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Anterior cruciate ligament reconstruction and knee osteoarthritis

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of choice for symptomatic ACL-deficient patients and can assist in full functional recovery. Furthermore, ACL reconstruction restores ligamentous stability to normal, and, therefore, can potentially fully reinstate kinematics of the knee joint. As a consequence, the natural history of ACL injury could be potentially reversed via ACL reconstruction. Evidence from the literature is controversial regarding the effectiveness of ACL reconstruction in preventing the development of knee cartilage degeneration. This editorial aims to present recent high-level evidence in an attempt to answer whether ACL injury inevitably leads to osteoarthritis and whether ACL reconstruction can prevent this development or not.

Key words: Anterior cruciate ligament; Osteoarthritis; Anterior cruciate ligament reconstruction; Prevention of osteoarthritis; Meniscus tear; Anterior cruciate ligament tear

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Core tip: This editorial aims to present recent evidence in an attempt to answer the following questions: (1) does anterior cruciate ligament (ACL) injury inevitably lead to osteoarthritis (OA)? (2) can ACL reconstruction prevent cartilage degeneration and to what extent is this possible? and (3) what are the risk factors for OA development after ACL injury?

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Abstract

Anterior cruciate ligament (ACL) injury is a traumatic event that can lead to significant functional impairment and inability to participate in high-level sports-related activities. ACL reconstruction is considered the treatment

Anterior cruciate ligament (ACL) tear is a devastating injury with both short and long term consequences. Short-term knee functional impairment is successfully

addressed with ACL reconstruction and rehabilitation that allows patients to return to previous sports activities. However, the long-term consequences of ACL injury and the role of ACL reconstruction towards fully restoring knee biomechanics and potentially preventing cartilage degeneration post-traumatically is surrounded with controversy. The aim of this editorial is to discuss the recent literature for the long-term effects of ACL reconstruction, in an attempt to seek answers on whether ACL reconstruction can prevent development of osteoarthritis (OA).

ACL RECONSTRUCTION AND OA

ACL deficiency leads to anteroposterior and rotational instability as well as functional impairment, as evidenced by subjective and objective knee functional scores. The role of instability as a predisposing factor for cartilage degeneration was highlighted early^[1]. Using regression analysis, a prospective analysis of 292 patients with knee injury, revealed a linear correlation between radiographic scores and maximum displacement measurements^[1].

ACL reconstruction is the treatment of choice for symptomatic ACL deficient knees. Undeniably, ACL reconstruction restores knee stability, knee kinematics are also reinstated, and functional scores can be also equivalent to ACL-intact knees^[2,3]. As a result, if knee instability and its resultant abnormal forces to cartilage was the sole factor for future OA development, ACL reconstructed knees would theoretically have similar incidence of OA compared to ACL uninjured knees.

ACL tear was reported to be associated with a higher risk for knee OA regardless reconstruction. A meta-analysis of six studies evaluating progression of OA after ACL injury showed that ACL-reconstructed knees had a relative risk of 3.62 vs uninjured knees (206 out of 395 vs 62 out of 395) in OA development, indicating that ACL reconstruction cannot fully prevent OA. Non-operative treated ACL-deficient knees showed a relative risk of 4.98 (40 out of 120 vs 8 out of 120), suggesting that ACL reconstruction can act preventively for OA compared to non-operative treatment^[4]. A relative risk of 3.89 for ACL-injured knees existed towards OA (240 out of 465) compared to contralateral knees (73 out of 507)^[4]. These data suggest that ACL reconstruction can prevent OA development to a certain degree. The presence of a higher risk for OA compared to the uninjured knee, demonstrates that ACL reconstruction cannot fully eliminate the increased risk of OA progression.

Some studies demonstrated that ACL reconstruction not only cannot fully prevent development of OA, but, in certain occasions, ACL reconstruction may be associated with a higher prevalence of knee OA. Specifically, a retrospective cohort study at 11 years post ACL injury showed that only 25% of conservatively treated knees developed OA vs 42% in ACL reconstructed knees^[5]. Similarly, another report demonstrated that patients that underwent ACL reconstruction had a higher incidence of knee OA^[1]. Furthermore, a more severe

degree of OA using radiographic criteria was shown after ACL reconstruction compared to ACL-injured knees. Specifically, the relative risk of progression to severe OA in ACL-injured knees using Kellgren and Lawrence grade III or IV was found to be 3.84 compared to the controls^[4]. In contrast, the relative risk in ACL-reconstructed knees was 4.71^[4]. These findings are typically attributed to the higher incidence of meniscus injury in these patients^[1,4]. However, most studies that compare the degree of cartilage degeneration between patients undergoing ACL reconstruction and patients with non-operative treatment showed either reduction in the risk of OA development or no difference in risk^[4]. The phenomena that can potentially lead to increased OA prevalence after ACL reconstruction are poorly understood. Further research that can identify additional risk factors that play a major role in OA development - apart from knee stability - is of paramount importance.

THE ROLE OF COMBINED MENISCUS AND CARTILAGE INJURIES IN OA DEVELOPMENT

A key factor that contributes to the development of OA is the presence of combined injuries, *i.e.*, the presence of meniscal or chondral injury combined with ACL tear. Specifically, patients suffering from a combined injury had a significantly higher chance to develop radiographic knee OA (Kellgren and Lawrence grade 2 or higher) compared to subjects with isolated ACL injuries^[6]. Indeed, 80% of the ACL reconstructed knees with associated meniscal or chondral injuries developed knee OA after 10-15 years vs only 62% of subjects with isolated ACL reconstructed injuries^[6]. In the same cohort study, the percentage of subjects that developed knee OA at the contralateral uninjured knee was 15%^[6]. The importance of menisci and cartilage status at the time of the ACL reconstruction was confirmed in another study with 7.5 years follow-up that demonstrated that IKDC radiographic score was abnormal in only 3% of patients with intact menisci and cartilage, while an abnormal IKDC score was obtained in 32% of patients that had both menisci damaged as well as cartilage lesions at the time of the initial surgery^[7]. Similar results were highlighted by a systematic review that reported a prevalence of knee OA after isolated ACL injury ranging between 0% to 13%. In contrast, when a meniscal injury was present, the prevalence of OA increased between 21% to 48%, highlighting the significant role of meniscal injuries to subsequent osteoarthritis^[8]. Unquestionably, the presence of a meniscal or chondral injury at the time of initial ACL tear is considered the most important predictor for the development of subsequent OA. Figure 1 describes the degree of contribution of ACL and associated injuries in the percentage of OA development.

The major role of meniscus and cartilage lesions at the time of surgery in the future development of OA was shown clearly by the findings of a recent study with long

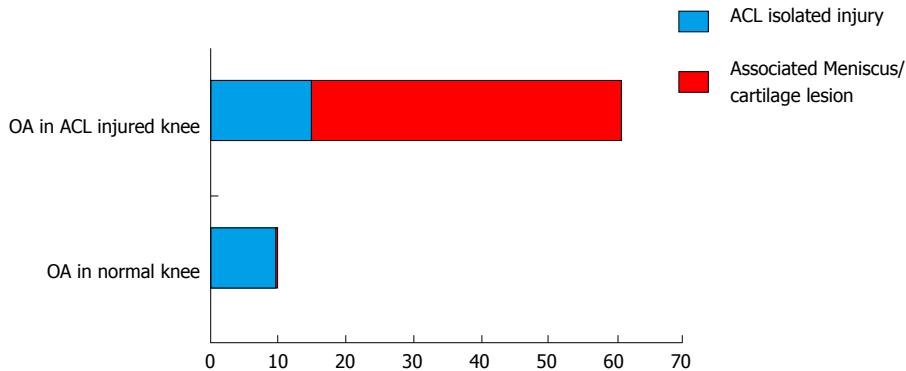


Figure 1 Percentage of patients developing osteoarthritis after an isolated anterior cruciate ligament injury and after anterior cruciate ligament plus associated injuries in comparison to osteoarthritis development to a non-injured knee. ACL: Anterior cruciate ligament; OA: Osteoarthritis.

term follow-up that excluded patients with concomitant injuries at the initial surgery at its assessment. Specifically, it was shown that, 20 years after ACL reconstruction, in 122 patients, 80% of those treated with patellar tendon graft and 87% of those treated with hamstrings tendon graft, respectively, had normal or nearly normal IKDC scores. Considering that the mean age of patients during the 20-year follow-up assessment was approximately 50 years of age, the prevalence of 20% and 13%, respectively, for OA presence in that age group can be considered comparable to that of normal population^[9].

PATHOGENESIS AND RISK FACTORS FOR OA AFTER ACL INJURY

One theory that aims to explain the increased incidence of OA in ACL injured knees without associated injuries is the theory of the initial impact. According to this theory, acute impact trauma to the articular cartilage initiates a degeneration process that can progress to osteoarthritis over the next years after the event. During ACL injury, pro-inflammatory cytokines, such as interleukin-6, interleukin-8, tumor necrosis factor-alpha, and keratan sulfate are increased and can remain elevated even three months after the injury^[10-12]. These changes, as well as changes in gene expression post impact injury could trigger cartilage catabolism and potentially initiate the process of cartilage degeneration^[11,13]. An indirect sign that supports this theory is the significant cartilage thickening seen in MRIs 5 years following an ACL tear, that can be attributed to abnormal swelling due to disruption of cartilaginous matrix integrity^[14]. However, the exact role of cartilage thickness change after ACL injury is yet to be determined.

