did not have a significant association with either BMD or WHO osteoporosis classification. This is in contrast to the majority of published literature[26], whereby it is understood that earlier menopause age is associated with lower BMD, and therefore increased incidence of osteoporosis and fragility fractures[27]. This study does not conclude that age of menopause has no effect on BMD, osteoporosis and fracture risk. However, it emphasises that a multi-faceted approach must be taken when attempting to address the field in question.

Limitations of the study included that much of the presented data focuses on the influence of gender on BMD, and consequently the influence of gender on osteoporosis and fracture risk. One must make note of the differences in frequency between males (n = 25) and females (n = 44). This was appropriately adjusted for in the statistical analyses conducted. This gender discrepancy is explained by the disproportionately higher incidence of fracture neck of femur in females as compared to males[28].

Recommendations for future research include a greater focus on how BMD may help reclassify patient fracture risk when added to the already calculated FRAX score based on 10-year probability of both major osteoporotic fracture and fracture neck of femur. This will aid to ensure osteoporosis preventative management is appropriately prioritised to reduce the incidence of fragility fractures. The findings in this paper also support the requirement for further research into the use of BMD as a surrogate biomarker for both fracture risk and osteoporosis prevention and management. This may be in the context of a cross-sectional study of fragility fractures at differing ages group and further

appropriate stratification as per age, with confounding factors adjusted for.

CONCLUSION

The results in this study place more emphasis on BMD when assessing fracture risk, in comparison to key factors incorporated into the FRAX predictive score. Menopause age and female gender had an indeterminate influence on BMD, as well as WHO classification of osteoporosis. BMI had a significant influence on BMD. Osteoporosis was more common in patients with extra-capsular hip fracture patterns. This study shows that BMD is significant in assessing risk of fracture neck of femur in comparison to the FRAX predictive score.

ARTICLE HIGHLIGHTS

Research background

There has been a steady increase in fragility fractures in the United Kingdom and worldwide. This has been seen in the increased number of patients admitted with fracture neck of femur. It is essential to gain a further understanding of the aetiology to understand preventative measures.

Research motivation

Increased prevalence of osteoporosis fragility fractures in the NHS, causing an increased economic burden.

Research objectives

The aim of this study was to investigate the significance of bone mineral density (BMD) in fracture neck of femur patients and compare it to the outcome of the Fracture Risk Assessment Tool (FRAX) score.

Research methods

Statistical analyses undertaken to ascertain the relationship between BMD and the individual factors included in the FRAX score.

Research results

The results in this study place more emphasis on BMD when assessing fracture risk, in comparison to key factors incorporated into the FRAX predictive score. Menopause age and female gender had an indeterminate influence on BMD, as well as World Health Organization classification of osteoporosis. BMI had a significant influence on BMD. Osteoporosis was more common in patients with extra-capsular hip fracture patterns. This study shows that BMD is significant in assessing risk of fracture neck of femur in comparison to the FRAX predictive score.

Research conclusions

This study demonstrated that BMD of the femoral neck measured by dual-energy X-ray absorptiometry scan is of added prognostic value when assessing patients for risk of fracture neck of femur in combination with the FRAX predictive scoring system.

Research perspectives

The findings in this paper also support the requirement for further research into the use of BMD as a surrogate biomarker for both fracture risk and osteoporosis prevention and management. This may be in the context of a cross-sectional study of fragility fractures at differing ages group and further appropriate stratification as per age, with confounding factors adjusted for.

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FOOTNOTES

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ORIGINAL ARTICLE

Prospective Study

Liverpool carpal tunnel scoring system to predict nerve conduction study results: A prospective correlation study

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Abstract

BACKGROUND

Carpal tunnel syndrome (CTS) is one of the most common peripheral nerve compressive neuropathies. The clinical symptoms and physical examinations of CTS are widely recognised, however, there is still debate around what is the best approach for assessment of CTS. Clinical assessment is still considered the gold standard, however, controversies do exist regarding the need for investigations such nerve conduction studies (NCS) to aid with management decisions.

AIM

To correlate the severity of NCS results to a scoring system which included symptoms, signs and risk factors.

METHODS

This was a prospective correlation study. We scored patients' signs and symptoms using our CTS scoring system. This was then correlated with the findings of the NCS. The scoring system included - four symptoms (2 Katz hand diagrams – one for tingling and one for numbness; nocturnal paresthesia and bilateral symptoms) and four clinical signs (weak thumb abduction test; Tinel's sign; Phalen sign and hypoalgesia in median nerve territory) and two risk factors (age more than 40 years and female sex). We classified the NCS results to normal, mild, moderate and severe.

RESULTS

There were 61 scores in 59 patients. The mean scores for the categories were as

follows: 6.75 for normal NCS; 5.50 for mild NCS; 9.17 for moderate NCS and 9 for severe NCS. All scores of 8 or more matched with NCS results of moderate and severe intensity apart from three scores which were greater than seven that had normal NCS. Eta score was 0.822 for the CTS score being the dependent value and the NCS category being the independent variable showing a strong association between the scoring system and the NCS group.

CONCLUSION
We feel that this simple scoring system can be used to predict and correlate the severity of NCS in patients with CTS.

Key Words: Carpal tunnel syndrome; Nerve; Compression neuropathy; Median nerve; Scoring

Core Tip: The use of our simple scoring method can help determine if patients with carpal tunnel syndrome need nerve conduction studies. Patients scoring less than 8 may have mild or moderate carpal tunnel syndrome and in these patients we recommend the use of nerve conduction studies. In patients scoring 8 or more, we do not recommend the use of nerve conduction studies for the diagnosis of carpal tunnel syndrome.

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INTRODUCTION

Carpal tunnel syndrome (CTS) is one of the most common peripheral nerve compressive neuropathies. The prevalence of CTS in the United Kingdom is 7%-16%. A General Practice Research Database found that 88 men and 193 women present as new cases per 100000 population per year[1]. The clinical symptoms and physical examinations are widely recognised, however there is still debate around what is the best approach for the assessment of carpal tunnel syndrome. Clinical assessment is considered the gold standard; however, controversies exist regarding the need for investigations such as nerve conduction studies (NCS) to aid with management decisions[2].

NCS is the investigation of choice when clinical diagnosis is inconclusive. It is also used to confirm the diagnosis of CTS. NCS have been found to be highly sensitive and specific for the diagnosis of CTS [3]. However, NCS can be painful and expensive. The reported false negative rate of NCS is between 1.5% to 16%[4,5]. The reported false positive rate is up to 46%[6]. The evaluation of NCS for CTS involves the measurement of conduction velocity across the carpal tunnel, as well as determination of the amplitude of sensory and motor responses. Focal demyelination can occur with increased median nerve compression. This results in local conduction block and slowing of motor and sensory conduction across the wrist. The axons of the median nerve can be damaged with even greater compression resulting in reduced amplitudes.

The grading of severity of CTS is as follows: Mild - prolonged sensory nerve action potential (SNAP), and/or slightly reduced SNAP amplitude. Moderate - abnormal median SNAP as above, plus prolonged median motor distal latency. Severe - prolonged median motor and sensory distal latencies, plus either an absent SNAP or low amplitude or absent thenar compound muscle action potential. Needle examination often reveal fibrillation, reduced recruitment, and motor unit potential charges[7,8].

There are validated measures such as the Boston Carpal Tunnel Syndrome Questionnaire which quantify symptoms and disability; however, this does not include clinical examinations. One study found that the clinical-neurophysiologic relationships are very strong when they evaluated the clinical picture with the disability scale of the Boston Carpal Tunnel Syndrome Questionnaire as well as clinical examinations findings. Conversely, the clinical-neurophysiologic relationship is not so clear and simple when they compared it with the symptoms only[9]. Other scoring systems include use of hand diagrams such as the Katz[10] hand diagram (looking at distribution of symptoms in the hand) and the CTS-6 scale (looking at symptoms and examination)[11]. A systematic review found there are limited evidence to support the use of these scoring systems[12].

Numerous patients with CTS have severe symptoms but no NCS changes, therefore we hypothesised that a scoring system combining symptoms, signs and risk factors can help with the diagnosis of CTS. The aim of the study was to correlate the severity of NCS results to a scoring system which included

symptoms, signs and risk factors.

MATERIALS AND METHODS

We prospectively collected data for fifty-nine patients who were referred to our hand unit with symptoms of carpal tunnel syndrome. All patients who were referred and diagnosed with CTS clinically were included in the study. Patient with symptoms but diagnosed with other diagnoses were excluded. All patients who clinically showed symptoms of CTS had the ten-point scoring system and NCS carried out. We prospectively collected data for 61 hands (59 patients) over a ten-month period.

We reviewed existing scoring systems and examination signs to develop a scoring system. We developed a 10-point scoring system which included symptoms, signs and risk factors. We scored our patients using the ten-point scoring system. The scoring system included; four symptoms (2 Katz[10] hand diagram – for tingling and numbness, nocturnal paresthesia and bilateral symptoms), four clinical signs (weak thumb abduction test, Tinel's sign, Phalen sign and hypoalgesia in median nerve territory) and two risk factors (age more than 40 years and female sex). We classified the NCS to normal, mild, moderate and severe as described above[8].

This study was conducted prospectively. Local clinical governance approval was obtained. All patients who underwent the ten-point scoring system and had NCS was included. Our ten-point scoring system (Table 1) was applied to patients with symptoms of CTS prior to NCS. The score of the ten-point scoring system was then correlated with the severity results of the NCS. The score was used to correlate with the NCS results but was not used to decide on treatment. As the scoring depended on the signs and symptoms no blinding could be applied to the assessors or the patients. The assessors of clinical signs and symptoms were not involved in the statistical analysis of the results. The data analysis was carried out by a member of authors who were blinded to the patients and tests.

The ten-point scoring system included tingling and numbness on a Katz hand diagram. Nocturnal paresthesia is defined as night numbness and tingling or wakening. Bilateral symptoms imply symptoms involving both hands. Signs included weak thumb abduction; Tinel's sign which is reproduction of the symptoms on tapping over the carpal tunnel; Phalen's sign which is reproduction of the symptoms for CTS on flexion of the wrist for 60 s. Hypoalgesia is defined as reduced sensitivity to a painful stimulus in the median nerve distribution.

Other data collected were age, sex, laterality of hand affected, NCS results and duration of symptoms. It was our common practice in our hospital to refer a patient for a NCS in suspected cases of CTS prior to surgical intervention. All patients in this study were from a single upper limb surgeon's practice. Statistical analysis was done using SPSS. Eta value was used to determine the association between NCS category and CTS score. Eta of 0 is no association and Eta of 1 is perfect association. One way ANOVA test was used to test difference between the groups. The partial Eta squared was used to test how much variability of the scores was accounted for by the NCS severity. Post hoc analysis was carried out to determine which NCS groups have differences between each other. The post hoc analysis used in this study was Scheffe.

RESULTS

There were 61 scores in 59 patients. There were 43 female and 18 male patients. The mean duration of symptoms was 17 mo (range 2-84 mo). Thirty-two were left hands and twenty-nine were right hands. There were 8 patients in the normal NCS category, 14 patients in the mild NCS category, 12 patients in the moderate NCS category and 27 patients in the severe NCS category. The mean age was 60 years (range 37-91 years).

The mean score for the categories were as follows: 6.75 for normal NCS, 5.50 for mild NCS, 9.17 for moderate NCS and 9 for severe NCS. All scores of 8 or more matched with NCS of moderate and severe intensity apart from three scores which were greater than seven that were normal on NCS (Table 2).

One of the three patients who had a score over 7 but had normal NCS was found to have a cervical disc herniation after a magnetic resonance imaging of the cervical spine. This patient underwent cervical disc decompression and had resolution of her symptoms. She did not require a carpal tunnel decompression. The other two patients with a score of 8 and 9 respectively underwent a carpal tunnel decompression despite normal NCS as clinically they were both symptomatic. Both patients reported resolution of symptoms post carpal tunnel decompression.

An Eta coefficient test was performed to determine the strength of correlation between the scores and the NCS categories of normal, mild, moderate and severe. An Eta score was 0.822 for the CTS score being the dependent value and the NCS category being the independent variable shows a strong association between the score and the NCS categories. A one-way ANOVA test showed there were a significant statistical difference between the severity groups ($P < 0.001$). The partial Eta squared was 0.676 meaning that 67.6% of the variability of the CTS score is accounted for by the severity of their CTS.

Table 1 The Liverpool ten-point carpal tunnel syndrome scoring system

	1 point	1 point	0 point
Symptoms			
Tingling (Katz hand diagram)	Classic pattern	Probable pattern	Unlikely pattern
Numbness (Katz hand diagram)	Classic pattern	Probable pattern	Unlikely pattern
Nocturnal paresthesia	Yes		No
Bilateral symptoms	Yes		No
Signs			
Weak thumb abduction	Yes		No
Tinels sign	Yes		No
Phalen's sign	Yes		No
Hypoalgesia	Yes		No
Risk factors			
Age > 40 yr	Yes		No
Female	Yes		No

Table 2 Correlation between our carpal tunnel syndrome scoring and nerve conduction studies results

Score/NCS	Normal	Mild	Moderate	Severe
0				
1				
2		1		
3				
4		2		
5	2	3		
6	2	4		
7	1	4		
8	2		3	9
9	1		4	9
10			5	9

NCS: Nerve conduction studies.

A post hoc analysis showed there were statistical significance between the CTS scores of patients with normal NCS and patients with moderate and severe NCS ($P < 0.001$). There was statistical significance between the CTS scores of patients with mild NCS compared with CTS scores of patients with moderate and severe NCS ($P < 0.001$). There was no significant statistical difference between CTS scores of patients with moderate NCS findings compared with severe NCS findings ($P < 0.979$).

DISCUSSION

An appropriate diagnosis of carpal tunnel syndrome is important as it is a common condition. There is no consensus on whether to base treatment decisions on clinical history and assessment only, or NCS should be done in every case. Within the UK, different areas have different rules on diagnosis and treatment. The British Orthopaedic Association guidelines states NCS is not routinely needed and should only be used if clinical examination and history are equivocal, if there is persistent or recurrent carpal tunnel syndrome or if there is an unclear diagnosis suggesting peripheral neuropathy[13].

NCS may not always be positive in patients who are symptomatic. Not every clinician request NCS because of the costs and delays associated with NCS[14]. One study looking at just history and examination findings concluded that the majority of patients who have CTS on the basis of their scoring system, further NCS studies did not change the probability of diagnosing the condition[11]. Another study looked at using a web-based CTS questionnaire prior to the patient's appointment and found that it provided a sufficiently accurate prediction of the likelihood of CTS to help in the initial planning, investigation and treatment of CTS[15].

A CTS scoring can help in planning and streamlining of services which is of significant importance especially in light of the current pandemic. We should aim to get the right diagnosis as effectively and as efficiently as possible and to use resources such as NCS in a cost-effective way.

The reported sensitivity and specificity for each of our sign and symptoms are as follows; classic or probable Katz hand diagram pattern (0.64, 0.73 respectively), nocturnal paraesthesia (0.51, 0.68 respectively), bilateral symptoms (0.61, 0.58 respectively), weak thumb abduction test (0.66, 0.66 respectively), Tinel sign (0.60, 0.80 respectively), Phalen sign (0.91, 0.86 respectively), hypoalgesia in median nerve (0.51, 0.93 respectively), age more than 40 years (0.80, 0.41 respectively)[10,16-21]. Female sex has an increased risk of developing CTS[22]. This may be due to females being over-represented in jobs that have a high risk of developing CTS. When the occupational exposure is truly similar, the risk of developing CTS is similar between both genders. In our cohort, 71% of patients were females. We did not obtain job specifications for our patients.