A recent prospective case-controlled study that measured MRI T2 relaxation times, cartilage oligomeric matrix protein (COMP) - an indicator of cartilage breakdown-, and C-reactive protein levels attempted to shed more light in the phenomena occurring after ACL injury that may be associated with OA development^[15]. Specifically, it was shown that the cartilage at the lateral knee compartment of ACL-injured patients with

associated bone marrow edema exhibited prolonged T2 relaxation times, suggesting that the bone marrow edema may represent areas of initial cartilage injury that could potentially predispose to cartilage degeneration^[15]. This study also demonstrated that cartilage that was not directly impacted may also be the subject of future degeneration due to changes in joint homeostasis, as shown by the elevated levels of serum COMP and the prolonged T2 relaxation times in areas where no bone marrow edema was present. At 1-year post ACL reconstruction, T2 relaxation time remained prolonged in certain areas, indicating that the alterations seen in cartilaginous matrix may persist^[15]. A cohort study with yearly follow-up assessment for 11 years showed that cartilage degradation as a result of the initial impact typically accelerates after 5 years from the injury^[16]. These recent data suggest that at the time of ACL injury a degradation process of the cartilaginous matrix initiates, either as the result of direct impact or due to alterations in joint homeostasis after the impact injury to the joint.

A second theory for the high incidence of OA after ACL injury involves chronic derangement of local joint-loading patterns that introduce high shear and compressive forces on the menisci and cartilage that lead to irreversible changes to cartilage homeostasis regardless of restoration of ligamentous stability^[17]. Specifically, ACL deficiency leads to increase in contact forces at the cartilage and alteration of knee joint kinematics^[18,19]. Furthermore, increased anterior tibial translation can increase stress at both menisci and this explains the high incidence of meniscal tears in ACL-deficient knees^[5,20,21]. These secondary injuries could be responsible for subsequent cartilage degeneration in the ACL-deficient knee.

The type of graft used in ACL reconstruction was recently considered that could play a role in future OA development. A recent study evaluating PT and HT grafts at 20 years post ACL reconstruction confirmed previous suggestions for OA development. Specifically, it was demonstrated that further surgery subsequently to ACL reconstruction as well as the use of patellar tendon as a graft increased the odds ratio of abnormal radiographic appearance of the knee by 2.6 and 2.4,

Table 1 Risk factors for osteoarthritis development after anterior cruciate ligament injury

Associated injuries at the time of ACL injury
Meniscus tear
Cartilage lesion
Demographic characteristics
Advanced age
High BMI
Reconstruction related factors
Patellar tendon graft
Loss of knee extension
Laxity in Lachman test
> 6 mo interval between injury and reconstruction
Poor performance at the single-legged hop test 1 yr postoperatively

ACL: Anterior cruciate ligament; BMI: Body mass index.

respectively. PT grafts were associated with radiographic OA in 61% of patients vs only 41% in HT grafts^[9]. In contrast, other reports did not confirm this difference^[22]. Additional high-level studies are necessary to further evaluate whether the use of patellar tendon predisposes towards OA progression and to further recognize potential pathogenetic mechanisms of this association.

Identification of factors that are associated with the development of knee OA after ACL injury is clinically important (Table 1). Apart from meniscal and chondral injury at the time of ACL reconstruction, advanced age and high BMI have also been suggested as risk factors for OA development after ACL reconstruction. Every 10 years of age was proposed that add 1.7 odds ratio risk towards OA, while other studies report age greater than 25 years at the time of ACL reconstruction as a predisposing factor^[5,23]. Every increment of BMI was associated with a 1.2 odds ratio for progression to OA^[5]. Other predisposing factors suggested were an interval of more than 6 mo between injury and reconstruction, loss of knee extension, and poor performance at the single-legged hop test 1 year postoperatively^[23,24]. A greater degree of laxity, as documented with Lachman test, was also associated with OA development^[25], which re-introduces the question how successfully can ACL reconstruction address anteroposterior and rotation instability post ACL tear^[26,27]. The recent interest in the anterolateral structures of the knee and their contribution in rotational knee stability led to techniques that combine ACL reconstruction with lateral extra-articular tenodesis^[28,29]. It would be interesting to evaluate long-term results of these procedures towards the development of OA.

Interestingly, ACL-reconstructed patients traditionally performed significantly better compared to non-operated patients in both subjective and objective scores and demonstrated significantly less laxity at KT-1000^[4]. This performance resulted in maintaining a higher participation in high risk pivoting activities and sports involvement. As a consequence, it may difficult to compare the development of OA between patients that fully participate in sports and return to their pre-injury

level of activity with patients that cannot fully participate in sports. Furthermore, in a study that evaluated performance on return in elite football players after ACL reconstruction, it was found that there was a significant descent in mean performance compared to controls^[30]. Therefore, ACL-reconstruction may contribute to restoration of most functional scores, but a minor deficit - that is obvious only in elite athletes - may still persist. This deficit could be associated with OA progression. For these patients, anterolateral ligament augmentation was recently suggested as a significant contributor to full restoration of function in these athletes^[31].

Lastly, the importance of rehabilitation programs after ACL reconstruction has been highlighted over the last few years and certain controversies have been resolved. Specifically, evidence suggests that accelerated rehabilitation protocols that introduce sequential phases are associated with better outcomes^[32]. Rehabilitation in phase 1 typically aims towards pain and oedema reduction, and regaining of range of motion. Phase 2 usually introduces progressive improvement of quadriceps and hamstring strength. The next phase adds improvement in neuromuscular control to the above^[32,33]. When strength and endurance are maximized, specific exercises that aim to fulfill return to sports criteria are introduced. The criteria used for return to sports are still subject of controversy; however, recent data suggest that functional test assessment, such as single-leg hop test, and muscle strength criteria, such as percentage of isokinetic strength should be introduced^[32,34,35]. The importance of maintaining an advanced level of physical activity is critical, as it appears to benefit both physical and mental health^[36,37]. In the future, this can be extremely important as new biological treatments for early osteoarthritis become available and, therefore, interventions that can confront the initial phenomena post ACL injury and prevent at the progression to osteoarthritis would be available^[38].

CONCLUSION

ACL tear is associated with an increased risk for OA development. This risk increases remarkably when an associated meniscal or chondral lesion is present. ACL reconstruction potentially restores knee stability and appears to reduce the risk of OA, but it cannot fully eliminate the increased risk. The initial impact of injury at the time of ACL tear could explain the association between OA and ACL tear, but additional research is needed to understand the exact pathogenesis of post-ACL injury OA. Identification of risk factors that can further increase the risk of knee OA is important in an attempt to control the natural history of cartilage degeneration after ACL tear.

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Fix and replace: An emerging paradigm for treating acetabular fractures in older patients

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in older patients. We present this in the context of the current literature. This invited editorial presents early results from our centre and the ongoing challenges are discussed.

Key words: Acetabular fracture; Total hip arthroplasty; Trauma

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Core tip: Acetabular fractures in older patients are challenging to manage. The "fix and replace" construct may present a new paradigm for the management of these injuries.

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Acetabular fractures in older patients pose a challenge for both patients and clinicians providing care. These fractures and the circumstances in which they occur require multidisciplinary management from both medical and surgical specialties, and new ways of managing these injuries in this patient cohort are required. The annual incidence of acetabular fractures is estimated at 2000 per year in the United Kingdom with 72.5% of these occurring in older patients (patients greater than 65 years of age)^[1,2]. With an ageing population, the incidence is increasing with one study demonstrating a 2.4 fold increase between 1980 and 2007^[3]. Furthermore, outcomes have historically been poor - with up to 30% of patients who are managed non-operatively having an unacceptable functional result^[4] and mortality is high (25% in one study^[5]). For patients managed with open

Abstract

Acetabular fractures in older patients are challenging to manage. The "fix and replace" construct may present a new paradigm for the management of these injuries. We present the current challenge of acetabular fractures

Table 1 Fix and replace cohort; early results (*n* = 19)

Characteristic	Details
Age	Average 77 yr (range 63-94)
Gender	9 females 10 males
Pre-morbid mobility	9 independently mobile 10 mobile with walking aid
Mechanism of injury	12 fall from standing height 3 road traffic collision 2 fall from height 1 seizure resulting in fall 1 unknown
Mobility day 1 post op	11 not mobile out of bed 6 sat out 2 unknown
Number of days to mobilise post up	Average 2.5 d (range 1-11)

reduction and internal fixation, results in older patients are significantly poorer compared to younger patients with up to 50% of older patients requiring an early total hip replacement^[6]. Overall, the quality of evidence is poor and limited to retrospective cohort reviews. As a result there is no clear consensus or guidelines on how best to manage these challenging injuries. As the incidence of these fractures in older patients is increasing, and outcomes of treatment uncertain or poor, better evidence and new strategies of treatment are required to improve the management of these injuries in this patient cohort.

Acetabular fractures in older patients may be viewed to be a similar injury to hip fractures (neck of femur) where the treatment aims to restore hip function to allow immediate weight bearing. As hip fractures represent a major fracture burden in older patients, a well developed conceptual framework has been established in the United Kingdom including a level one evidence-based treatment pathway (Orthopaedic Blue Book), national guidelines (NICE Guideline 2011)^[7] and an associated best practice tariff. Fundamental pillars in this treatment pathway include multi-disciplinary team (MDT) care, timely surgery and full weight bearing post operatively (BOAST Guideline 1 Version 2). The hip fracture framework - and the financial incentives associated with it - have significantly improved outcomes post hip fracture with year on year reductions in mortality^[8]. There was a hip fracture paradigm shift; one is now needed for fractures on the other side of the hip joint - the acetabular fracture. The hip fracture framework - MDT care, early surgery and early full weight bearing - can be equally applied to acetabular fractures in older patients.

To achieve the aim of immediate mobilization post fracture, a surgical paradigm shift is also required from the prolonged immobilisation associated with non-operative treatment or operative fixation alone to surgical treatment that enables immediate weight bearing. A paper from two decades ago stated, "Hip arthroplasty for acute treatment of acetabular fractures is rarely indicated"^[9]. Our conceptual framework has changed since then. Acetabular fractures in the elderly have a particular injury pattern: A separate quadrilateral-plate

component and roof impaction in the anterior column fractures with medialisation of the femoral head, and comminution and marginal impaction in posterior-wall/column fractures^[3]. Surgical fixation methods must take this in to account and total hip arthroplasty (THA) is an important component of the surgical armamentarium in these fractures. THA aids in the goal of early full weight bearing. Non-weight bearing or restricted weight bearing is difficult or impossible for older patients. Particularly in the frail and cognitively impaired, restricted weight bearing significantly increases medical complications and prolongs dependence on care. They are often observed to slowly decline, both physically and psychologically; and usually do not recover to their pre-fracture function, with overall loss of quality of life. A management strategy is required that allows early, unrestricted weight bearing.

Is the "fix and replace" construct a new surgical paradigm in the management of the elderly acetabular fracture? There is room for early optimism. Rickman *et al*^[10] in the United Kingdom reported on a cohort in 2014. Their surgical technique included plate stabilization of both acetabular columns plus simultaneous THA using a tantalum socket and a cemented femoral stem. All 24 patients mobilized with full weight bearing by day 7 postoperatively. Complications included: Superficial wound infection, symptomatic deep venous thrombosis and one in-hospital death from myocardial infarction. A more recent international report^[10] reiterates the challenges posed by this group of patients. Their cohort of 18 patients included younger patients (average 66 years, range 35-81) but with excellent Harris Hip Scores at almost 2 years average follow-up.

Early results from our centre are promising. Our current "fix and replace" cohort includes 19 patients (14 with a minimum of 3 mo follow-up). The age range is from 63 to 94 with 9 females and 10 males. Initial data from our cohort is summarized in Table 1. Cognitive impairment is not a contraindication in our institution. Anecdotally these patients seem to benefit the most with their full weight bearing status post operatively. They are generically unable to comply with anything less. In our series, 9 (47%) were independently mobile prior to admission and the most common mechanism of injury was a fall from a standing height. Our surgical approach includes open reduction and internal fixation of the anterior fracture component (through a modified Stoppa approach) followed by posterior column reconstruction with a THA or hip arthroplasty revision (in 4 cases) (through a posterior or Kocher Langenbeck approach). Open reduction internal fixation of both acetabular columns is achieved with standard reconstruction acetabular plates (Synthes), occasionally supplemented by suprapectineal plates (Stryker) to buttress quadrilateral plate comminution and prevent medial migration of the cup. For acetabular cup reconstruction, we use a trabecular metal shell (TMARS, Zimmer Biomet) to address any bone defects and enable further fracture fixation with screw fixation in both columns. A cup is then cemented into the shell (either polyethylene lipped liner or a dual mobility

cup) in appropriate alignment to optimise hip stability. A cemented femoral stem is then used. The cost of these implants is approximately £6000 per case.

The mean time to get out of bed (with assistance) was 2.5 d. This is a significant improvement on the alternative of usually a minimum of 2 wk bed rest and another 6 wk of restricted weight bearing status with non-operative management. Despite efforts aiming for early mobilization, most patients (58%) did not get out of bed on the first post-operative day. The mean post operative Oxford Hip Score was 31, at a minimum of 3 mo.

Medical complications in this cohort included: A urinary tract infection, a lower respiratory tract infection, acute kidney injury, malignant neuroleptic syndrome in a patient with Parkinson's disease and a non-fatal pulmonary embolus. Two groups of patients posed a particular challenge: Patients with neurological conditions such as Parkinson's disease and patients with periprosthetic fractures (the "fix and revise" cohort). There were 6 hip dislocations in 5 patients (2 in the "fix and revise" group, 2 in the Parkinson's group and 1 Parkinson's patient with a "fix and revise"). Of these dislocations, 2 underwent a closed reduction; there were 3 stem revisions (one with subsequent Girdlestone after a repeat dislocation) and one Girdlestone in a patient with severe Parkinson's disease. The dislocations that required open reduction and revision were in the group with severe Parkinson's disease, and/or periprosthetic fractures. Dislocation rates and subsequent complications are known to be high in this group^[11-13]. There were two deaths in the cohort— one due to an out of hospital cardiac arrest 20 mo post surgery and one due to pneumonia 8 mo post-surgery.

The early results of this cohort highlight the potential gains with this strategy (early mobilization compared to non-operative management) but also concerns related to length of surgery and cost of treatment. Complications have been medical as well as directly related to surgery and continuous service evaluation allows medical and surgical care to be adapted as our protocol develops.

Despite the early promising potential, questions remain. There are concerns about the length of surgery and the physiological reserve required to withstand this. Are the complications that can arise from this complex surgery surmountable? Do the benefits of early mobilization outweigh the potential risks of sciatic nerve injury, periprosthetic infection, haemorrhage (including potential catastrophic bleeding from the friable elderly presacral plexus), hip dislocation, periprosthetic fracture or failure of the construct? Who in this cohort benefits from the "fix and replace" construct? What are our goals beyond early weight bearing?

Which is better: Non-operative management, operative management with open reduction and internal fixation alone or operative management with open reduction and internal fixation and THA? There is no agreed consensus^[5,13].

A 2014 systematic review presents pooled data from 8 studies demonstrating that satisfactory surgical fixation had only been achieved in 45.3% of patients and 23.1% of patients had significant pain and reduced function necessitating THA. When surgical fixation alone and surgical fixation with THA was compared, there was no increase in complications compared to patients who underwent surgical fixation alone^[5]. The paper highlights that there is a paucity of high quality data to draw robust conclusions. Clinical trials are now needed to provide high quality evidence that address the above described challenges and ultimately determine the optimum management of acetabular fractures in older patients. The new "fix and replace" paradigm may help provide the answer.

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Development of an internally braced prosthesis for total talus replacement

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Author contributions: Regauer M had the primary idea of an internally braced prosthesis for total talus replacement, designed the research project, performed the research project including the cadaver surgery and was responsible for acquisition of data, writing the paper and design of illustrations and figures; Lange M and Baumbach S contributed relevant literature and helped to design the illustrations and figures; Soldan K and Peyerl S were responsible for the design, technical development and final production of the first prototype of the internally braced prosthesis; Böcker W and Polzer H revised the article critically for important intellectual content and were responsible for the final approval of the version to be published.

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Abstract

Total loss of talus due to trauma or avascular necrosis, for example, still remains to be a major challenge in foot and ankle surgery with severely limited treatment options. Implantation of a custom made total talar prosthesis has shown promising results so far. Most important factors for long time success are degree of congruence of articular surfaces and ligamentous stability of the ankle. Therefore, our aim was to develop an optimized custom made prosthesis for total talus replacement providing a high level of primary stability. A custom made hemiprosthesis was developed using computed tomography and magnetic resonance imaging data of the affected and contralateral talus considering the principles and technology for the development of the S.T.A.R. prosthesis (Stryker). Additionally, four eyelets for fixation of artificial ligaments were added at the correspondent footprints of the most important ligaments. Two modifications can be provided according to the clinical requirements: A tri-articular hemiprosthesis or a bi-articular hemiprosthesis combined with the tibial component of the S.T.A.R. total ankle replacement system. A feasibility study was performed using a fresh frozen human cadaver. Maximum range of motion of the ankle was measured and ligamentous stability was evaluated by use of standard X-rays after application of varus, valgus or sagittal stress with 150

N. Correct implantation of the prosthesis was technically possible *via* an anterior approach to the ankle and using standard instruments. Malleolar osteotomies were not required. Maximum ankle dorsiflexion and plantarflexion were measured as 22-0-28 degrees. Maximum anterior displacement of the talus was 6 mm, maximum varus tilt 3 degrees and maximum valgus tilt 2 degrees. Application of an internally braced prosthesis for total talus replacement in humans is technically feasible and might be a reasonable procedure in carefully selected cases with no better alternatives left.

Key words: Ankle; Avascular necrosis; Total loss of talus; Prosthesis; Hemiprosthesis; InternalBrace; Talus replacement

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Core tip: Implantation of a total talar prosthesis has shown promising results so far. The aim was to develop an optimized prosthesis providing a high level of primary stability. A custom made hemiprosthesis was developed using computed tomography and magnetic resonance imaging data. Four eyelets for fixation of artificial ligaments were added at the footprints of important ligaments. Correct implantation of the prosthesis in a cadaver model was possible *via* an anterior approach. Maximum ankle dorsiflexion and plantarflexion were measured as 22-0-28 degrees. Maximum anterior displacement of the talus was 6 mm, maximum varus tilt 3 degrees and maximum valgus tilt 2 degrees.

Regauer M, Lange M, Soldan K, Peyerl S, Baumbach S, Böcker W, Polzer H. Development of an internally braced prosthesis for total talus replacement. *World J Orthop* 2017; 8(3): 221-228 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v8/i3/221.htm> DOI: <http://dx.doi.org/10.5312/wjo.v8.i3.221>

INTRODUCTION

Total loss of talus due to trauma^[1-5] or avascular necrosis^[6-9], for example, still remains to be a major challenge in foot and ankle surgery with severely limited treatment options^[2,4,5,8,9]. Furthermore, collapse of the talar body as a complication of total ankle arthroplasty^[10], talectomy in infection and septic talus necrosis^[11] or severe bone defects due to tumor resection^[12] may result in the need for total talar replacement, especially in younger and active patients (Figure 1).