This study shows our simple ten-point scoring system have a high correlation with the NCS results. Our CTS score differentiated between patients with normal/mild NCS symptoms to patients with moderate/severe NCS findings. The difference is significant between patients with normal/mild NCS findings compared with patients with moderate/severe NCS findings. We have CTS in patients across the range of the CTS scores but the aim of the scoring system is to identify patients who would most likely benefit from NCS prior to carpal tunnel decompression as their clinical findings are equivocal.

We did not find a difference between patients with moderate and severe NCS findings or between patients with normal and mild NCS findings. However, clinically we feel both the moderate and severe group would be treated with a carpal tunnel decompression, therefore it is more important to differentiate between patients with normal and mild vs. moderate and severe NCS. In patients with normal and mild NCS, treatment will also depend on their symptoms. If symptoms are severe then they will more likely receive surgical intervention otherwise they would initially undergo a period of conservative management. Surgical intervention would only be undertaken should the patient fail their trial of conservative management.

The strength of our study is having a scoring system that combines signs, symptoms and risk factors. There are limitations to our study. It was a relatively small number of patients and we would need further studies to validate our scoring system. We did not have the co-morbidities or occupation of the patients and we did not re-do the scores after surgical decompression to see if the score can be used to monitor outcome post CTD. Further studies looking to include these factors would be beneficial.

CONCLUSION

We feel that this simple scoring system can be used to predict and correlate the severity of NCS in patients with CTS. Based on our study, we believe that patients who score less than eight may require NCS to confirm the diagnosis of CTS. However, patient who score more than 7 have a 93% chance of having moderate to severe CTS on NCS. Use of our simple scoring methods can help determine patients with moderate and severe CTS. In this group of patients, we recommend not using NCS. Patients scoring less than 8 may have mild or moderate CTS and, in this group of patients, we recommend the use of NCS. Further studies, looking to validate the scoring system clinically would be useful.

ARTICLE HIGHLIGHTS

Research background

There is still debate around what is the best approach for assessment of Carpal tunnel syndrome (CTS). Controversies do exist regarding the need for investigations such as the need for nerve conduction studies (NCS) to aid with management decisions.

Research motivation

We hypothesised that a scoring system combining symptoms, signs and risk factors can help with the diagnosis of carpal tunnel syndrome and whether nerve conduction studies would be required.

Research objectives
The aim of the study was to correlate the severity of nerve conduction study results to a scoring system which included symptoms, signs and risk factors.

Research methods
We scored patients' signs and symptoms using our CTS scoring system. This was then correlated with the findings of the NCS. The scoring system included - four symptoms and four clinical signs and two risk factors. We classified the NCS results to normal, mild, moderate and severe.

Research results
All scores of 8 or more matched with NCS results of moderate and severe intensity apart from three scores which were greater than seven that had normal NCS. Eta score was 0.822 for the CTS score being the dependent value and the NCS category being the independent variable showing a strong association between the scoring system and the NCS group.

Research conclusions
Based on our study, we believe that patients who score less than 8 may require NCS to confirm the diagnosis of CTS. However, patients who score more than 7 have a 93% chance of having moderate to severe CTS on NCS. The use of our simple scoring methods can help determine patients with moderate and severe CTS. In this group of patients, we recommend not using NCS. Patients scoring less than 8 may have mild or moderate CTS and in this group of patients, we recommend the use of NCS.

Research perspectives
The use of our Liverpool carpal tunnel scoring system can have the potential to be used to help determine if NCS is required. Further studies looking into the validation of the scoring system is required.

FOOTNOTES

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ORIGINAL ARTICLE

Prospective Study

Clinical efficacy of the Ankle Spacer for the treatment of multiple secondary osteochondral lesions of the talus

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Abstract

BACKGROUND

The Ankle Spacer was developed as a joint-sparing alternative to invasive end-stage surgeries. Currently, there are no clinical studies on the Ankle Spacer.

AIM

To describe the operative technique and the clinical efficacy of the Ankle Spacer for the treatment of multiple, cystic osteochondral lesions of the talus in patients with failed prior operative treatment.

METHODS

This is a prospective study during which patients were assessed preoperatively, at 2- and 6 wk, and at 3, 6, 12 and 24 mo postoperatively. Patients with multiple, cystic or large (≥ 15 mm) osteochondral lesions of the talus after failed prior surgery were included. The primary outcome measure was the numeric rating scale (NRS) for pain during walking at 2 years postoperatively. Secondary outcome measures included the NRS in rest and during stair climbing, the American Orthopaedic Foot and Ankle Society Hindfoot Score, the Foot and Ankle Outcome Score, the Short- Form 36 physical and mental component scale, and the Range of Motion (ROM). Radiographic evaluations were conducted to evaluate prosthetic loosening and subsidence. Revision rates and complications were also assessed.

RESULTS

Two patients underwent an Ankle Spacer implantation on the talus. The NRS during walking improved from 6 and 7 preoperatively to 2 and 2 points postoper-

atively at 2 years, in patient 1 and 2, respectively. The other patient-reported outcome measures also improved substantially. There were no re-operations nor complications. Radiological imaging showed no loosening of the implant and no change of implant position.

CONCLUSION

The Ankle Spacer showed clinically relevant pain reduction during walking, improvement in clinical outcomes as assessed with PROMs, and no complications or re-operations. This treatment option may evolve as a joint-sparing alternative to invasive end-stage surgeries.

Key Words: Hemi-arthroplasty; Ankle Spacer; Talar surface implant; Osteochondral lesions of the talus; End-stage

Core Tip: Our aim was to provide an overview of the clinical efficacy of a novel implant system that is a hemi-arthroplasty of the ankle. This device can be used for multiple, secondary osteochondral lesions of the talus and isolated osteo-arthritis of the talar dome. In this prospective case series, it was shown that this novel device showed promising clinical outcomes and can be considered safe.

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INTRODUCTION

Osteochondral lesions of the Talus (OLT) are pathologic lesions of the talar cartilage and the subchondral bone. These lesions can occur in up to 50% of acute ankle fractures and sprains[1]. For OLTs of larger size (*i.e.*, above 10 or 15 mm in diameter) and of non-fragmentous morphology, the 'standard' operative treatment options such as autologous chondrocyte implantation, osteochondral autograft transfer systems, and a Talar OsteoPeriostic grafting from the Iliac Crest procedure may result in satisfactory clinical outcomes[2-4]. However, in some patients, there are multiple secondary lesions present of large and cystic nature. For these lesions, it is not always possible to harvest an osteo(chondral) autograft that is large enough to replace all the diseased osteochondral tissue of the talus without damaging the donor site or compromising the congruency of the ankle joint. Allograft treatment could be considered for the treatment of these type of lesions. However, these contain the disadvantages of loss of viability and stability in one-third of the grafts, and possibly clinically fail due to immunological reactions[5,6]. However, when there are multiple secondary (*i.e.*, failed prior surgery) lesions present on the talar articular surface in combination with a large and cystic nature, the above-described operative interventions are to be expected to result in relatively inferior outcomes.

To avoid inferior surgical outcomes in patients with persisting complaints after previous unsuccessful conservative management and operative therapy, other effective operative interventions are performed including an ankle arthrodesis or a total ankle prosthesis[7-9]. An (arthroscopic) ankle arthrodesis results in satisfactory clinical outcomes mostly concerning pain[10-12]. However, the operative intervention in question can result in functional limitations due to loss of the range of motion (ROM) of the ankle[13]. Furthermore, an ankle arthrodesis may potentially result in an increased long-term risk of arthritis in adjacent hindfoot joints, particularly the subtalar joint[14]. An alternative option is the placement of a total ankle prosthesis, for which a substantial amount of bone needs to be resected[15]. In order to address the problem of decreased joint motion (in the case of an ankle arthrodesis) and major bone resection (in the case of a prosthesis), a one-piece hemi-arthroplasty covering the talar surface, and leaving the tibia plafond untouched, can be a potential solution to the aforementioned challenges.

Although previous operative interventions similar to such a hemi-arthroplasty have been described in the literature, the studies applied operative techniques with resection of a substantial part of the talar cortical bone and cartilage in order to verify fitting of the implant thereby taking away a potential successful ankle arthrodesis in case of clinical failure[16-18]. Consequently, a novel bone-sparing hemi-prosthesis has been developed (The Ankle Spacer) to enable resurfacing of the talar dome and simultaneously preserving the ROM and potentially optimize physical functioning. Potential advantages include preservation of ankle motion, decreased stress on the midfoot and subtalar joints, and the possibility to perform an ankle fusion after failed hemi-arthroplasty. Up to now, no operative technique description

combined with the first clinical outcomes has been described in the literature. It is therefore the purpose of the present study to describe the operative technique and the clinical efficacy of the Ankle Spacer for the treatment of multiple, cystic OLTs in patients with failed prior operative treatment. Despite the fact that no clinical trials have been published on this specific implant, it is hypothesized that the 2-year postoperative follow-up will show a clinically relevant pain reduction and prosthesis survival.

MATERIALS AND METHODS

Study design

The study concerns a non-randomized, non-blinded, non-comparative prospective trial, with a 2-year follow-up period at the outpatient clinic aiming at assessing pain, function and implant survival, and thereby investigating the clinical efficacy of the Ankle Spacer. The study was approved by the local Medical Ethics Committee (Internal Review Board, IRB) of the Amsterdam University Medical Centre with reference number MEC 2017_175 and was performed in accordance with the principles of the Declaration of Helsinki and the medical Research Involving Human Subjects Act. The study was sponsored by Arthrex as a post market study with reference number EMEA-17037.

Patient selection

All patients eligible for operative implantation of the Ankle Spacer visiting the outpatient clinic between March 2017 and March 2019 for an OLT with a diameter of 15mm or more (anterior-posterior or medial-lateral), an OLT that failed prior operative intervention(s) or patients with multiple OLTs on the talar dome surface, were requested if they were willing to participate in the present clinical trial. If they were interested, patients were informed about this study and were given two wk to decide upon participation. In case patients provided their consent, they were screened for meeting the inclusion and exclusion criteria (Table 1).

Timeframe and outcome assessment

Preoperatively, standing weight bearing conventional radiographs and a computed tomography scan (CT) were taken. Preoperative patient-reported outcome measures (PROMs) consisted of the Numeric Rating Scale (NRS) of pain (during walking, in rest and during stairclimbing), patient satisfaction regarding complaints, activity and treatment, the American Orthopaedic Foot and Ankle Society (AOFAS) Hindfoot Score, Foot and Ankle Outcome Score (FAOS) and the Short-Form 36 (SF-36 physical and mental component scale). The AOFAS score physician subscale and ROM were assessed by an independent researcher who was not involved in the operative procedure[19,20]. Follow-up assessment was performed at two and six weeks, three and six months, one-year and two years postoperatively. At these follow-up moments the patients were requested to fill out a questionnaire consisting of the above-mentioned PROMs and a physical examination was performed to test the ROM (expect for the postoperative visits at 2 wk and 6 wk after the surgery). Radiographs were taken one day, 6 wk, one year and two years postoperatively. At one-year of follow-up, a CT-scan was made (Figure 1 describes the flow-chart outlining the study procedures). In addition, postoperative complications were recorded. Demographic data were also collected. The primary outcome measure in question was the NRS of pain during walking at 2-years follow-up and implant survival. All other outcome measures described above were secondary outcomes.

Description of the device

The Arthrex Ankle Spacer is a one-piece implant system that replaces the talar side of the tibio-talar joint (Figure 2). The Ankle Spacer replaces the articulating upper surface of the talus and offers several implant sizes in millimeters (18, 20, 22, 24, 26, 28) in order to fit to the different sizes of the talus. It is anatomically designed to the native talar dome to provide an optimal fit to the distal articular tibial surface. The implant is polished to a mirror effect on the articulating surface and has a rough titanium plasma spray (TPS) coated under surface with two posts and spikes for implant fixation (US10,350,079 B2). The rough surface enables secondary fixation due to bone ingrowth. Spikes at the posterior part of the prosthesis allow for further fixation to the bone. The weight of the ankle spacer weighs varies from 11 to 22 g, depending on the size of the spacer.

Operative technique

Before receiving the Ankle Spacer, the patient received 2 g of cefazoline pre-operatively. The procedure was carried out under general anesthesia. The patient was placed in the supine position with a tourniquet applied around the thigh and a rolled-up apron underneath the lateral malleolus to facilitate eversion of the foot to improve exposure of the talus. A longitudinal incision between 10 and 15 cm was centered over the ankle immediately lateral to the tibialis anterior tendon. The incision was deepened to the ankle joint while retracting the extensor hallucis longus and the neurovascular bundle laterally. If present, the osteophytes on the anterior tibia edge were removed. Subsequently, the cartilage was

Table 1 Inclusion and exclusion criteria

Patient	Gender	Age	BMI (kg/m²)	Prior procedures
1	M	36	27	2013: Removal of anterior bony ankle impingement
				2013: Arthroscopic screw fixation of talar osteochondral lesion
				2014: Screw removal
				2015: Hyaluronic acid injections (multiple)
				2016: Arthroscopic Bone Marrow Stimulation for talar osteochondral lesion
2	F	56	23	2005: Spongiosaplasty for talar osteochondral lesion
				2008: Arthroscopic bone marrow stimulation for talar osteochondral lesions
				2014: Retrograde drilling for talar osteochondral lesion
				2017: Hyaluronic acid injections (multiple)

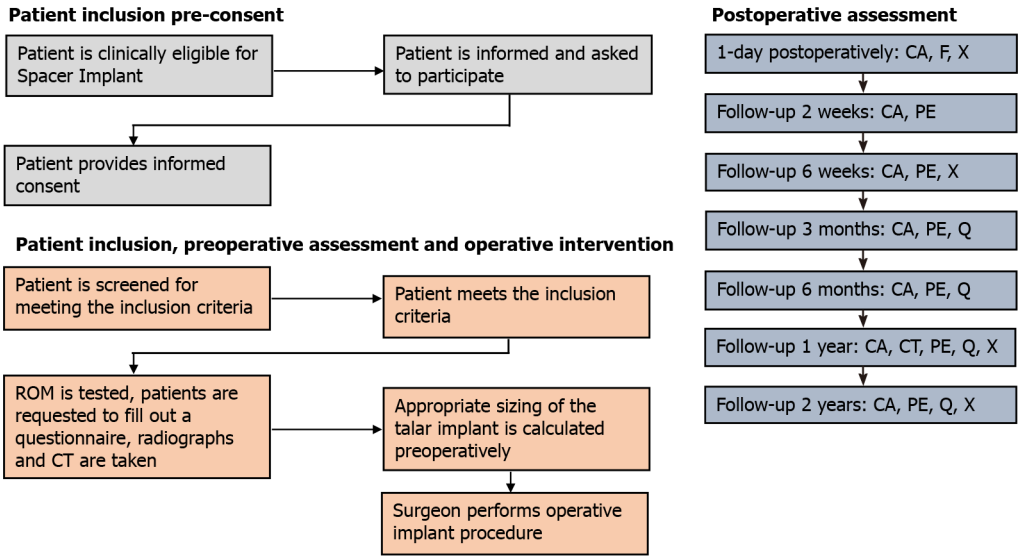

Figure 1 Flow-chart of the study design and main procedures participants will undergo during this study. CA: Complication assessment; CT: Computed tomography; PE: Physical examination; Q: Questionnaires; ROM: Range of motion; X: Mortise and lateral radiographs.

removed (Figure 3A) on the upper talar surface as well as part of the underlying subchondral bone (Figure 3B).

Additionally, microfracturing was performed to support ingrowth for secondary ankle spacer fixation (Figure 3C).