Because arthrodesis of the ankle or the complete rearfoot as well as tibiocalcaneal fusion after talectomy can produce severe disability of the ankle and the foot, different study groups have already developed a prosthesis to replace the talar body^[13-16] or even the complete talus^[10,17-20]. Lampert *et al*^[12] and Ketz *et al*^[21] combined a custom total talar prosthesis with the tibial component of a standard total ankle prosthesis, and



Figure 1 Magnetic resonance imaging of a 32-year-old male patient showing complete avascular necrosis of the talus.

Giannini *et al*^[22] recently reported on a custom-made total talonavicular replacement in a professional rock-climber.

Implantation of a custom made talar body^[13-16] or total talar prosthesis^[10,17-20] in humans has already shown promising results so far. In 1997 Harnroongroj *et al*^[16] was the first to report on a series of 16 patients treated by use of a quite primitive talar body prosthesis which has been implanted by a medial transmalleolar approach. Eight of nine patients who were evaluated 11 to 15 years postoperatively had a satisfactory result, which is quite comparable to the results reported after standard total ankle replacement at that period of time. The exceptional patient in this series had an unsatisfactory result because the prosthetic stem had sunk into the talar neck and needed revision surgery 13 years after the index operation^[16]. Total talar replacement with a prosthesis was first performed in Japan in 1999. Several subsequent prosthetic design revisions have resulted in improved outcomes after prosthesis implantation^[14]. Taniguchi *et al*^[14] reported favorable results in eight of 14 patients after a mean follow-up period of 83 mo using a second-generation prosthesis which only partially replaced the talar body. As mentioned in their report, the third-generation prosthesis completely replacing the talus is currently recommended and has been associated with much better outcomes than the second-generation prosthesis^[14]. Tsukamoto *et al*^[10] first reported treatment of talar collapse after total ankle arthroplasty in a patient with rheumatoid arthritis by talar replacement with a third-generation prosthesis. However, this type of prosthesis still had a subtalar stem for fixation to the calcaneus by use of bone cement. Magnan *et al*^[13] extended this procedure using a total talar prosthesis and combined it with the standard S.T.A.R. total ankle arthroplasty system (Waldemar Link, Hamburg, Germany) in a 45-year-old professional male skier and rock-climber. Stevens *et al*^[17] even reported on a 14-year-old girl who underwent total talar replacement after an open talar dislocation. And again it was Harnroongroj to report on the largest series of 33 patients with by far the longest follow-up period of 10-36 years after implantation of a talar body prosthesis^[15]. In this series published in 2014,

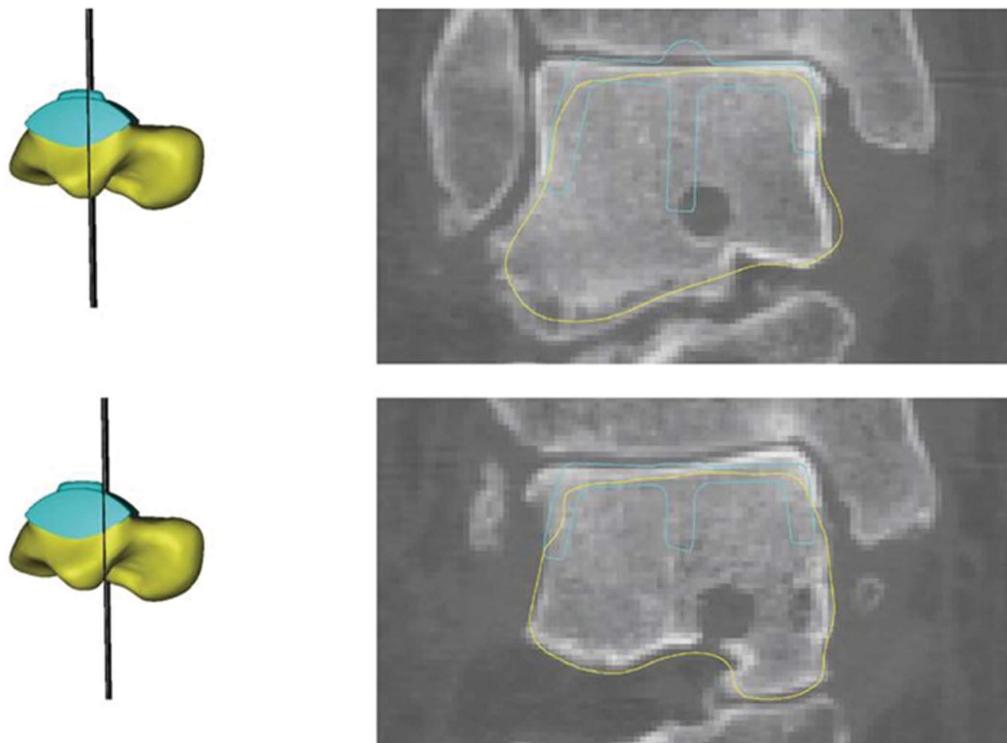


Figure 2 A customized hemiprosthetic was developed using computed tomography and magnetic resonance imaging data of the affected and contralateral talus considering the option of integrating the S.T.A.R. prosthesis (Stryker) into the design.

28 of the 33 prostheses were still in place at the time of final follow-up while five had failed prior to five years.

Advantages of total talar replacement include preservation of joint mobility, a relatively short period of restricted weight bearing, rapid pain relief and preservation of limb length^[18]. A native talus is well-seated within the ankle, fitted firmly between the tibia, the fibula, tarsal navicular, and the calcaneus. It has no muscular attachments and over 60% of its surface is covered with articular cartilage^[17]. Therefore, stability of the talus or a total talus prosthesis, respectively, depends on the integrity of the main ligaments and on the adjacent bones that build up the ankle mortise and the subtalar joint as well as on the anatomical shape of the talus itself^[16].

For example, early prosthesis failure occurred as a result of size mismatch in two patients in the large series reported by Harnroongroj *et al*^[15]. And according to Ando *et al* the procedure of total talar replacement carries at least a theoretical risk of anterior instability of the prosthesis, because the anterior talofibular ligament (ATFL) and deep deltoid ligaments are divided during the procedure^[16]. To address this problem of ligamentous stabilization, Stevens proposed the addition of porous coating at the main ligamentous attachment sites of the ATFL and the deltoid ligament to provide improved stability^[17].

According to this, most important factors for long time survival of a prosthesis for total talus replacement are degree of congruence of articular surfaces and ligamentous stability of the ankle and subtalar joint.

Therefore, to further improve the idea of total talus

replacement, our aim was to develop an optimized custom made prosthesis for total talus replacement providing maximum possible congruence of the articular surfaces and a maximum high level of primary stability immediately after implantation. We introduced the use of preoperative magnetic resonance imaging (MRI) data and an internal bracing technique we had been using successfully for augmentation of severe ligamentous injuries of the foot and ankle since several years^[22,23]. The primary aim of this so called InternalBrace™ technique is reconstruction or repair of vital tissue rather than replacement with non-vital tendon transplants. The InternalBrace™ acts as a corner stone or check-rein to stability allowing physiological and limiting pathologic motion. Thereby this method applies the classical AO principles to soft tissues.

DEVELOPMENT OF AN INTERNALLY BRACED TALAR PROSTHESIS

A custom made hemiprosthetic was developed considering the relevant anatomical principles and the technology for the development of the S.T.A.R. total ankle prosthesis (Stryker)^[24-28].

As we believed that a computed tomography (CT) might underestimate the real dimensions of the talus to be replaced, we added an MRI and calculated the mean dimensions of the talus between CT and MRI data to approximate the real dimensions of the talus as accurately as possible (Figures 2 and 3). Most other authors only used X-rays and CT scans for designing the



Figure 3 Components of the customized hemiprosthesis for combination with the S.T.A.R. prosthesis (Stryker).



Figure 4 Eyelets for fixation of artificial ligaments (FiberTape®, Arthrex) were added at the corresponding footprints of the main ankle ligaments. View from lateral on the eyelet (black arrow) for the artificial anterior talofibular ligament.

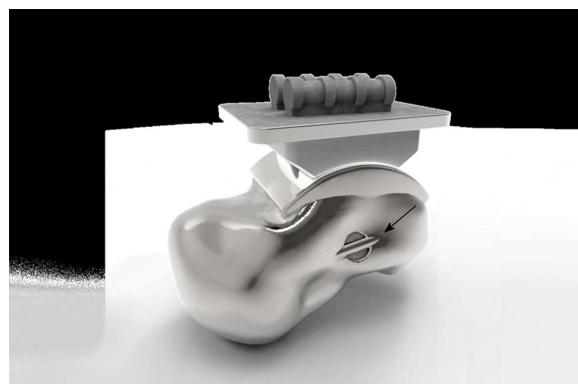


Figure 6 View from medial on the eyelet (black arrow) for fixation of the artificial deltoid ligament.



Figure 5 View from anterior on the eyelet (black arrow) for the artificial anterior talofibular ligament.



Figure 7 In the view from posterior the eyelets are not visible.



Figure 8 View from plantar on the eyelets (black arrows) for the artificial interosseous talocalcaneal ligament.

prosthesis^[10,15-18]. In cases where the index talus has been severely destructed the prosthesis can be designed alternatively using the mirror image of the CT and MRI data from the contralateral ankle.

Additionally, four eyelets for fixation of artificial ligaments (Figures 4-8) were added at the correspondent footprints of the ATFL, the deltoid ligament and the interosseous talocalcaneal ligament (ITCL). We used artificial ligaments called FiberTape® (Arthrex, Naples, United States) for performing the InternalBrace™ technique at surgery (Figures 9-13).

Two modifications can be provided according to the clinical requirements: A tri-articular hemiprosthesis in

case of completely intact surrounding articular surfaces or a bi-articular hemiprosthesis combined with the tibial component of the S.T.A.R. total ankle replacement system



Figure 9 Anterolateral stabilization of the customized hemiprostheses by use of an InternalBrace™ in the anatomic course of the anterior talofibular ligament viewed from lateral.

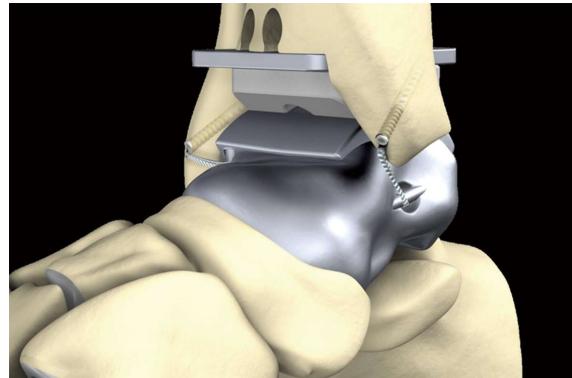


Figure 12 Anterolateral and anteromedial stabilization of the customized hemiprostheses by use of an InternalBrace™ in the anatomic courses of the anterior talofibular ligament and the deltoid ligament viewed from anteromedial.

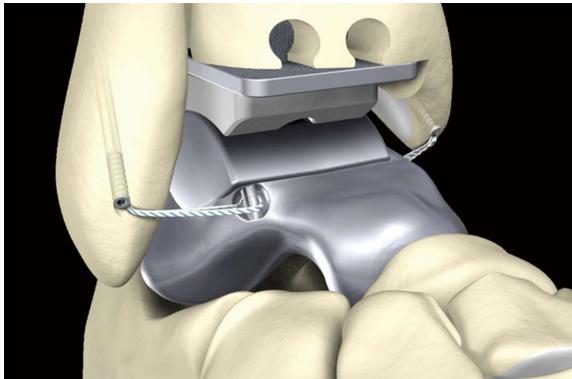


Figure 10 Anterolateral and anteromedial stabilization of the customized hemiprostheses by use of an InternalBrace™ in the anatomic courses of the anterior talofibular ligament and the deltoid ligament viewed from anterolateral.



Figure 13 Anteromedial stabilization of the customized hemiprostheses by use of an InternalBrace™ in the anatomic courses of the deltoid ligament viewed from posteromedial.



Figure 11 Anterolateral and anteromedial stabilization of the customized hemiprostheses by use of an InternalBrace™ in the anatomic courses of the anterior talofibular ligament and the deltoid ligament viewed from anterior.

in case of additional damage to the articular surface of the tibial pilon (Figure 3).

SURGICAL TECHNIQUE

A feasibility study was performed using a 36-year-old male fresh frozen whole leg human cadaver. In the supine

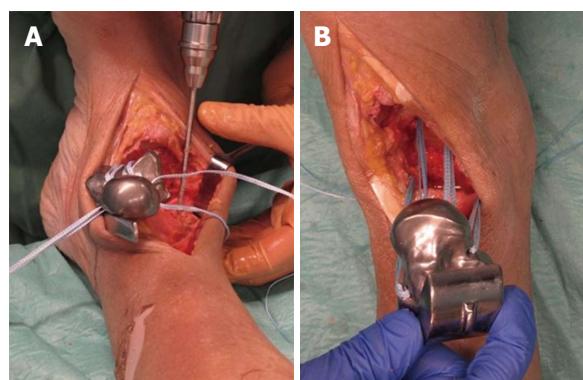


Figure 14 A feasibility study was performed using a fresh frozen male human cadaver. A: Preparing of the bone tunnels at the anatomic footprints of the native ligaments for fixation of the artificial ligaments; B: All four artificial ligaments were shuttled through the bone tunnels before insertion of the prosthesis.

position, a straight skin incision was made according to a standard anterior approach to the ankle joint for total ankle arthroplasty (Figure 14). After opening the anterior capsule of the ankle joint, the talus was divided into five main parts by use of a chisel and completely resected. Then the bone tunnels were prepared at the anatomic

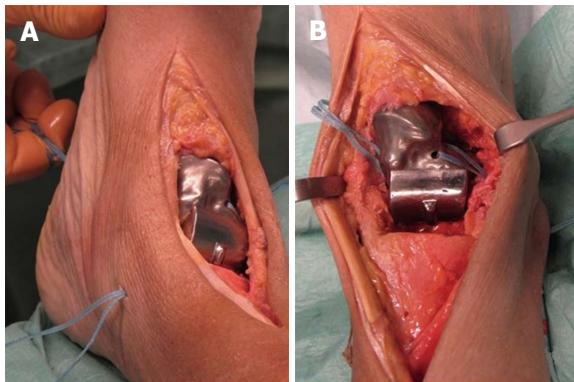


Figure 15 Prostheses and bone tunnels before insertion of the prosthesis. A: The prosthesis was inserted from anterior while steady tensioning the four artificial ligaments; B: View from anterior on the pre-tensioned anterior talofibular ligament.

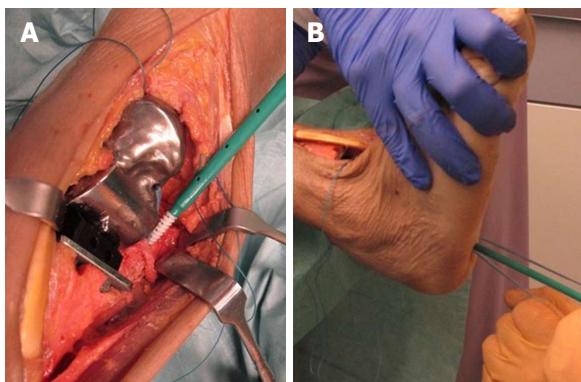


Figure 16 Aperture fixation of the correctly pre-tensioned artificial ligaments at the anatomic footprints with an interference screw (SwiveLock® 4.75 mm, Arthrex, Naples, United States). A: Direct aperture fixation of the anterior talofibular ligament at the distal fibula; B: Retrograde indirect aperture fixation of the interosseous talocalcaneal ligament at the calcaneus performed percutaneously from plantar.

footprints of the native ligaments for fixation of the artificial ligaments (Figure 14). All four artificial ligaments for replacement of the ATFL, the deltoid ligament and the ITCL were shuttled through the eyelets of the prosthesis and through the bone tunnels before insertion of the prosthesis (Figure 14). Then the prosthesis was inserted from anterior while steady tensioning the four artificial ligaments (Figure 15). Figure 15B shows a view from anterior on the pre-tensioned ATFL.

After insertion of the tibial component and the inlay of the S.T.A.R. total ankle prosthesis we performed an aperture fixation of the correctly pre-tensioned artificial ligaments at the anatomic footprints with an interference screw (SwiveLock® 4.75 mm, Arthrex, Naples, United States). Direct aperture fixation of the artificial ATFL and the deltoid ligament was performed at the distal fibula (Figure 16A) and the medial malleolus, respectively, and retrograde indirect aperture fixation of the ITCL at the calcaneus was performed percutaneously from plantar (Figure 16B).



Figure 17 Radiographic examination of the maximum range of motion of the ankle joint after internally bracing of the customized hemiprostheses. A: Neutral position; B: Maximum dorsiflexion 22°; C: Maximum plantarflexion 28°. Note the visible bone tunnel in the calcaneus (black arrow) with the interference screw inside the proximal part of the tunnel (white arrow) to prevent tunnel widening by indirect aperture fixation at the subtalar joint performed percutaneously from plantar.

FEASIBILITY STUDY

Correct implantation of the internally braced total talar prosthesis was technically possible *via* a standard anterior approach to the ankle and using standard instruments. Malleolar osteotomies were not required.

Radiographic examination of the maximum range of motion of the ankle joint after internally bracing of the customized hemiprostheses was performed. Figure 17 shows neutral position (Figure 17A), maximum dorsiflexion of 22° (Figure 17B), and maximum plantarflexion of 28° (Figure 17C). Note the visible bone tunnel in the calcaneus (black arrow) with the interference screw inside the proximal part of the tunnel (white arrow) to

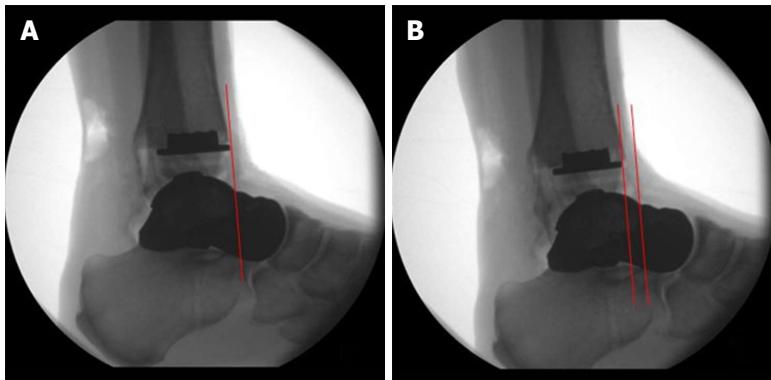


Figure 18 Maximum anterior displacement of the talus was 6 mm (B) compared to the neutral position (A).