The tibiotalar joint was manually distracted and the appropriate trial Ankle Spacer was inserted into the joint. The trial Ankle Spacer was placed in a central position in the medial-lateral direction. The trial was fixated in the slotted hole with a K-wire and the trial inserter was removed afterwards.

Then, dynamic dorsi- and plantarflexion of the ankle was performed as this allowed self-alignment of the temporarily fixed trial. Afterwards, the trial spacer was fixated with a K-wire in the second hole in order to prevent dislocation, after which both K-wires were advanced bi-cortically in order to achieve proper fixation. Fluoroscopy was used to confirm proper sizing and positioning of the trial Ankle Spacer.

The double drill sleeve was aligned to the two holes on the Ankle Spacer and were maintained in a perpendicular angle relative to the surface of the ankle spacer. Subsequently, drilling was started with the first drill until the moment it stopped on the drill sleeve. This first drill was left for fixation in the drill hole, and then the second drill was to drill the second hole, in exactly the same manner.

Then all instruments were removed. Prior to inserting the Ankle Spacer, the prepared bone bed was thoroughly cleaned and inspected. The Ankle Spacer was inserted on the talar dome using the ankle space inserter, while placing the two posts on the bottom of the Ankle Spacer into the prepared drill holes for fixation. The implant was impacted with an impactor until the posts were fully seated in the drill holes (Figure 4A and Figure 4B). The joint capsule was closed and the layers were closed subsequently.

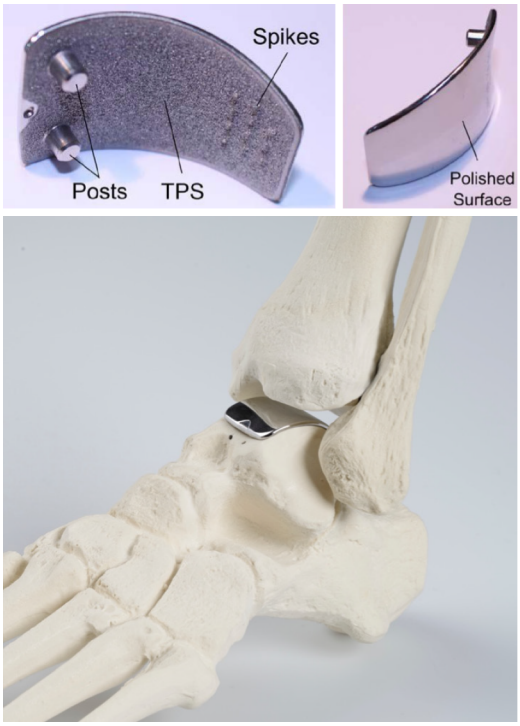

Figure 2 The Ankle Spacer Implant.

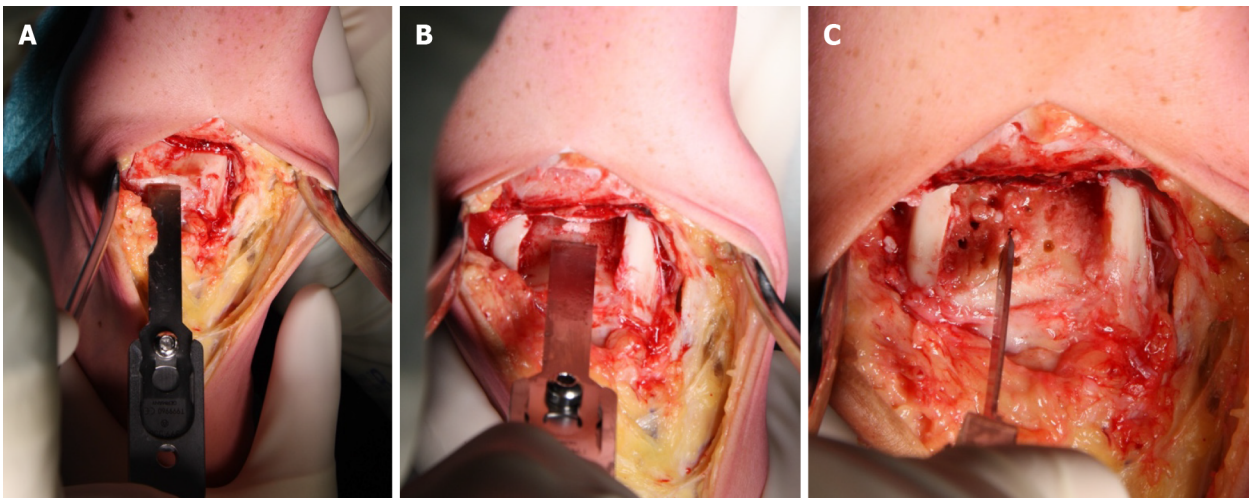

Figure 3 Preparation of cartilage and bone prior to insertion. A: Removal of the talar cartilage; B: Removal of the subchondral bone; C: Bone marrow stimulation of the subchondral bone.

Post-operative protocol

Postoperatively, wound dressing with adequate padding was applied. At hospital discharge a removable lower leg splint was applied. Careful active and passive dorsi- and plantarflexion motion (flexion-extension exercises) without weight bearing monitored by a physiotherapist were started two days after surgery. After two wk of non-weight bearing, depending on the degree of wound and soft tissue healing, mobilization was started with progressive weight bearing to tolerance in a Walker. Flexion-extension exercises were continued. Six wk after surgery, intensive physiotherapy and rehabilitation was started for at least a period of 6 wk.

Power calculation and study population

A power analysis was conducted to estimate the needed sample size for this prospective non-comparative trial using the NRS for pain as primary outcome measure with a clinical relevant difference of 1 point and a standard deviation of 1.5 points. Additionally, in this calculation a standard p-value of 0.05 ($\alpha = 0.05$) and a power of 80% were used. This indicated that a total of 20 patients would need to be included in the trial in order to detect a clinically important difference in pain comparing pre- and

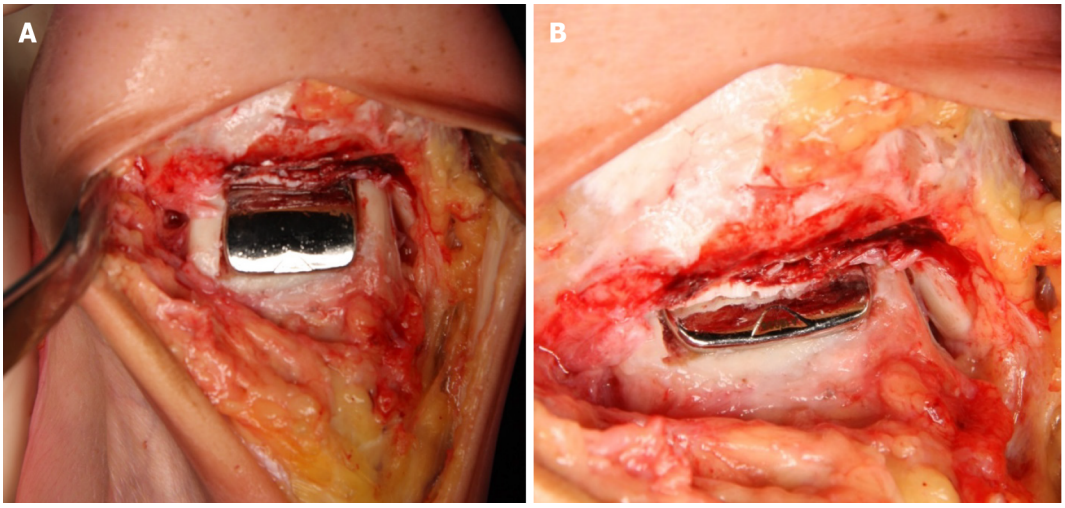

Figure 4 After the insertion of the Ankle Spacer. A: End-result after the insertion of the Ankle Spacer; B: End-result after the insertion of the Ankle Spacer.

postoperative NRS scores. Due to the relative rarity of patients presenting at our outpatient department with the exact above-described inclusion and exclusion criteria, two patients could be identified with fitting indications who were operated on with the implantation of the Ankle Spacer. The age of these patients was 36 and 56 years old (one male, one female). No patients were lost to follow-up. Prior procedures that were performed are listed in Table 2 alongside demographic factors. The pre-operative CT scans of the patients as presented in Figures 5 and 6.

Statistical analysis

All statistical analyses were performed by means of SPSS version 20.0 (SPSS Inc., Chicago, IL, United States). Data will be presented as descriptive analyses through qualitative comparisons in the different patients. Consequently, data will be presented per patient, aiming at presenting changes in scores preoperatively *vs* postoperatively.

RESULTS

Primary outcome

The primary outcome measure, the NRS of pain during walking improved from 6 preoperatively to 2 points at 2 years follow-up in patient 1, and from 7 preoperatively to 2 points postoperatively at 2 years follow-up in patient 2. This entails an improvement of 4 points and 5 points in patient 1 and 2, respectively (Figure 7).

Secondary outcomes

The other PROMs can be appreciated in Table 3. There were no complications and no reoperations. Radiologically, for all postoperative radiographs and CT-scans it was concluded that there were no indications of loosening of the implant, no implant migration, and no subsidence was noted (Figure 8). The ROM assessments were described in Table 4.

DISCUSSION

This is the first study describing the results of the newly developed Ankle Spacer. The Ankle Spacer is a one-piece implant system that replaces the talar side of the tibiotalar joint, and can therefore be considered a hemi-arthroplasty procedure. The implant had been designed in order to overcome a number of downsides that are associated with the current treatment options for large, cystic, or multiple osteochondral lesions of the talus that have failed prior operative intervention(s). One of these treatment option being applied in the younger patient population is an arthroscopic ankle arthrodesis which results in highly satisfactory clinical outcomes mostly concerning pain outcomes[10-12]. The downside of this operative intervention is that it results in functional limitations due to loss of ROM of the ankle [13]. Furthermore, an ankle arthrodesis increases the long-term risk of (radiographic) osteoarthritis in adjacent hindfoot joints, particularly in the subtalar joint[14,21]. An alternative option is the placement of a total ankle prosthesis, for which a substantial amount of bone needs to be resected[15,22]. In order to tackle the downsides of these treatment options, develop a bone-sparing procedure and resurfacing

Table 2 Patient characteristics

Inclusion criteria	Exclusion criteria
Age ranging from 18 to 80 yr	Severe ankle malalignment (more than 5° varus or valgus)
Failed previous conservative treatment	Suspicion of grade two or higher (Kellgren-Lawrence-Score) ankle joint degeneration on the tibia side
Complaints for at least 6 mo	Ankle Fracture less than 6 mo ago
Talar osteochondral lesions (multiple degenerative talar cysts present, and/or prior failed operative treatment and/or multiple defects and/or a diameter of 15mm or more)	Tendinitis
	Advanced osteoporosis
	Adiposity grade I (BMI of 30 kg/m^2 or more)
	Diabetes mellitus / reumathoid arthritis / severe neuro-arthropathy
	Blood supply limitations and active infections, which may retard healing
	Foreign-body sensitivity
	Currently participating in an investigational drug or another device study that clinically interferes with the current study endpoints

BMI: Body mass index; F: Female; M: Male.

the talar dome to preserve ROM and potentially optimize physical functioning, the Ankle Spacer, a novel bone-sparing hemi-prosthesis, has been developed. The outcomes of treatment with the Ankle Spacer were described in the present article. Potential advantages include preservation of ankle motion, decreased stress on the midfoot and subtalar joints, and the possibility to perform an ankle fusion after failed hemi-arthroplasty.

It is therefore clear that the Ankle Spacer is a new and innovative device. The current study is the first clinical trial performed investigating the efficacy of the Ankle Spacer, and therefore there is no clinical literature on this particular prosthetic device at this time to compare our clinical results to. Our current clinical results must therefore be compared to similar devices having been researched over the past decade. An articular and subchondral bone resurfacing implant procedure on one side of the joint (hemi-arthroplasty) can be considered a relatively novel operative intervention. Promising clinical results have been reported for similar treatment in the femoral and humeral head, as well as the first metatarsal and patellar surface. [16,23-27]. Van Bergen *et al*[17,18,28] showed that a focal resurfacing implant is a promising treatment for talar OLTs that have failed prior operative treatment[28]. They concluded that in a patient series including 38 patients the clinical results at a mean follow-up of three years were satisfactory. A different study by Holton *et al*[29] demonstrated that the use of a different resurfacing implant in the form of an articular resurfacing component maintained a good clinical improvement for patients at mid-term follow-up. A study by Brunner *et al*[30] which is less clinically comparable as it replaces the whole entity of the ankle, as opposed to the resurfacing of the talar surface as done by the Ankle Spacer or as opposed to the resurfacing implant as used by van Bergen *et al*[4,6,31], showed that short- term to mid-term results for patients treated with the Scandinavian Total Ankle Replacement (STAR) prosthesis have been encouraging. The long-term results were clinically inferior compared to the short-term and mid-term results. Additionally, studies on the Total Ankle Replacement (TAR), which is, to a certain though limited extent, comparable to the Ankle Spacer, have shown that long-term results demonstrated improved pain scores as it was observed to be a viable and durable operative implantation option[32,33]. Another implantation technique in the form of a Tornier Salto Talaris Anatomic Ankle has been described in the literature. Mid- term results showed that the survivorship of this implant was calculated to be around 95%[34,35]. A study by Queen *et al*[36] found that at a follow-up of 2 years investigating 51 patients after a fixed-bearing Total Ankle Replacement significant improvements in gait mechanics, pain reduction and functioning were observed.

As an objective conclusive remark on the evidence found on similar operative techniques, one can state that similar operative techniques yielded favorable clinical, radiological and safety outcomes. When comparing these three aspects to our results it can be concluded that in our treated patients, similar outcomes were found. Postoperative improvement was especially clear in the observed primary outcome measure which was the NRS pain during walking. This outcome measures typically describes the state and magnitude of pain in patients with OLTs of the talus as these patients experience pain especially when performing weight bearing activities, but often are unable to participate in sports due to complaints[4]. It was shown that this primary outcome measure improved from 6 and 7 preoperatively

Table 3 Preoperative and postoperative outcomes for patients 1 and 2

Patient 1						
Time-Point	FAOS	SF-36	AOFAS ankle hindfoot score	NRS satisfaction with current activity level	NRS satisfaction with daily functioning despite any complaints	NRS satisfaction with treatment so far
Preoperatively	Pain: 56; Symptoms: 46; ADL: 68; Sports: 20 QoL: 25	PCS: 28; MCS: 61	61	3	3	8
3 mo postoperatively	Pain: 86; Symptoms: 82; ADL: 91; Sports: 40 QoL: 63	PCS: 44; MCS: 55	82	7	8	9
6 mo postoperatively	Pain: 79; Symptoms: 86 ; ADL: 93; Sports: 60 QoL: 63	PCS: 45; MCS: 53	75	7	8	9
1 year postoperatively	Pain: 46; Symptoms: 67; ADL: 79; Sports: 25 QoL: 44	PCS: 39; MCS: 56	77	6	4	7
2 years postoperatively	Pain: 62; Symptoms: 81; ADL: 90; Sports: 55 QoL: 69	PCS: 51; MCS: 52	100	8	8	9
Patient 2						
Preoperative	Pain: 81; Symptoms: 79; ADL: 91; Sports: N.A. QoL: 25	PCS: 44; MCS: 56	72	5	6	7
3 mo postoperatively	Pain: 64; Symptoms: 68; ADL: 66; Sports: 30 QoL: 0	PCS: 33; MCS: 41	69	2	2	2
6 mo postoperatively	Pain: 68; Symptoms: 69 ; ADL: 72; Sports: 30 QoL: 13	PCS: 29; MCS: 54	71	1	5	1
1 year postoperatively	Pain: 72; Symptoms: 50; ADL: 72; Sports: 30 QoL: 19	PCS: 33; MCS: 51	68	2	5	2
2 years postoperatively	Pain: 81; Symptoms: 68; ADL: 78; Sports: 55 QoL: 50	PCS: 43; MCS: 53	88	9	9	8

ADL: Activities in daily living; AOFAS: American Orthopaedic Foot and Ankle Society; FAOS: Foot and ankle outcome score; MCS: Mental component scale; NRS: Numeric rating scale; PCS: Physical component scale; QoL: Quality of life; SF-36: Short-form 36.

to 2 and 2 postoperatively at 2 years, in patient 1 and 2, respectively. As a result, we can conclude that for both patients a minimal clinically important difference was reached when comparing the preoperative state of pain to the postoperative state of pain at 2 years after the surgery. As an improvement of at least −1.0 on the NRS scale of 0 to 10 points is significantly associated with the concept of a "better improvement", and an improvement of -2.0 on this scale is associated with a "much better improvement"[31]. The improvement was also reflected in the radiological outcomes and the subjective satisfaction scores that were taken both preoperatively and postoperatively at the different follow-up moments in which it was clear that the patients stated that they were satisfied with their level of activity. Moreover, this was also reflected in the postoperative AOFAS Hindfoot Scale, which ranged from 88 to 100, scores that can be considered to represent a successful surgery.