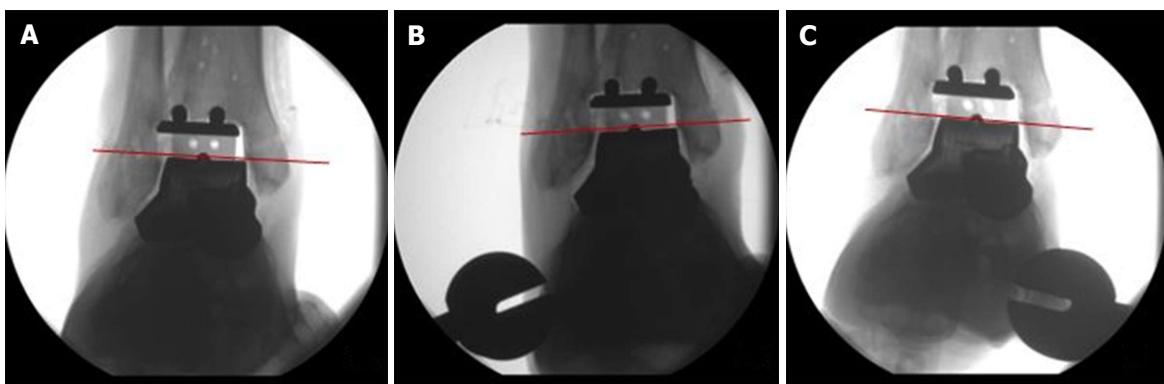


Figure 19 Compared to the neutral position (A) maximum varus tilt was 3° (B) and maximum valgus tilt was 2° (C).

prevent tunnel widening by indirect aperture fixation at the subtalar joint performed percutaneously from plantar.

Primary ligamentous stability of the internally braced total talar prosthesis was evaluated by use of standard X-rays after application of varus, valgus or sagittal stress with 150 N: maximum anterior displacement of the talus was 6 mm (Figure 18), maximum varus tilt 3 degrees and maximum valgus tilt 2 degrees (Figure 19) resembling quite physiological ankle function.

ON THE HORIZON

Application of an improved internally braced custom made prosthesis for total talus replacement in humans is technically feasible, and first experimental results show a very high primary stability of the implanted prosthesis. Based on our results the described procedure might be a reasonable treatment option in carefully selected cases with no better alternatives left. Due to the quite low frequency of adequate cases, multicentric evaluation seems to be necessary to provide high quality scientific data of outcome results and possible complications after implantation of an internally braced prosthesis for total talus replacement.

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Prevention and management of post-instability glenohumeral arthropathy

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Abstract

Post-instability arthropathy may commonly develop in high-risk patients with a history of recurrent glenohumeral instability, both with and without surgical stabilization. Classically related to anterior shoulder instability, the incidence and rates of arthritic progression may vary widely. Radiographic arthritic changes may be present in up to two-thirds of patients after primary Bankart repair and 30% after Latarjet procedure, with increasing rates associated with recurrent dislocation history, prominent implant position, non-anatomic reconstruction, and/or lateralized bone graft placement. However, the presence radiographic arthrosis does not predict poor patient-reported function. After exhausting conservative measures, both joint-preserving and arthroplasty surgical options may be considered depending on a combination of patient-specific and anatomic factors. Arthroscopic procedures are optimally indicated for individuals with focal disease and may yield superior symptomatic relief when combined with treatment of combined shoulder pathology. For more advanced secondary arthropathy, total shoulder arthroplasty remains the most reliable option, although the clinical outcomes, wear characteristics, and implant survivorship remains a concern among active, young patients.

Key words: Arthropathy; Glenohumeral; Dislocation; Latarjet; Instability

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Core tip: Non-anatomic stabilization procedures may result in overconstraint or incongruence of the glenohumeral

joint with resultant instability arthropathy. Proud suture anchors can create a traumatic wear pattern resulting in an iatrogenic arthropathy. Secondary arthropathy may occur in up to two-thirds of patients after Bankart repair and 30% after coracoid transfer at mid- to long-term follow-up, although clinical outcomes may vary. When conservative measures have failed, various arthroscopic procedures may be considered to address mechanical symptoms and other pain generators. Total shoulder arthroplasty remains the most reliable option for advanced instability arthropathy, although concern exists above survivorship in patients under 50 years.

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INTRODUCTION

Glenohumeral instability is a frequent problem encountered within high-risk patient populations^[1,2], and it poses important short- and long-term implications for shoulder function. While numerous previous studies have focused on the ideal management, risk stratification, and/or surgical technique for addressing patients with shoulder instability, few have examined the natural history of instability events as it relates to secondary arthrosis. The presence of concomitant shoulder instability and premature degenerative wear creates a difficult clinical scenario, and optimal treatment requires a fundamental knowledge of underlying anatomy and current, evolving treatment options.

With the largest range of motion of any articulation and minimal osseous constraint, the glenohumeral joint is largely stabilized by rotator cuff compression and its inherent concavity, which is deepened by its circumferential labral attachment. In addition to the anterior and posterior inferior labrum, the inferior glenohumeral ligament (IGHL) complex provides vital restraint to humeral translation. The anterior band of the IGHL limits anterior instability in elevated positions of abduction and external rotation, whereas the posterior band acts in forward flexion and internal rotation. Additionally, the rotator interval, which contains the coracohumeral, middle glenohumeral, and superior glenohumeral ligaments, has been a focal area of research. However, its contributions to inferior and anteroposterior glenohumeral restraint remains a continuing source of debate^[3,4].

Shoulder instability is classically defined by the directionality of excessive glenohumeral translation in association with a provocative examination. However, this must be differentiated from patients with asymptomatic laxity, particularly those with multidirectional involvement. Anterior instability accounts for the vast majority of patients with shoulder dislocations, with a reported

incidence rate ranging from 0.08 to 0.24 patients per 1000 person-years in civilian populations^[5-7]. Within a higher risk military demographic, the incidence may rise to nearly 3% per year when subluxation events are also considered^[1]. Conversely, posterior instability has historically accounted for only a smaller fraction of all unstable shoulders, with approximately 2% to 10% reported^[8-10]. More recent series indicate that isolated posterior instability may comprise over a quarter of patients with shoulder stabilization, and approximately 20% of additional patients will undergo surgery for combined or bidirectional instability^[11]. Especially within young active patients, circumferential labral pathology may also be common with isolated or recurrent anterior shoulder instability^[12,13], so there must be a high index of suspicion in the evaluation of these at-risk individuals.

MANAGEMENT OF GLENOHUMERAL INSTABILITY

Initial management

The initial management of an acute shoulder dislocation includes reduction of the glenohumeral joint followed by a period of immobilization in a sling with rest, ice, and anti-inflammatory medications. After the acute phase, initiation of passive range of motion and guided physical therapy can begin. Traditionally, patients were placed in a sling, which typically puts the shoulder into internal rotation. Duration in a sling varies according to the treating physician, and can range from very brief initial sling use to 2-3 wk of immobilization in variable positions^[14].

The indications for surgical management include recurrent instability following a trial of nonoperative treatment, ongoing pain and dysfunction from recurring subluxations, or selected, higher patient demographics with shoulder instability. There has also been focus on primary surgical stabilization in the young first-time dislocator, especially among young athletes and military servicemembers. A study in West Point cadets demonstrated the importance of age as a predictor for redislocation, with patients less than 20 years old having a 92% rate of redislocation with non-operative treatment^[15]. Similarly, a retrospective review of young athletes, predominantly rugby players with average age of 21 years, demonstrated that 94.5% of the patients treated non-operatively sustained recurrent dislocation vs only one patient (3.5%) in the operative group^[16].

In another prospective randomized controlled trial in active duty service members, Bottone *et al*^[17] compared 14 patients treated with four weeks of immobilization with 10 patients treated initially with acute arthroscopic Bankart repair. Of the 12 patients in the non-operative group available for follow-up, 9 (75%) developed recurrent instability. Comparatively, only one patient (11.1%) in the operative group developed recurrent instability. As a result, the authors advocated acute arthroscopic stabilization for young, high risk patients with a first-time anterior

dislocation in order to reduce the rate of recurrent instability and worsening secondary pathology, including glenohumeral arthropathy.

Open vs arthroscopic

Bankart repair and capsulorrhaphy were traditionally performed *via* an open deltopectoral approach, and historically considered the gold standard for repair. However, over the past three decades, clinical outcomes with an arthroscopic technique have improved dramatically, and many surgeons view this as an equivalent procedure to the classic open Bankart procedure. Variations of the open approach largely differ according to management of the subscapularis, with complete and partial tendon takedown described, as well as horizontal splitting techniques^[18,19]. With the evolution of contemporary suture anchor technology, the arthroscopic Bankart repair has become increasingly more common, and advocates highlight its enhanced cosmesis, avoidance of surgical site morbidity (*i.e.*, subscapularis compromise), ability to treat all associated intra-articular pathology, and improved external rotation. This debate has continued in the existent literature, and most studies have preferentially focused on recurrence rates and patient outcomes scores among comparative series. In a 2004 meta-analysis, the documented recurrence rate (subluxation or dislocation) for arthroscopic repair was 20%, whereas use of an open technique demonstrated a significantly lower rate (10%) of subsequent instability^[20]. Additionally, the authors found that a higher proportion of patients in the open group had a good or excellent Rowe score postoperatively. However, this study encompassed older techniques for arthroscopic labral repair, including trans-glenoid sutures and bioabsorbable suture tacks, which may introduce selection bias. A subsequent prospective randomized controlled trial of open vs arthroscopic Bankart repairs with modern suture anchor technique demonstrated a significantly lower recurrence rate at two years in the open group (11%) compared with the arthroscopic group (23%)^[21]. Furthermore, the authors found age less than 25, male gender and presence of a Hill-Sachs lesions as risk factors for recurrent instability. Conversely, a large scale study from the United States military demonstrated that open anterior stabilization had nearly two-fold higher rate of short-term revision surgery than those with arthroscopic procedures after multivariate analysis, although this failed to control for degree of occult bone loss.

Augmentation

Variations of the original Bankart repair have been introduced over the years in an attempt to further mitigate rates of recurrent instability. These methods have included a number of different bone and soft tissue transfers used in the setting of bony deficiency and/or irreparable soft tissue damage. Historically, the Magnuson-Stack procedure was a non-anatomic transfer of the subscapularis from its native insertion on the lesser tuberosity to the greater tuberosity in an attempt to increase tension and improve stability^[22,23]. Similarly, the Putti-Platt procedure provided

a longitudinal, “pants over vest” shortening of the subscapularis and underlying capsule in order to tighten the anterior soft tissue restraints^[24]. However, clinical outcomes with both of these non-anatomic procedures significantly disrupted the length-tension relationship of the subscapularis, leading to anterior overtensioning, loss of external rotation, and premature glenohumeral arthritis^[25-28].

Alternatively, Latarjet described a technique of transfer of the coracoid process to the anterior inferior glenoid as a bony augmentation^[29]. A slightly different type of coracoid transplantation procedure was described by Helfet and named in honor of his mentor, Walter Bristow^[30]. The Latarjet has become increasing popular as an option for the treatment of glenoid or bipolar bone loss, which is a significant predictor of recurrent instability after arthroscopic repair^[31]. Modifications to the initial description were made by Young *et al*^[32], which included fixation with two screws, repairing the anterior capsule to the coracoacromial ligament retained on the coracoid graft and placing the graft through a split in the subscapularis to provide a “sling” effect of the conjoined tendon. Further adaptations, such as the congruent arc technique, have also been proposed. In this circumstance, the inferior aspect of the coracoid, as opposed to the lateral surface described in the original technique, is rotated to match the contour of the glenoid neck and extend the potential articular surface^[33,34].

Other alternatives may be considered for complex shoulder instability with critical bone loss or engaging bipolar lesions. Potential graft sources for anterior glenoid reconstruction may include autograft or allograft iliac crest, allograft distal tibia, allograft glenoid, and/or local distal clavicular autograft^[35-37]. All of these procedures are predicated on the goal of extending the articular surface of the glenoid without providing a bony constraint to anterior humeral translation^[38]. On the humeral side, the “remplissage” procedure provides a capsulotenodesis of the posterior capsule and infraspinatus tendon into the Hill-Sachs lesion to prevent its engagement with the glenoid^[39]. This non-anatomic, arthroscopic procedure can be combined with a labral repair to provide stability even in the setting of glenoid bone loss^[40].

POST-INSTABILITY ARTHROPATHY

In an attempt to describe and characterize the natural history of the development of dislocation arthropathy after a primary shoulder dislocation, Hovelius *et al*^[41] followed 257 shoulders initially treated with non-operative management at long-term follow-up. At 25-year follow-up, 227 shoulders met criteria for inclusion. Of those, 29% had developed mild arthropathy, 9% moderate, and 17% severe, and less than half (44%) were classified as normal. Risk factors for development of secondary arthropathy included age greater than 25 at time of initial dislocation, high energy mechanism of injury during sporting activity, and history of alcohol abuse. When evaluating the same patient cohort requiring subsequent

stabilization surgery, Hovelius *et al*^[42] concluded that approximately two-thirds of patients under the age of 25 with surgery for first-time anterior dislocation developed at least mild arthropathy by final follow-up.

In addition to assessing the long term results of primary dislocations treated with initial non-operative management, the rates of secondary arthropathy have also been quantified for other methods of treating anterior shoulder stabilizations. To this end, Hovelius *et al*^[43] performed a retrospective comparative analysis of 26 shoulders with open Bankart repair and 30 shoulders with Bristow-Latarjet procedure at greater than 15-year follow-up. Of the shoulders that underwent Bankart repair, 16 (61.5%) went on to develop arthropathy (14 mild, 2 moderate), as compared to 9 (30%) shoulders in the Latarjet group (5 mild, 3 moderate, 1 severe). Interestingly, all patients who developed moderate or severe arthropathy, from either treatment group, reported being very satisfied with their outcome. This may reflect a disconnect between radiographic outcomes and patient-reported function after symptomatic instability has resolved, and this has been documented in other prior series as well^[27,44].

In a separate long term study assessing both the clinical and radiographic outcomes after Lateraljet procedure performed for recurrent instability, Allain *et al*^[45] found that none of the 58 shoulders had recurrent dislocation at 10-23 years postoperatively, although 6 had apprehension, and 1 had intermittent subluxations. However, only 22 shoulders (38%) demonstrated no evidence of glenohumeral osteoarthritis. Thirty-four shoulders (59%) had radiographic evidence of osteoarthritis, with the majority (25 shoulders) being grade 1 with no detrimental effects on upper extremity function. Two additional patients had severe, grade 4 changes with eccentric wear present, and there was a significant correlation between degree of secondary arthropathy and functional scores on both Constant and Rowe outcome measures. Recurrent dislocation, as opposed to subluxation, was significantly associated with a higher rate of secondary arthrosis, whereas number of shoulder dislocations and time to surgery were not significant predictors.

With failed primary stabilization procedures, patients with revision surgery may also be at heightened risk for instability arthropathy due to attritional bone loss and increasing injury complexity. Tauber *et al*^[46] investigated the reasons for failure after index stabilization surgery, but also assessed for the subsequent development and/or progression of arthritic changes after revision surgery. The authors found no significant difference in the progression of arthritis between bony glenoid augmentation procedures and soft tissue repairs at time of revision surgery, although only 14 of 41 (34%) had no radiographic signs of arthritis at the time of revision surgery. At mean 49 mo follow-up, only 5 shoulders (12%) continued to demonstrate no evidence of glenohumeral arthritis. The authors suggest that once the development of arthritis has been initiated, subsequent surgery for revision anterior stabilization

may not mitigate the onset or progression of secondary arthropathy.

The notion that the natural history of dislocation arthropathy is unchanged by surgical stabilization is echoed in a more recent study by Hovelius' group^[47]. At 33-35 years from transfer of the coracoid for shoulder stabilization, 31 shoulders were available for follow-up. Of these shoulder, 39% were normal, 27% had mild OA, 23% moderate and 11% severe. These findings were similar to their previous study (outlined above) on the long term outcome of shoulder dislocations treated non operatively^[41]. Interestingly, the majority of patients remained as satisfied with their outcomes at long-term follow-up as they were at 2-4 years from surgery, and only one patient required re-operation for recurrent instability.

Despite these long-term nature of these studies, most investigations do not control or evaluate for the role of surgical technique or patient-specific factors on the development of dislocation arthropathy^[34,41,43,45,47]. It is well established that the overtensioning of the capsular and/or subscapularis, as in the historical non-anatomic procedures, may overconstrain the glenohumeral joint and contribute to premature onset of arthritis with asymmetric, anterior glenoid wear. Additionally, non-absorbable or metallic implants, prominent anchor placement, and/or malpositioned arthroscopic knots can abrade the articular surface of the humeral head, thus increasing the risk for the arthritic change (Figure 1). Most series also emphasize that lateral placement of coracoid bone graft can hasten the development of dislocation arthropathy, or at least significantly increase the rate of secondary chondral damage^[45,48]. While some authors theorize that intra-articular coracoid graft placement (*i.e.*, capsule repaired to the lateral vs medial edge of the graft used) may increase the chances of humeral head abrasion^[48,49], there is no clear data correlating this technique with clinical or radiographic endpoints.

CONSERVATIVE TREATMENT

Periarticular injections

Injections for management of shoulder arthropathy are considered a treatment alternative as they represent a less invasive treatment method to surgery. Although there are several types of injections, the efficacy of these injections is not well articulated in the existent literature.

Diagnostic injections may also have utility when clinical examination alone does not yield a clear diagnosis or primary source of pathology. While also offering potential therapeutic value, diagnostic injections can be performed with short acting local anesthetics, particularly xylocaine or lidocaine, into the specific areas of interest, such as the biceps sheath and acromioclavicular joint. Particularly given the association between infusion pain pumps and irreversible chondrolysis^[50], longer acting medications (*e.g.*, bupivacaine) should be avoided over shorter acting agents due to greater potential for chondrotoxicity^[51-56].

Cortisone injections are also frequently used for



Figure 1 Anteroposterior (A) and lateral (B) X-rays of a 39-year-old male with dislocation arthropathy status post instability procedure with metal anchors.

the nonoperative treatment of glenohumeral arthritis; however, their efficacy has not been well studied and the majority of scientific evidence is based on limited case series^[57-59]. Corticosteroids interrupt the inflammatory cascade and typically result in a transient decrease in secondary pain. Unfortunately, the efficacy and duration of symptomatic relief is not known and often patient-dependent, typically ranging from weeks and months. Therefore, a limitation of cortisone injections is lack of consistent durability. Additional concerns exist regarding the potential systemic side effects and increased risk of infection when performed within 3 mo of an arthroplasty procedure^[60].

While used less frequently, injectable non-steroidal anti-inflammatory drugs (NSAIDs), such as Ketorolac, may result in fewer side effects and may have similar efficacy to cortisone^[61]. As with cortisone, NSAIDs may also lack effect durability and represent a temporizing treatment option. Further research is required to better ascertain the role and relative efficacy of local NSAID injections in young patients with post-instability arthritis.