Furthermore, it was observed that there were no complications, no reoperations nor revisions, which implicates that, when extrapolating these results for a larger population based on our experience, the insertion of the Ankle Spacer can be regarded a safe procedure. This outcome should be interpreted in the light of the high re-intervention rates that are associated with Total Talar Prostheses, as some studies report that up to 38% of the patients need revision surgery within the first year after total ankle arthroplasty[37]. With regards to ROM, it was shown that the ROM did not decrease in the patients, potentially due to the fact that patients received adequate postoperative physiotherapy and because of the fact that the Ankle Spacer was inserted just below the level of the subchondral bone plater not affecting joint congruency. This is clinically relevant to take into account when comparing ROM outcomes after placement of the Ankle Spacer to outcomes after an ankle arthrodesis procedure[38].

This study should be interpreted in light of its strengths and weaknesses. Strengths of this study include its prospective and thorough methodology, completeness of follow-up, and the use of various validated outcome measures in the assessment of a not yet studied resurfacing implant. Limitations

Table 4 Preoperative and postoperative range of motion outcomes patient 1 and 2

	Patient 1		Patient 2	
	Dorsiflexion in degrees (affected/unaffected side)	Plantarflexion in degrees (affected/unaffected side)	Dorsiflexion in degrees (affected/unaffected side)	Plantarflexion in degrees (affected/unaffected side)
Preoperative	5 / 10	35 / 40	5 / 5	40 / 40
2 wk postoperatively	5 / 15	20 / 40	2 / 15	25 / 40
6 wk postoperatively	7 / 10	35 / 40	5 / 10	35 / 40
3 mo postoperatively	10 / 10	35 / 45	5 / 10	35 / 40
6 mo postoperatively	10 / 10	35 / 45	10 / 10	35 / 40
1 yr postoperatively	10 / 10	35 / 45	10 / 10	35 / 40
2 yr postoperatively	10 / 10	35 / 45	7 / 10	35 / 40

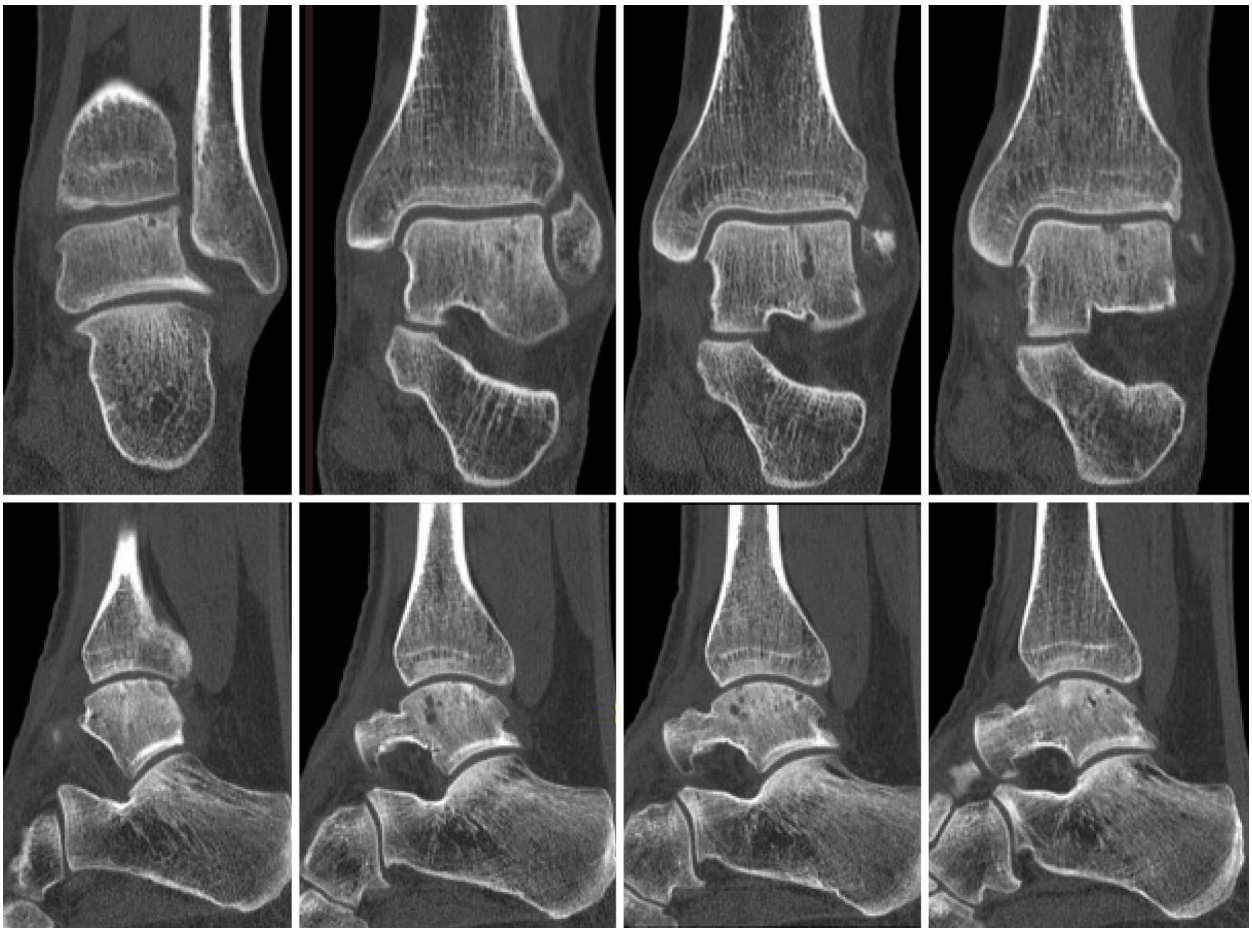

Figure 5 Pre-operative computed tomography scan of patient number 1: Upper part shows coronal slides with the images from left to right going into the posterior to anterior direction. The lower part shows sagittal slides with the images from left to right going from lateral to medial.

include the absence of a controlled group, lack of long-term follow-up outcomes ranging past the two years follow-up, and the small series of patients. However, we have found in our tertiary referral clinic that operates in an academic setting with the status of an official (inter)national expertise center for the treatment of OLTs in the ankle that the indication for an Ankle Spacer implantation is highly rare, even though we receive a high number of patients on a yearly basis. As a result, it was therefore noted that the Ankle Spacer has been removed from the market due to limited indications and strict regulatory

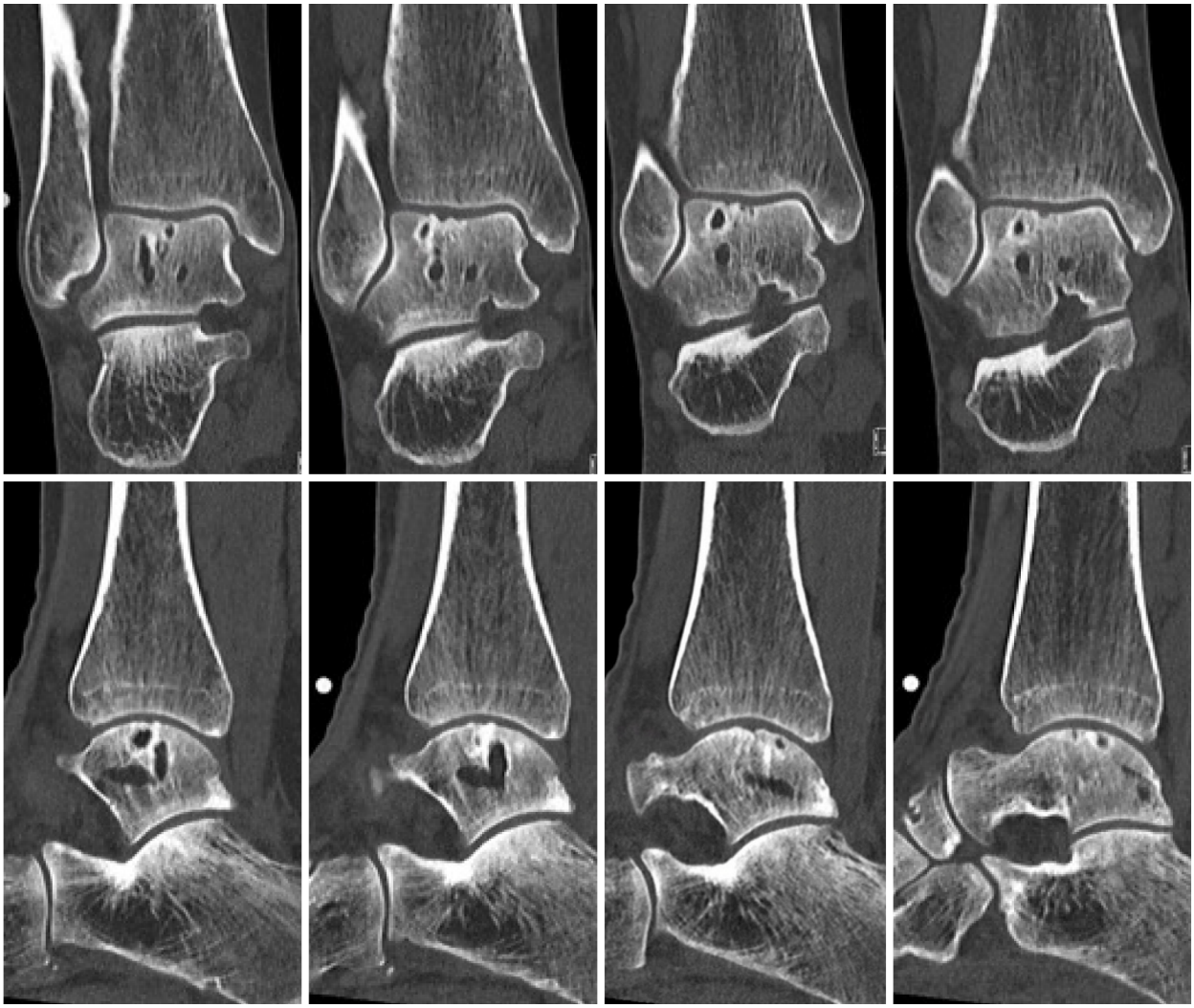

Figure 6 Pre-operative computed tomography scan of patient number 2: Upper part shows coronal slides with the images from left to right going into the posterior to anterior direction. The lower part shows sagittal slides with the images from left to right going from lateral to medial.

requirements.

The clinical relevance of the present study can be interpreted in the light of the highly specific indication for the implantation of the Ankle Spacer. This device is particularly suited for patients with multiple OLTs of the talar dome having failed prior operative intervention(s) with an unaffected distal tibial part of the ankle joint. This study shows that the Ankle Spacer is effective for this particular and rare patient group, thereby functioning as a joint-sparing alternative to more invasive operative interventions, such as an ankle arthrodesis or total ankle arthroplasty.

CONCLUSION

The Ankle Spacer showed clinically relevant pain reduction during walking, improvement in clinical outcomes as assessed with PROMs, and no complications or re-operations. This treatment option may therefore evolve as a joint-sparing alternative to an ankle arthrodesis, a total talar implant or a total ankle arthroplasty/resurfacing.

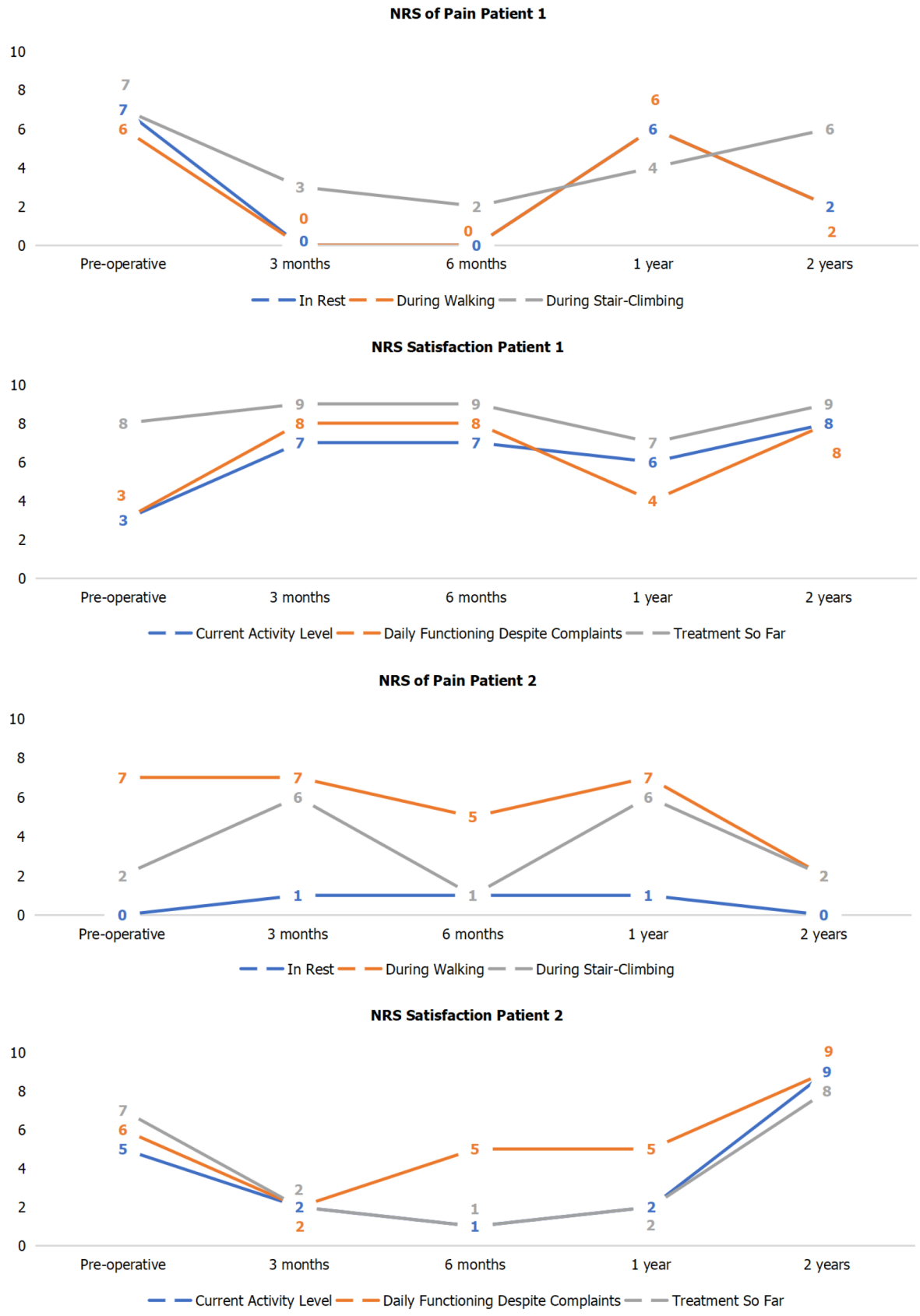

Figure 7 Pre-and postoperative Numeric Rating Scale scores of pain and satisfaction for patients 1 and 2.

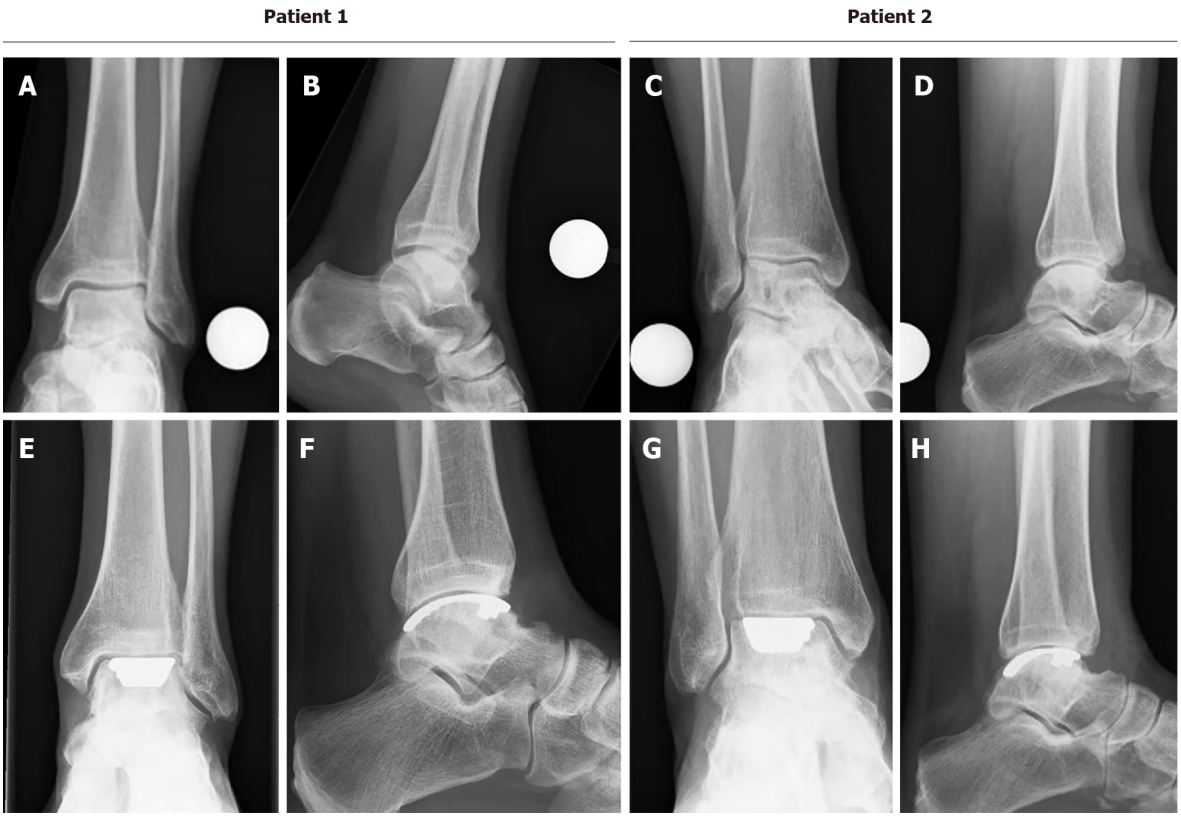

Figure 8 Preoperative and postoperative radiographs. A and C: Preoperative mortise radiographs; B and D: Preoperative lateral radiograph; E and G: Postoperative mortise radiograph (2-years); F and H: Postoperative radiograph.

ARTICLE HIGHLIGHTS

Research background

Osteochondral lesions of the Talus (OLT) are pathologic lesions of the talar cartilage and the subchondral bone. These lesions can occur in up to 50% of acute ankle fractures and sprains. For OLTs of larger size (*i.e.*, above 10 or 15 mm in diameter) and of non-fragmentous morphology, the 'standard' operative treatment options such as autologous chondrocyte implantation, osteochondral autograft transfer systems, and a Talar OsteoPeriostic grafting from the Iliac Crest procedure may result in satisfactory clinical outcomes. However, in some patients, there are multiple secondary lesions present of large and cystic nature. For these lesions, it is not always possible to harvest an osteo(chondral) autograft that is large enough to replace all the diseased osteochondral tissue of the talus without damaging the donor site or compromising the congruency of the ankle joint. Allograft treatment could be considered for the treatment of these type of lesions. However, these contain the disadvantages of loss of viability and stability in one-third of the grafts, and possibly clinically fail due to immunological reactions. However, when there are multiple secondary (*i.e.*, failed prior surgery) lesions present on the talar articular surface in combination with a large and cystic nature, the above-described operative interventions are to be expected to result in relatively inferior outcomes.

Research motivation

Currently, it is difficult to treat patients with osteochondral lesions of the ankle that are of multiple, cystic and secondary nature. This is because the lesions are considered relatively large and difficult to treat. For this indication, it was usually performed to fuse the ankle joint. However, in the past 2 to 5 years, novel innovative surgical options have been developed, such as the Ankle Spacer, in order to overcome an ankle fusion or ankle prosthesis.

Research objectives

To describe the operative technique and the clinical efficacy of the Ankle Spacer for the treatment of multiple, cystic OLTs in patients with failed prior operative treatment.

Research methods

In a prospective study including patients with multiple, cystic or large osteochondral lesions of the talus were included who failed previous surgical treatment. We looked at the numeric rating scale (NRS) for

pain during walking at 2 years after implantation of the Ankle Spacer and we also assessed the NRS in rest and during stair-climbing, the American Orthopaedic Foot and Ankle Outcome Score, the Foot and Ankle Outcome Score, the Short-Form 36 and the range of motion of the ankles both pre-operatively as well as post-operatively. Radiographic evaluations were conducted to evaluate prosthetic loosening and subsidence. Revision rates and complications were also assessed.

Research results

In this prospective study, two patients underwent the implantation of an Ankle Spacer for osteochondral damage on the talar dome. We found that there were clinically relevant pain reductions during walking as well as important improvements in clinical outcomes as assessed with the patient-reported outcome measures. Furthermore, it was found that there were no complications nor re-operations.

Research conclusions

The Ankle Spacer showed good clinical outcomes and clinically relevant pain reduction during walking, improvement in clinical outcomes as assessed with PROMs, and no complications or re-operations. This treatment option may therefore evolve as a joint-sparing alternative to an ankle arthrodesis, a total talar implant or a total ankle arthroplasty/resurfacing.

Research perspectives

Future research should be focused at the development of a prospective, self-learning algorithm taking into account the individual patient factors influencing outcomes after conservative and surgical treatment so that we can assess which patients would benefit most from which treatment options.

FOOTNOTES

Author contributions: Dahmen J, Altink JN, Vuurberg G, Wijdicks C, Stufkens S and Kerkhoffs G have made substantial contributions to conception and design, acquisition of data, analysis and interpretation of data, and have been involved in drafting the manuscript; Dahmen J and Altink JN have been involved in the acquisition of data; all authors have been involved in revising the manuscript, critically for important intellectual content, and have given final approval of the version to be published.

Institutional review board statement: The study was approved by the local Medical Ethics Committee (Internal Review Board, IRB) of the Amsterdam University Medical Centre with reference number MEC 2017_175 and was performed in accordance with the principles of the Declaration of Helsinki and the medical Research Involving Human Subjects Act (WMO).

Informed consent statement: All patients provided informed consent prior to the participation in the study.

Conflict-of-interest statement: The study was sponsored by Arthrex as a post market study with reference number EMEA-17037.

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SYSTEMATIC REVIEWS

COVID-19 pandemic: An update on the reaction attitude of the spine societies and their members worldwide

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Abstract

BACKGROUND

All surgical specialties have been influenced by the coronavirus disease 2019 (COVID-19) pandemic, and substantial changes have been determined in medical assistance, especially in elective surgery. Several spine societies have published recommendations to provide optimal care during this unique situation.

AIM

To discuss the recommendations by many spine societies for the management of spinal diseases during the COVID-19 pandemic.

METHODS

The present study was performed according to the PRISMA guidelines. A review of the MEDLINE database (PubMed – National Library of Medicine), Google, and Google Scholar was performed from March 2020 to date for articles published in the English Language.

RESULTS

Spine associations and societies worldwide were divided into three groups: Continental, specialty and country-based societies. A total of 27 spine associations were included in this review. There were eight major continental associations, but only one-third of these had published guidelines and recommendations on this topic. On the other hand, the specialty-based societies have not addressed the topic, except in two cases.

CONCLUSION

The national spine societies showed the deepest concern on this topic with several publications in scientific journals influenced by the local epidemiological severity. Contrarily, continental and specialty-based societies showed less interest in this topic.

Key Words: COVID-19; Pandemic; Spine surgery; Spine society; Guidelines; Recommendations

Core Tip: We designed a review to verify the reaction of the worldwide spine societies to the coronavirus disease 2019 pandemic. Twenty-seven associations were identified. Continental and specialty-based companies showed less reaction attitude than the regional scientific societies, probably due to the local epidemiological severity of the disease.

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INTRODUCTION

With the start of the global pandemic of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in December of 2019, governments and healthcare providers were put on alert, fearing this novel virus that would ultimately lead to the declaration of a global pandemic on March 11.

This naturally resulted in healthcare systems around the world bracing for impact. The biggest hurdle that these systems expected was the need to accommodate a huge surge of patients requiring intensive care (early data suggested that 15%-35% of patients affected with the virus would need admission to the intensive care units). This load would effectively break a healthcare system.

The scientific community has continued to study SARS-CoV-2 to understand its pathogenicity while also trying to avoid the collapse of the healthcare structure and decrease the number of collateral deaths.

Several studies on the recommendations have been published by the major spine scientific societies worldwide[1-5]. The concluding observations of this review highlighted how these surgical scientific communities had promptly reacted to the emergency by issuing documents and guidelines. Here we review the literature concerning the release of documents, guidelines, or recommendations by spine societies, providing a comprehensive overview on these topics, thus providing a useful resource for spine surgeons worldwide.

MATERIALS AND METHODS

According to the PRISMA guidelines, a review of the MEDLINE database (PubMed - National Library of Medicine), Google, and Google scholar were performed on Monday, March 2, 2020, to date, for articles published in the English language. Search terms included: COVID-19 coronavirus AND pandemic AND spine AND surgery AND spine societies AND guidelines AND recommendations (Figure 1). We reviewed search results to assess the relevance of documents on these topics, including editorials, letters, and webpages. References were reviewed to locate other articles of interest.

RESULTS

Twenty-eight associations and societies deal with the scientific aspects and interventional treatment of spine disorders. Spine associations and societies worldwide were divided into three groups: Continental (C) (n = 8), specialty (Sb) (n = 7), and country-based (Cb) (n = 12) societies. There were eight C-companies (Table 1), but only three [North America Spine Society (NASS), World Spine Column Society (WSCS), Asia Pacific Spine Society] published guidelines in international scientific journals. The Sb societies (Table 2) seem not to have addressed the topic. Only the Spine Intervention Society (SIS) published an online paper on their website with its guidelines. Furthermore, the AO spine website shows different strategies for maintaining internal research and training.

All 12 Cb (Table 3) produced a publication: seven in scientific journals (French Spine Surgery Society), Saudi Spine Society (Saudi SS), Singapore Spine Society, Chinese Spine Society, The Japanese Society for Spine Surgery and Related Research, Egyptian Spine Association, Brazilian Spine Society) and the remaining five in websites or editorial documents (British Association of Spine Surgeons, Italian Spine Society, Association of Spine Surgeons of India, German Spine Society, Canadian Spine Society).

Table 1 List of the 8 spinal continental societies

Continental societies	Links
World Spinal Column Society	https://www.worldspinalcolumn.org/
The Africa Spinal Cord Injury Network	http://www.afscin.org/afscin-4-2020
Asian Spinal Cord Network	https://ascon.info/
International Spinal Cord Society	https://www.iscos.org.uk/
North American Spine Society	https://www.spine.org/
European Spine Society	https://www.eurospine.org/
Asia Pacific Spine Society	https://www.apssonline.org/
Latin America	https://www.silaco.org/acerca

Table 2 List of the 7 specialty-based societies

Specialty-based societies	Links
International Society for the Advancement of Spine Surgery	https://www.isass.org/
AOSpine	https://aospine.aofoundation.org
Society for Minimally Invasive Spine Surgery	http://ismiss.com/1-0-Home.html
Scoliosis Research Society	https://www.srs.org/
Cervical Spine Research Society	https://www.csrs.org/
The International Society for the Study of the Lumbar Spine	https://www.issls.org/
Spine Intervention Society	https://www.spineintervention.org/

Table 3 List of the 12 country-based societies

Country-based societies	Links
Italian Spine Society	https://www.gis-italia.org/
Saudi Spine Society	http://saudispine.org/
Association of Spine Surgeons of India	http://assi.in
Singapore Spine Society	https://www.singaporespinesociety.org.sg/
German Spine Society	https://www.dwg.org/startseite/
French Spine Society	http://scfr.it
Egyptian Spine Association	https://www.facebook.com/Egyspine/
Chinese Spine Society	https://www.apssonline.org/
Iranian Spine Surgery	http://www.aicnss.com/
British Ass. Spine Surgeons	https://spinesurgeons.ac.uk/
Canadian Spine Society	https://spinecanada.ca/
Brazilian Spine Society	http://www.plataformainterativa2.com/coluna/

The literature search yielded a sum of 28 articles that were relevant to spine surgery and coronavirus disease 2019 (COVID-19) (Table 4). We were able to identify four main topics developed in these papers.

DISCUSSION

COVID-19, also known as acute respiratory disease, is an infectious respiratory disease caused by SARS-CoV-2. The first cases were identified in China, and after that, diffused around the world through respiratory droplets, with a high lethality rate. In this scenario, the COVID-19 pandemic has changed

Table 4 Selection of 28 articles from members of the spine societies

Article title	Journal	Society/Country	Ref.
Triaging Spine Surgery in the COVID-19 Era	*Journal of Spinal Disorders and Techniques*	AO Spine	[1]
Triaging Spine Surgery and Treatment during the COVID-19 Pandemic	*Journal of Orthopaedics and Traumatology*	USA	[2]
French Spine Surgery Society guidelines for management of spinal surgeries during COVID-19 pandemic	*World Journal of Clinical Cases*	French	[3]
Strategy for the Practice of Spine Oncological Surgery During the Covid-19 Pandemic	*Spine*	Italy	[6]
Spine Surgery and COVID-19: The Influence of Practice Type on Preparedness, Response, and Economic Impact	*Global Spine Journal*	AO Spine	[7]
Spine Surgery and COVID-19: Challenges and Strategies from the Front Lines	*Journal of Bone and Joint Surgery*	Singapore	[8]
Spine Surgery and COVID-19: Early Experiences From Singapore	*Spine*	Singapore	[9]
COVID-19 Nonessential Surgery Restrictions and Spine Surgery: A German Experience	*Spine*	Germany	[10]
The Impact of COVID-19 pandemic on Spine Surgeons: An Asia Pacific Spine Society (APSS) Survey	*Spine*	Asia Pacific	[11]
COVID-19 and Spine Surgery: A Review and Evolving Recommendations	*Global Spine Journal*	USA	[4]
Spine surgery in Atlantic Canada in the COVID-19 era: lessons learned so far	*Spine*	Canada	[12]
Spine Surgery in Italy in the COVID-19 Era: Proposal for Assessing and Responding to the Regional State of Emergency	*World Neurosurgery*	Italy	[13]
The Saudi Spine Society guidelines on spinal surgery during the COVID-19 pandemic	*Journal of Orthopaedics and Research*	Saudi	[5]
Recommendations for resuming elective spine surgery in the COVID-19 era	*British Journal of Anaesthesiology*	USA	[14]
Principles for Managing Patients with Spinal Ailments in the Coronavirus Disease 2019 Era: What Do We Know So Far? An Evidence-Based, Narrative Review	*Asian Spine Journal*	India	[15]
Medical care for spinal diseases during the COVID-19 pandemic	*Clinics*	Brazil	[28]
The management of emergency spinal surgery during the COVID-19 pandemic in Italy	*Bone and Joint Journal*	Italy	[16]
Scoring System to Triage Patients for Spine Surgery in the Setting of Limited Resources: Application to the Coronavirus Disease 2019 (COVID-19) Pandemic and Beyond	*World Neurosurgery*	USA	[17]
Management of Spine Trauma in COVID-19 Pandemic: A Preliminary Report	*Archives of Bone and Joint Surgery*	Iran	[18]
Advice on Standardized Diagnosis and Treatment for Spinal Diseases during the Coronavirus Disease 2019 Pandemic	*Asian Spine Journal*	China	[19]
The Role of Spine Surgeons in the Era of COVID-19 Outbreak	*Neurospine*	China	[20]
Addressing Coronavirus Disease 2019 in Spine Surgery: A Rapid National Consensus Using the Delphi Method *via* Teleconference	*Asian Spine Journal*	Singapore	[21]
Adapting Policy Guidelines for Spine Surgeries During COVID-19 Pandemic in View of Evolving Evidences: An Early Experience From a Tertiary Care Teaching Hospital	*Cureus*	India	[22]
Addressing a national crisis: the spine hospital and department's response to the COVID-19 pandemic in New York City	*Spine Journal*	USA	[23]
Essential Spine Surgery During the COVID-19 Pandemic: A Comprehensive Framework for Clinical Practice from a Specialty Orthopedic Hospital in New York City	*HSS Journal*	USA	[24]
Impact of the COVID-19 pandemic on spinal surgery in Singapore	*Singapore Medical Journal*	Singapore	[25]
The Novel Corona Virus COVID-19 and Spinal Surgery Practice: Review and Updates	*The Egyption Spine Journal*	Egypt	[26]
Spine Surgery: Precautions and Strategies to Minimize Perioperative Risks Amid COVID-19 Outbreak	*Spine Surgery and Related Research*	Japan	[27]

COVID-19: Coronavirus disease 2019.

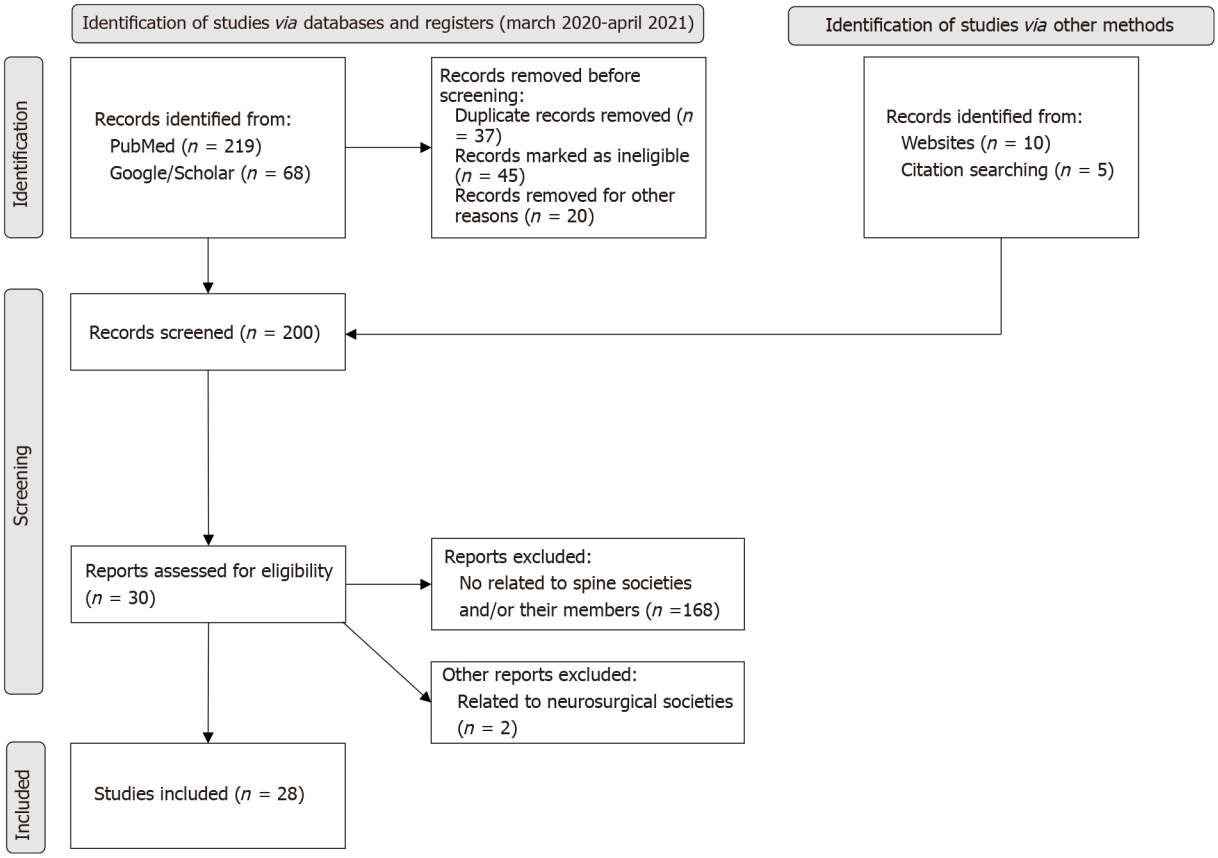

Figure 1 PRISMA flow chart.

medical and surgical practices worldwide. Major scientific societies have issued guidelines and recommendations to optimize resources and ensure treatment without putting patients' lives at risk. Urgent or non-deferrable emergency interventions were favoured, postponing those in the election but seeking their reactivation as soon as possible[6,10,12,14,18]. These changes have had a significant socio-economic impact. Specialty-based societies have also taken action, and in particular, the neurosurgical scientific community has promptly developed recommendations for managing patients with cranial or spinal pathologies[29]. A group of Italian neurosurgeons summarized these guidelines in a recent publication[30]. They discussed the "grey zone" left by the generalized guidelines regarding neurosurgery and how they should be acting to resume control.

Similarly, we wanted to verify the reaction of the worldwide spine societies to this emergency. This topic, to our knowledge, has not previously been addressed in the literature. Twenty-six associations, present on the web as companies or networks that deal with the interventional treatment of spinal pathologies, were identified. Three out of eight (37.5%) major continental companies (Saudi SS, NASS, WSCS) had issued guidelines in the form of scientific work in a journal or document. In particular, the NASS guidance, released on April 22, probably remains the most cited and applied document in subsequent scientific paper[21,26-28]: "*……after reviewing the recommendations regarding procedures and treatments developed by the Centers for Medicare and Medicaid Services (CMS) and the American College of Surgeons (ACS), NASS convened a multidisciplinary task force of orthopaedic surgeons, neurosurgeons and PM&R/pain specialists to provide spine-care specific guidance for procedures*" (see the entire document by the link in Table 2). The Asia Pacific society published a survey about the impact of a pandemic on surgical activity[11]: a total of 222 respondents from 19 countries completed the questionnaire. The mean reduction of clinic volume for all countries was 48.1%. Surgical theatres were closed, reduced, or limited to semi-emergency and emergency surgeries, and spine surgeons were moderately concerned about contracting COVID-19 during their clinical practice extremely concerned to transmit the disease to their family members.

Most Sb societies seem not to have addressed the topic. Only the SIS published a website document with its guidance. The AO spine website shows some corporate strategies for maintaining internal research and training. The greatest interest was from 12 Cb, with publications in journals, websites, or editorial documents. However, other regional societies are lacking. Four themes were seen recurring in our review of 28 articles relating to the new proposed guidelines and line of action. The highest recurring theme, which was seen in 100% of the articles, was the use of protective personal equipment and protocols to follow with COVID positive and COVID suspected patients to curb the spread and limit the transmission (Table 4).

The second was the use of a multidisciplinary panel to evaluate each patient admitted and the urgency[8,9,13]: doctors would have to decide based on the COVID burden imposed on the healthcare system and hospitals[15,17,19,24].

The third theme aimed to decrease the general activity of the healthcare system, increasing the number of hospital intensive care and departments able to treat infected people and the expected wave of patients. This topic was further discussed in detail the distinction of patients concerning their clinical picture and severity[20,22,23,25,27], given priority and urgency in treatment.

The fourth and last theme, which was seen only in seven articles, was the use of a team-based approach: each team could act independent, developing its own schedule and location, reducing work delay and decreasing the mixing of the different teams. A minimal effect on their department's function was recorded. When viewing the Cb spine societies, we found different approaches to achieve similar objectives, ensuring a treatment activity on the most urgent patients or patients who cannot be postponed without increasing the risks of exposure or contact with the virus.

Most of the approaches were directed towards a "second phase", which defines a period when the healthcare system is not overburdened by the pandemic. One point shared was the distinction and separation of patients based on clinical urgency and COVID status, resulting in the avoidance of unneeded risk. Checklists and forms, along with history taking and evaluation of the physician to both the patient's condition and the system's utilization, were extremely useful. The evaluation of the system was carried out by taking into consideration risks and resources. These were respectively weighted on the patient's history and system capabilities, for example, by checking the ability of a healthcare facility to deal with an emergency situation. Surgery was chosen only when possible and needed, while a deferral was preferred to elective and low urgency cases. To guarantee patients during the hospital stay, hygiene, self-isolation rules, and restrictions on companionship rules were adopted. Fast-track recovery and online follow-up restricted the number of unneeded people in the hospital.

CONCLUSION

Only one-third of continental spine societies have issued recommendations. The international specialist companies have little addressed the topic, except for the SIS and partly the AO spine. Paradoxically, the national companies were more stimulated to issue their guidelines. The local epidemiological severity has likely influenced the reactive corporate attitude. Spine specialists at different levels realized the liability of not addressing spinal cases and the possible liabilities that could arise if taken up during a pandemic. Articles and online video conferences presented real-life scenarios that proved the gravity of the situation. The discussed guidelines and seminars showed their efficacy to control the spread of COVID-19 and the efficiency of the healthcare system. The points raised by the spine worldwide societies may not solve all issues related to spinal case management in the COVID era, but at least they have set forward a relevant ground to raise possible questions for the future's sake, as well as the possibilities of reflecting upon these ideas on other similar areas of medicine. As a doctor of the Singaporean Spine Society commented, "We are all in the same storm, just different boats, and we should all work together to save each other".

ARTICLE HIGHLIGHTS

Research background

During the second phase of the coronavirus disease 2019 (COVID-19) pandemic, some authors have felt the need to summarize and order data on the recommendations issued by the major surgical scientific societies in the world. The concluding observations of this review highlighted how these surgical scientific communities had promptly reacted to the emergency by issuing documents and guidelines. In particular, the neurosurgical scientific community has promptly developed recommendations for managing patients with cranial or spinal pathologies.

Research motivation

We designed a review of the literature concerning the release of documents, guidelines, or recommendations by the spine societies in the world, intending to offer an overview on these topics to which spine surgeons worldwide can easily refer.

Research objectives

This study aimed to discuss the recommendations by many spine societies for the management of spinal diseases during the COVID-19 pandemic.

Research methods
A review of the MEDLINE database according to the PRISMA guidelines.

Research results
We identified 28 associations present on the Internet as companies or networks that deal with the interventional treatment of spinal pathologies. We distinguished societies, associations, or networks worldwide into three groups. The literature search yielded a sum of 28 articles that were relevant to spine surgery and COVID-19.

Research conclusions
Only one-third of continental spine societies have issued recommendations. The international specialist companies have dealt little or nothing with the topic, except the SIS and partly AO spine. Paradoxically, the national companies were more stimulated to issue their guidelines. The local epidemiological severity has likely influenced the reactive corporate attitude.

Research perspectives
Articles and online video conferences presented real-life scenarios that proved the gravity of the situation. The discussed guidelines and seminars showed their efficacy to control the spread of COVID-19 and the efficiency of the healthcare system. The discussing points by the spine worldwide societies may not solve all issues related to spinal case management in the COVID era, but at least they have set forward a relevant ground to raise possible questions for the future's sake, as well as the possibilities of reflecting upon these ideas on other similar areas of medicine.

FOOTNOTES

Author contributions: Ramieri A and Miscusi M designed the research; Alshafeei O and Trungu S performed the research; Ramieri A and Alshafeei O analyzed the data; Alshafeei O and Ramieri A wrote the paper; Costanzo G and Raco A supervised the paper; all authors read and approved the final manuscript.

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SCIENTOMETRICS

Assessing the academic achievement of United States orthopaedic departments

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Abstract

BACKGROUND

Assessing academic productivity allows academic departments to identify the strengths of their scholarly contribution and provides an opportunity to evaluate areas for improvement.

AIM

To provide objective benchmarks for departments seeking to enhance academic productivity and identify those with significant improvement in recent past.

METHODS

Our study retrospectively analyzed a cohort of orthopaedic faculty at United States-based academic orthopaedic programs. 5502 full-time orthopaedic faculty representing 178 programs were included in analysis. Variables included for analysis were National Institutes of Health funding (2014-2018), leadership positions in orthopaedic societies (2018), editorial board positions of top orthopaedic journals (2018), total number of publications and Hirsch-index. A weighted algorithm was used to calculate a cumulative score for each academic program. This study was performed at a large, United States medical school.

RESULTS

All 178 programs included in analysis were evaluated using the comprehensive weighted algorithm. The five institutions with the highest cumulative score, in decreasing order, were: Washington University in St. Louis, the Hospital for Special Surgery, Sidney Kimmel Medical College (SKMC) at Thomas Jefferson University, the University of California, San Francisco (UCSF) and Massachusetts General Hospital (MGH)/Brigham and Women's/Harvard. The five institutions

with the highest score *per* capita, in decreasing order, were: Mayo Clinic (Rochester), Washington University in St. Louis, Rush University, Virginia Commonwealth University (VCU) and MGH/Brigham and Women's/Harvard. The five academic programs that had the largest improvement in cumulative score from 2013 to 2018, in decreasing order, were: VCU, SKMC at Thomas Jefferson University, UCSF, MGH/Brigham and Women's/Harvard, and Brown University.

CONCLUSION

This algorithm can provide orthopaedic departments a means to assess academic productivity, monitor progress, and identify areas for improvement as they seek to expand their academic contributions to the orthopaedic community.

Key Words: Bibliometrics; Academic achievement; Number of publications; National Institutes of Health funding; Hirsch-index

Core Tip: Assessing academic productivity allows academic departments to identify the strengths of their scholarly contribution and provides an opportunity to evaluate areas for improvement. By identifying measures of academic productivity for full-time faculty at academic orthopaedic programs in the United States, we were able to establish a comprehensive weighted algorithm for valuation of the scholarly achievement of each program. Furthermore, by establishing and documenting the findings and methodology of this algorithm, programs have the opportunity to assess, monitor, and identify areas of growth as they seek to expand their academic contributions to the orthopaedic community.

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INTRODUCTION

The evaluation of academic orthopaedic surgery programs based on scholarly contribution is difficult to assess. Faculty are often measured by bibliometric variables that represent their academic productivity such as citation indices, number of publications and amount of research funding[1-3]. Our study aimed to measure the current scholarly productivity of orthopaedic departments in the United States. The results of this analysis are an assessment of orthopaedic programs based on the academic contributions of their faculty. In addition to recognizing highly academic departments, our study aims to provide orthopaedic departments with a tool that can be continually utilized to monitor academic productivity and, thus, identify areas for improvement.

There are many difficulties associated with evaluating the academic productivity of orthopaedic surgery programs. The subjective nature of certain metrics, such as national reputation and faculty satisfaction, used in rankings like *Doximity* or *U.S. News & World Report*[4-7] often make standardizing academic achievement difficult. Furthermore, current productivity is not always accurately reflected, as the productivity of alumni for the preceding 15 years are included in these rankings[4]. Another difficulty in evaluating academic achievement is the lack of consensus as to the weight that different objective bibliometric measures should have when determining overall academic contribution.

Efforts to quantify academic achievement have gained popularity amongst various specialties over the past decade. Publicly available metrics such as National Institutes of Health (NIH) funding, faculty Hirsch-indices (h-index) and number of publications have been used in plastic surgery, ophthalmology, dermatology, urology and a variety of other medical specialties to provide a measurement of an institution's academic prowess[8-15]. The h-index is a well validated tool to accurately measure academic output and has been lauded in the orthopaedic community[16-18]. The h-index is defined as the number of publications (h) an individual has that receive at least h citations, with each other publication having < h citations[19]. Therefore, the h-index can never exceed the number of publications a faculty member has and considers both quality and quantity of a faculty member's publications. NIH funding has also been validated as an accurate measure of scholarly impact across different specialties [9,20].

Previous studies in other specialties have utilized algorithms that weigh metrics of academic achievement to ultimately rank programs based on their academic productivity[12,21,22]. Our current study uses data from 2014-2018 to provide a five-year updated, enhanced analysis of our previous study [23], and continue to assess orthopaedic programs based on the academic output of their faculty. Cumulative statistics as well as *per* capita statistics, which help to highlight both programs with a large volume of academic output as well as smaller programs with a high academic yield, were used in this study. Furthermore, in order to acknowledge programs that have improved their scholarly productivity, we quantified the change in cumulative score from our previous paper that used data from 2013 to our current study that uses data from 2014-2018. As scholarly productivity is often linked with academic promotion, the ability to attract talented faculty and other important factors[3], standardized methods are necessary to accurately assess the academic achievement of orthopaedic surgery programs. The authors believe that the establishment of a consistent and representative algorithm of program achievement can be used as a tool to continually monitor progress over time and, importantly, provide guidance to individual programs on target areas to enhance overall scholarly productivity.

MATERIALS AND METHODS

Programs included for analysis were identified through a search of the Accreditation Council for Graduate Medical Education website[24]. Faculty included for analysis were identified using faculty lists on individual departmental websites. An email was subsequently sent to program directors and coordinators for each institution to verify that the list of faculty on the department website was accurate and up to date. In an effort to standardize faculty lists, only faculty with a full-time appointment in the respective department of orthopaedic surgery were included for analysis. This included research faculty but did not include surgeons from other specialties, house staff, co-appointed faculty, part-time faculty or emeritus faculty as depicted on individual departmental websites. All inputted data and calculations were reviewed by multiple authors independently to ensure accuracy.

Our current study includes the same bibliometrics as our prior study[23] to quantify academic productivity for each faculty member. While some of these metrics are cumulative over a faculty member's career, including total number of publications and h-index, other metrics such as NIH funding from 2014-2018, leadership society membership for 2018 and journal editorial board membership for 2018 provide a more current evaluation of academic productivity. As NIH funding can fluctuate dramatically, five years of NIH funding was analyzed. The bibliometrics of each faculty member within an orthopaedic surgery department were cumulated. A weighted algorithm was subsequently used to compute a score for each academic institution to assess their scholarly contribution. Change in cumulative score for each program from 2013 to 2018 was then calculated.

The weighted score was calculated as follows. For each of the five categories, each academic program was assigned a score from zero to one, with the program with the highest score in an individual category assigned a one. The category-specific score for each academic institution was calculated by dividing the value of a specific outcome measure attained by an institution by the value of that outcome measure attained by the highest achieving institution. That score was then either multiplied by 2.0 for the category of NIH funding, 1.0 for the categories of number of publications and h-index or 0.5 for the categories of leadership society membership and journal editorial board membership. Thus, NIH funding accounted for 40% of the total score, number of publications and h-index each accounted for 20% and society leadership and journal editorial board membership each accounted for 10% (Figure 1). For example, the faculty from the University of Iowa accounted for 2789 total publications. This was divided by the highest number of publications (13494) achieved by any institution (the Hospital for Special Surgery, Cornell) and multiplied by 1.0 (weighing factor for number of publications). A score of 0.207 was then given to the University of Iowa for the "number of publications" category. The same computation was then repeated with each bibliometric being divided by the number of full-time faculty within a department to calculate the *per* capita measurement.

The validated Scopus database was used to determine the total number of publications and h-index for each individual faculty member[25,26]. Scopus was chosen to analyze the total number of publications as Scopus only includes peer-reviewed literature and has the broadest coverage of any database [25]. Our analysis of total number of publications will therefore include all types of publications from an individual's career. The NIH Research Portfolio Online Reporting Tool was used to obtain NIH funding from 2014-2018[27].

Our analysis also included the two largest general orthopaedic societies in the United States: The Orthopaedic Research Society (ORS) and the American Academy of Orthopaedic Surgeons (AAOS) as well as the preeminent society from each orthopaedic subspecialty to stay consistent with our prior study. These societies were chosen to give an equal representation to all orthopaedic subspecialties. In an effort to decrease inherent bias, no societies that are nomination-dependent were included for analysis. Faculty on editorial boards of American orthopaedic journals with an impact factor over 2.5 were included for analysis. These journals included all journals from our previous study as well as the *Orthopaedic Journal of Sports Medicine* and *Clinical Research on Foot and Ankle.*

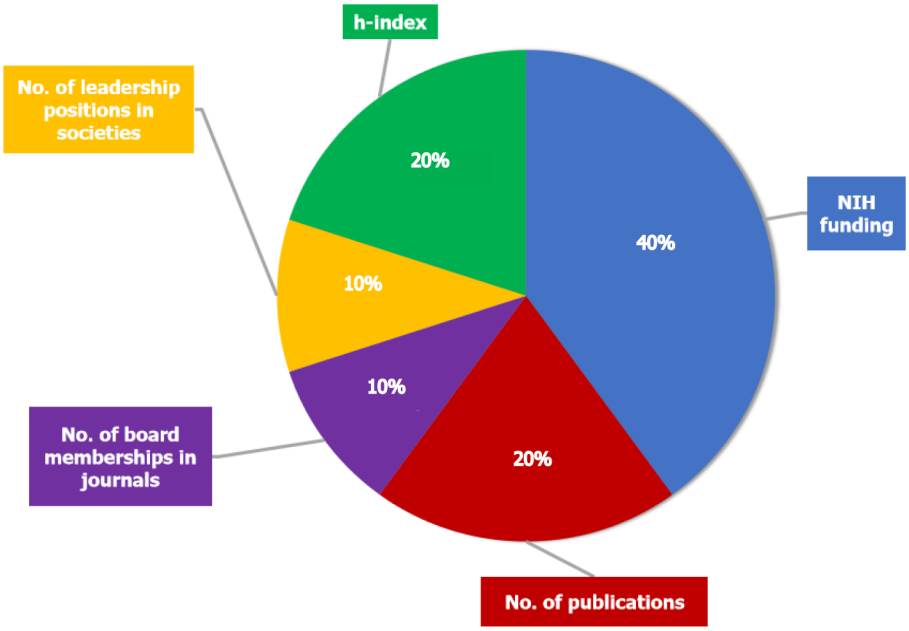

Figure 1 Weighted algorithm showing overall academic achievement. The five criteria used to evaluate each academic orthopaedic program's contributions are shown. Metrics of original academic thought-National Institutes of Health funding (2014-2018), h-index and total number of publications-were weighted to each represent 40%, 20% and 20%, respectively, of the overall score. Metrics of leadership-editorial positions and society leadership in 2018-were weighted to each represent 10% of the overall score. Each programs' individual score in each category was multiplied by the weight of the criteria and summed to create a weighted score of overall academic achievement. h-index: Hirschberg-index; NIH: National Institutes of Health.

RESULTS

Of 181 academic orthopaedic programs with an accredited residency program were included for data analysis. Three institutions were excluded due to the lack of a list of faculty members on departmental websites and limited contacts to find this information. 36 out of the remaining 178 programs responded to the authors' email for a response rate of 20.2%.

Programs received cumulative NIH grant funding between 2014-2018 ranging from $31.9 million [University of California, San Francisco (UCSF)] to no NIH funding. Washington University in St. Louis ($29.3 million), Virginia Commonwealth University (VCU) ($28.6 million), University of Rochester ($23.0 million), Brown University ($22.1 million) and Sidney Kimmel Medical College (SKMC) at Thomas Jefferson University ($18.2 million) represent the next five institutions with the highest NIH funding during this period (Table 1).

The total number of publications for full-time faculty of an orthopaedic department ranged from 12 to 13494 at the Hospital for Special Surgery (Cornell). The five institutions with the most publications following the Hospital for Special Surgery were SKMC at Thomas Jefferson University (9259), Mayo Clinic (Rochester) (8735), Washington University in St. Louis (6616), Massachusetts General Hospital (MGH)/Brigham and Women's/Harvard (6421), and Rush University (5661) (Table 2).

The Hospital for Special Surgery had the highest cumulative h-index with 3318, followed by SKMC at Thomas Jefferson University which had a h-index of 1988 (Table 3).

Fifty-two programs had faculty members holding at least one leadership position in orthopaedic surgery societies in the United States, representing 29.2% of the 178 programs evaluated. Full-time faculty at MGH/Brigham and Women's/Harvard garnered the most leadership positions with seven, followed by Duke University with six. Four leadership positions were held by faculty at the Hospital for Special Surgery, Johns Hopkins University, Mayo Clinic (Rochester), Rush University, and SKMC at Thomas Jefferson University (Table 4).

Full-time faculty at the Hospital for Special Surgery held the most editorial board positions at top orthopaedic and subspecialty journals with 20 positions, followed by MGH/Brigham and Women's/Harvard with 19 positions and Washington University in St. Louis with 18 editorial board positions (Table 5).

All 178 programs were evaluated using the comprehensive weighted algorithm. Based on this algorithm, Washington University in St. Louis was shown to be the most academically productive orthopaedic surgery program in the United States. The following five most academically productive orthopaedic programs were: The Hospital for Special Surgery, SKMC at Thomas Jefferson University, the UCSF, MGH/Brigham and Women's/Harvard and Mayo Clinic (Rochester) (Figure 2).

Table 1 Ten United States orthopaedic surgery residency programs with the largest total Dollar amount of National Institutes of Health funding received from 2014-2018

Institution	NIH funding	Points (weighted)
University of California, San Francisco	$31928483	2
Washington University in St. Louis	$29320191	1.836616603
Virginia Commonwealth University	$28619478	1.792723945
University of Rochester	$23035238	1.442927182
Brown University	$22064165	1.382099175
SKMC at Thomas Jefferson University	$18237937	1.142424274
University of Pennsylvania	$17252775	1.080713731
Mayo Clinic (Rochester)	$16801697	1.052458208
University of Utah	$16762167	1.049982049
Yale University	$16184261	1.01378202

SKMC: Sidney Kimmel Medical College; NIH: National Institutes of Health.

Table 2 Ten United States orthopaedic surgery residency programs with the highest total number of publications by institutional full-time faculty, 2018

Institution	Publications	Points (weighted)
Hospital for Special Surgery (Cornell)	13494	1
SKMC at Thomas Jefferson University	9259	0.68615681
Mayo Clinic (Rochester)	8735	0.64732474
Washington University in St. Louis	6616	0.49029198
MGH/Brigham and Women's/Harvard	6421	0.47584111
Rush University	5661	0.41951979
New York University	4882	0.36179043
University of Pennsylvania	4603	0.34111457
University of Pittsburgh	4407	0.3265896
Stanford University	3903	0.28923966

MGH: Massachusetts General Hospital; SKMC: Sidney Kimmel Medical College.

Based on per-capita measurements of academic achievement that accounts for the number of full-time faculty in each program, the most academically productive orthopaedic surgery programs were: Mayo Clinic (Rochester), Washington University in St. Louis, Rush University, VCU, MGH/Brigham and Women's/Harvard, and Duke University (Figure 3).

VCU had the largest improvement in their score from 2013 with a 1.62 point change. SKMC at Thomas Jefferson University (1.40), UCSF (1.39), MGH/Brigham and Women's/Harvard (1.31), Brown University (1.23) and Icahn School of Medicine at Mount Sinai (0.92) were the next five institutions with the largest improvement in cumulative score since 2013 (Table 6).

DISCUSSION

This study aims to assess the scholarly contribution of orthopaedic departments using objective bibliometrics from 2014 to 2018. With so many metrics available to assess academic achievement, this is admittedly both difficult and controversial. In light of the financial, reputational and academic pressures surrounding academic productivity, our goal was to (1) Acknowledge academic institutions for their scientific contribution; (2) Allow academic departments to communicate best practices to one another; and (3) Provide a method to longitudinally monitor academic improvement to facilitate a discussion as

Table 3 Ten United States orthopaedic surgery residency programs with the highest cumulative h-index of institutional full-time faculty, 2018

Institution	h-index	Points (weighted)
Hospital for Special Surgery (Cornell)	3318	1
SKMC at Thomas Jefferson University	1988	0.59915612
Washington University in St. Louis	1680	0.50632911
Mayo Clinic (Rochester)	1627	0.49035564
MGH/Brigham and Women's/Harvard	1454	0.43821579
University of California, San Francisco	1178	0.35503315
University of Pittsburgh	1126	0.33936106
New York University	1109	0.33423749
University of California, Los Angeles	1101	0.3318264
Rush University	1078	0.32489451

h-index: Hirschberg-index; MGH: Massachusetts General Hospital; SKMC: Sidney Kimmel Medical College.

Table 4 Eleven United States orthopaedic surgery residency programs with the highest amount of full-time faculty holding leadership positions in the two largest general orthopaedic surgery societies in the United States and a subspecialty society for each of the nine orthopaedic subspecialties, 2018

Institution	Leadership positions	Points (weighted)
MGH/Brigham and Women's/Harvard	7	0.500
Duke University	6	0.429
Hospital for Special Surgery (Cornell)	4	0.286
Johns Hopkins University	4	0.286
Mayo Clinic (Rochester)	4	0.286
Rush University	4	0.286
SKMC at Thomas Jefferson University	4	0.286
University of North Carolina	3	0.214
Cleveland Clinic	3	0.214
Washington University in St. Louis	3	0.214
Yale University	3	0.214

Two largest general orthopaedic surgery societies in the United States: AAOS and ORS; Nine orthopaedic subspecialties: ASES, AOSSM, MSTS, AAHS, AAHKS, OTA, NASS, POSNA, and AOFAS. AAOS: American Academy of Orthopaedic Surgeons; ORS: Orthopaedic Research Society; AAAHKS: American Association of Hip and Knee Surgeons; AAHS: American Association for Hand Surgery; AOFAS: American Orthopaedic Foot & Ankle Society; ASES: American Shoulder and Elbow Surgeons; AOSSM: American Orthopaedic Society for Sports Medicine; MSTS: Musculoskeletal Tumor Society; NASS: North American Spine Society; OTA: Orthopaedic Trauma Association; POSNA: Pediatric Orthopaedic Society of North America; MGH: Massachusetts General Hospital; SKMC: Sidney Kimmel Medical College.

to the definition of academic success.

It is imperative to consider that the mission of orthopaedic programs and faculty is not always rooted in academic achievement, but rather is based on operative and clinical capability, outreach to underserved populations, teaching and mentorship, and/or technological innovation. Undoubtedly, there are metrics other than academic productivity that define a program's "success." Although many of the results of this study are organized numerically, the findings are not intended for comparison against one another. The purpose of this study was not to "rank" orthopaedic departments, but rather to establish a tool that programs may use to assess their own academic productivity against their respective baseline values established in this study. The conclusions reached in this study only pertain to academic productivity as related to the specific bibliometrics analyzed. Additionally, departments inherently differ in size and maturity of research infrastructure. Nonetheless, in a culture that is

Table 5 Nine United States orthopaedic surgery residencyprograms with the highest amount of editorial board positions held by institutional full-time faculty in 2018

Institution	Editorial board positions	Points (weighted)
Hospital for Special Surgery (Cornell)	20	0.5
MGH/Brigham and Women's/Harvard	19	0.475
Washington University in St. Louis	18	0.45
SKMC at Thomas Jefferson University	16	0.4
University of Pittsburgh	15	0.375
Johns Hopkins University	11	0.275
Columbia University	11	0.275
Stanford University	11	0.275
University of Michigan	11	0.275

The journals included were the *American Journal of Sports Medicine*; *Osteoarthritis and Cartilage*; *Journal of Bone and Joint Surgery*; *Arthroscopy*; *Journal of Orthopaedic Research*; *Clinical Orthopaedics and Related Research*; *Knee Surgery, Sports Traumatology, Arthroscopy*; *Orthopaedic Journal of Sports Medicine*; *Bone and Joint Journal*; *Spine Journal*; *Spine*; *Clinical Research on Foot and Ankle*; *Journal of the American Academy of Orthopaedic Surgeons*; *Journal of Arthroplasty*; and *Journal of Shoulder and Elbow Surgery*. MGH: Massachusetts General Hospital; SKMC: Sidney Kimmel Medical College.

Table 6 Ten United States orthopaedic surgery residency programs with the largest positive change in weighted points from 2013

Institution	Change in points from 2013
Virginia Commonwealth University	1.62
SKMC at Thomas Jefferson University	1.40
University of California, San Francisco	1.39
MGH/Brigham and Women's/Harvard	1.31
Brown University	1.23
Icahn School of Medicine at Mount Sinai	0.92
University of Utah	0.90
Hospital for Special Surgery (Cornell)	0.86
Cleveland Clinic Foundation Program	0.83
Columbia University	0.76

MGH: Massachusetts General Hospital; SKMC: Sidney Kimmel Medical College.

constantly interested in evaluations, analyzing academic productivity using objective metrics remains an important factor to appraise orthopaedic departments.

There are several limitations of this study to consider. One important limitation to our study is the subjective nature by which the weighted algorithm was formulated. The authors believe that our previous study[23] did not place enough emphasis on the effect that basic science research has on academic productivity. Although other sources of basic science funding such as the Department of Defense and the Orthopaedic Research and Education Foundation exist, the NIH is the largest public funder of biomedical research worldwide[27]. Therefore, as basic science is a large portion of the NIH portfolio[27], NIH funding was given additional weight (40% of cumulative score) relative to other bibliometrics included. As the distribution of points in our current study slightly differs from our previous paper, our calculation of score improvement from 2013 to 2018 is subject to limitations. Given that any choice of variables for a weighted algorithm will have an element of subjectivity to it, the authors accept these limitations. The authors also acknowledge that it may be difficult to identify part-time, co-appointed or emeritus faculty based solely on departmental websites. Furthermore, there are undoubtedly changes in faculty lists over from 2013 to 2018. However, universities and academic centers have different criteria for "joint appointments." As such, in an effort to decrease inherent bias, part-time or co-appointed faculty were not included. All 178 programs were also contacted in an attempt to confirm faculty lists.

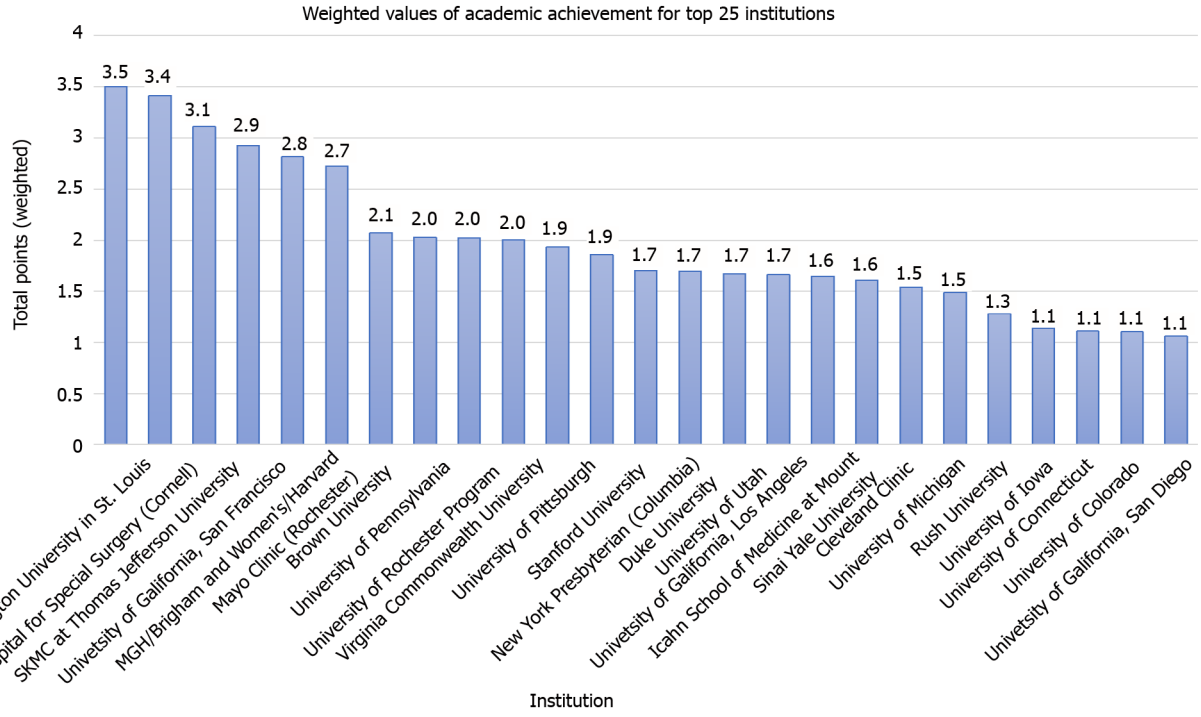

Figure 2 A total of 176 United States academic orthopaedic surgery programs received points using a weighted algorithm. The overall order of the 25 most cumulatively academically productive programs using data from 2014-2018 is shown.

Further limitations of this study lie in the actual bibliometrics used. The h-index has been validated both within and outside of the orthopaedic community[16-18], however it is not without its criticisms. The h-index does not proportionally reflect the impact of authors who have published a small number of highly cited studies, nor does it proportionally reflect the impact of authors who have published a large number of scarcely cited studies. The h-index and the total number of publications also do not take into account the order that authors are listed and thus, the impact that each author had[28,29]. Augmentations of the h-index have been proposed[28-30], however until they are widely accepted and publicly available, the authors believe that the h-index remains the best metric. Furthermore, the authors only reported journal editorial board members and leaders in orthopaedic academic societies for the 2018 calendar year as most journals and societies do not have this data for prior years publicly available. This excluded either of these metrics for years prior. In an effort to minimize this limitation, editorial board and society leadership each only accounted for 10% of the overall score. While the authors believe a snapshot of recent academic productivity is important when evaluating recent academic achievement, it is imperative to understand how the availability of prior data would affect these results.

Based on this algorithm, Washington University in St. Louis, the Hospital for Special Surgery, SKMC at Thomas Jefferson University, the UCSF and MGH/Brigham and Women's/Harvard are currently the five most cumulatively academically productive orthopaedic surgery programs. The Mayo Clinic (Rochester), Washington University in St. Louis, Rush University, VCU and MGH/Brigham and Women's/Harvard are currently the five most academically productive orthopaedic surgery programs *per* capita. The five academic programs that had the largest improvement in cumulative score from 2013 to 2018 were: VCU, SKMC at Thomas Jefferson University, UCSF, MGH/Brigham and Women's/Harvard, and Brown University.

CONCLUSION

This algorithm is easily reproducible and provides a metric that departments can use to track their academic productivity over time as well as identify areas for improvement. These reported bibliometrics can continually be updated in upcoming years as a measure of changing scholarly contribution. Programs that have shown dramatic improvement in scholarly contribution since our 2013 study can be seen as model programs. Programs striving for similar improvement would have other programs identified to serve as roadmaps, opening up an avenue for communication. Furthermore, as factors affecting academic promotion are often difficult to assess, this standardized algorithm may, importantly, aid academic medical centers to determine promotion. This is not a list of the "best" orthopaedic surgery institutions as clinical care metrics were not included in the analysis. This analysis

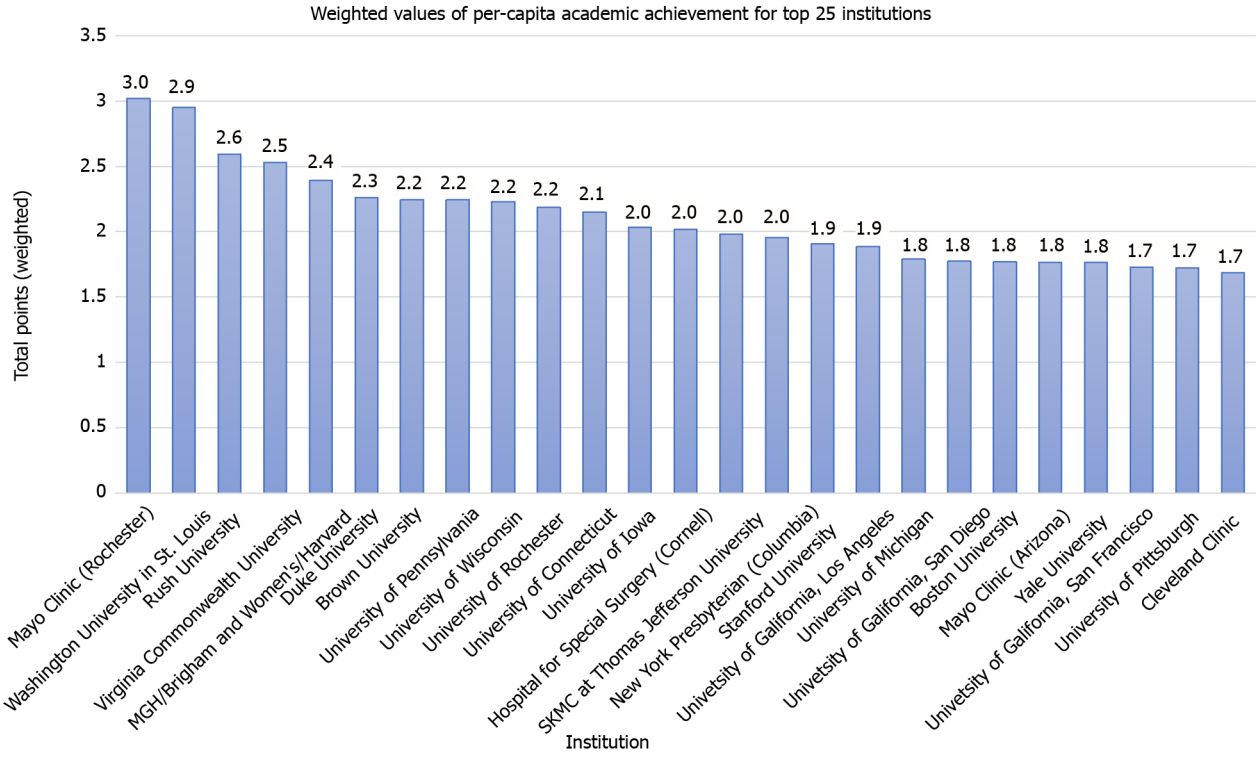

Figure 3 A total of 176 United States academic orthopaedic surgery programs received points using a weighted algorithm. The overall order of the 25 most academically productive programs using data from 2014-2018 and normalizing for the number of faculty *per* program is shown.

did not attempt to take into account the quality of clinical care provided, or the clinical education provided to medical students, residents or fellows, therefore the authors would like to reiterate that this algorithm was not used to rank orthopaedic departments.

ARTICLE HIGHLIGHTS

Research background

Orthopaedic surgery faculty are often measured by bibliometric variables that represent their academic productivity such as citation indices, number of publications and amount of research funding.

Research motivation

Assessing academic productivity allows academic departments to identify the strengths of their scholarly contribution and provides an opportunity to evaluate areas for improvement.

Research objectives

To provide objective benchmarks for departments seeking to enhance academic productivity and identify those with improvement in recent past.

Research methods

Our study retrospectively analyzed a cohort of orthopaedic faculty at United States-based academic orthopaedic programs. Variables included for analysis were National Institutes of Health funding (2014-2018), leadership positions in orthopaedic societies (2018), editorial board positions of top orthopaedic journals (2018), total number of publications and Hirsch-index. A weighted algorithm was used to calculate a cumulative score for each academic program.

Research results

The five institutions with the highest cumulative score, in decreasing order, were: Washington University in St. Louis, the Hospital for Special Surgery, Sidney Kimmel Medical College (SKMC) at Thomas Jefferson University, the University of California, San Francisco (UCSF) and Massachusetts General Hospital (MGH)/Brigham and Women's/Harvard. The five institutions with the highest score *per* capita, in decreasing order, were: Mayo Clinic (Rochester), Washington University in St. Louis, Rush University, Virginia Commonwealth University (VCU) and MGH/Brigham and Women's/Harvard.

The five academic programs that had the largest improvement in cumulative score from 2013 to 2018, in decreasing order, were: VCU, SKMC at Thomas Jefferson University, UCSF, MGH/Brigham and Women's/Harvard, and Brown University.

Research conclusions

This algorithm can provide orthopaedic departments a means to assess academic productivity, monitor progress, and identify areas for improvement as they seek to expand their academic contributions to the orthopaedic community.

Research perspectives

The authors would like to reiterate that this is in no way a ranking system as there are many unique challenges that institutions face. We hope that this provides a tool that programs may use to assess and improve their own academic productivity, while simultaneously providing an opportunity to praise the growth and achievement of institutions on a cumulative as well as *per* capita basis.

FOOTNOTES

Author contributions: The above authors were each included in substantial contributions to research design, or the acquisition, analysis or interpretation of data, drafting the paper or revising it critically, approval of the submitted and final versions.

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