Viscosupplementation/hyaluronic acid injections and orthobiologics: Viscosupplementation, while FDA-approved for knee osteoarthritis, is considered off-label for use in the shoulder. A prior meta-analysis performed evaluating the use of hyaluronic acid (HA) injections in the shoulder for a variety of disorders, including osteoarthritis, revealed an absence of evidence for clinically significant improvement^[62]. More recently, a subsequent meta-analysis of 8 studies evaluating osteoarthritis of the glenohumeral joint, including two randomized prospective trials, suggested a lack of convincing evidence for the efficacy of HA injections^[63-67].

Given the lack of definitive efficacy, reimbursement for HA injections is limited. Theoretically it should behave in the shoulder similar to the knee as both are synovial joints. Recently, scientific support for viscosupplementation in the knee was challenged by guidelines published by the American Academy of Orthopaedic Surgeons (AAOS), making application in general less likely to be supported by third party payers. Nevertheless, its safety profile and ease of administration make it a safe and reasonable

alternative to more invasive treatment options.

Further innovations in orthobiologics represent the vanguard of nonoperative treatment for many musculoskeletal conditions, although clinical trials are lacking. Specifically, platelet-rich plasma (PRP) or stem cell injections may have potential as viable treatment option for glenohumeral arthritis, but no literature currently exists to support their use. Recent literature indicates that there may be benefit for PRP injections in the setting of knee arthritis^[68]. Biologic alternative injections that modulate cartilage repair processes and regulate inflammatory mediators are a principle area of current research but no definitive treatment options have been developed to date.

Physical therapy

Little to no literature exists regarding the use of physical therapy as a form of treatment for glenohumeral osteoarthritis. A recent clinical practice guideline from the AAOS stated that there was "no evidence for or against" the use of physical therapy or other modalities such as "massage, joint mobilization, joint manipulation, exercise, phonophoresis, iontophoresis, ultrasound, laser, acupuncture, and/or electrical stimulation"^[69]. Given the low risks associated and limited alternatives, physical therapy may be a reasonable consideration in patients desiring non-surgical management. However, it may also exacerbate symptoms related to painful, advanced arthritis. If restoration of motion or dynamic control of residual instability are among the primary goals, then a physical therapist or self-directed home exercise program may provide value among available treatment options^[70].

Oral medication

A variety of oral analgesics are available for treatment of osteoarthritis including NSAIDs, oral corticosteroids, acetaminophen, topical analgesics, and various non-regulated supplements such as chondroitin sulfate, vitamins, and herbal supplements. Non-narcotic analgesics are routinely recommended for the treatment of pain associated with glenohumeral arthritis, but as with other conservative interventions, there is no specific evidence documenting their effectiveness. Nonetheless,

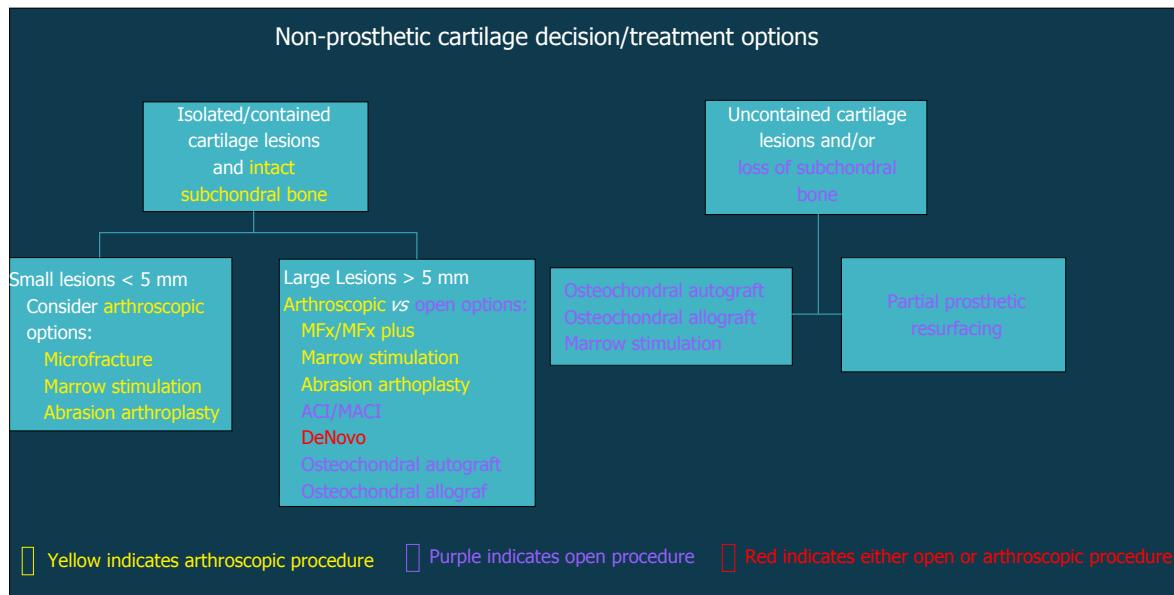


Figure 2 Flow-chart demonstrating decision algorithm for non-prosthetic cartilage treatment options.

these medications are considered a first-line alternative to more invasive interventions, must be balanced with the potential side effects. Specifically, NSAIDs may be contraindicated for patients with known kidney disorders, gastritis or a history of peptic ulcer disease, hypertension, coronary artery diseases, and/or other medical problems that impair drug metabolism.

SURGICAL MANAGEMENT

Treatment decision making

When conservative treatment fails to ameliorate symptoms in patients with instability arthropathy, a multitude of potential surgical options exist. Ultimately, treatment should be decided through a shared decision-making process and tailored to their unique anatomic factors, physiological age, comorbidities, and functional demands. In contrast to patients with osteoarthritis, individuals with early arthropathy due to glenohumeral instability are often younger, more active, and involved in both athletics or intense occupational duties. Accordingly, the potential clinical benefits of a given procedure must be balanced with its efficacy, durability, and impact on future surgical treatment.

Relevant clinical variables such as size or extent of glenohumeral chondral lesion(s), residual instability, concomitant motion loss, and presence of associated pathology.

Patients with altered glenohumeral kinematics must be identified and addressed alone or in conjunction with an additional surgical procedure (Figure 2). When post-instability arthropathy has developed due to over-tensioning of either the anterior or posterior capsule, an arthroscopic capsular release may be considered to restore normal kinematics. Furthermore, loss of appropriate rotator

cuff function, particularly the subscapularis, can result in shoulder dysfunction and must also be addressed accordingly. Finally, patients with a collagen disorder (e.g., Ehlers Danlos) represent a particularly difficult population to manage. Given that many of these patients will have had several prior surgeries, reconstructive options will be limited in the setting of post-instability arthropathy, including continuing conservative care, arthroscopic debridement, or potentially, arthrodesis.

In general, surgical strategies for post-instability arthropathy are contingent on the degree and severity of the associated articular cartilage lesions. Variable arthroscopic and open procedures may be indicated for localized disease and/or focal defects of the glenohumeral joint (Figure 3). However, when the articular involvement is more advanced and secondary arthritis has developed (Figure 4), arthroplasty options may be preferentially considered in the absence of marked rotator cuff disease, significant neurologic deficits, and/or structural glenohumeral bone loss with residual instability.

Non-arthroplasty options

Glenohumeral debridement: Arthroscopic debridement of the glenohumeral joint (Figure 5) has been reported as having variable, if not modest success among several case series^[71-73]. While most of these studies do not detail the precise surgical interventions, simple removal of symptomatic loose bodies or foreign bodies (e.g., prominent suture material), debridement of hypertrophic synovitis, and/or capsular release may have a positive short-term effect on most patients^[74].

Adjunctive procedures: The addition of adjunctive procedures has not been extensively evaluated, although treatment of biceps-labral complex, rotator cuff, acromioclavicular, or subacromial pathology may also yield

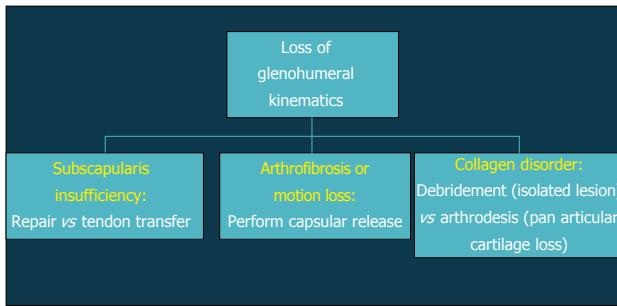


Figure 3 Flow-chart depicting treatment options after loss of glenohumeral kinematics.

partial, symptomatic relief. Skelley *et al*^[75] revealed worse surgical results when arthroscopic glenohumeral debridement and capsular release was performed strictly without any additional procedures. As a result, the authors suggest that isolated arthroscopic debridement and capsular release when done without any other concomitant procedures may not provide lasting enough benefit to justify its use.

More recently, the Comprehensive Arthroscopic Management (CAM) procedure was described by Millet *et al*^[76] for younger, active patients early glenohumeral arthritis. The CAM procedure differs from previous arthroscopic debridement in that it also features an extensive capsular release, humeral osteoplasty with inferior osteophyte removal, axillary neurolysis, and a biceps tenodesis, when appropriate. Retrospective, short term follow-up of 30 shoulders in 29 patients with an average age of 52 years (range 33 to 68 years) revealed 85% survivorship at 2 years with statistically significant improvement in pain and functional scores. Worse preoperative functional scores and joint space measurements less than 2 mm were more likely experience clinical failure and require subsequent shoulder arthroplasty. By contrast, patients with worse pre-operative motion experienced greater postoperative satisfaction, suggesting that the CAM procedure may be ideally suited for those patients affected by with motion loss due to impinging osteophytes or capsular tightness. In a separate analysis, the authors further evaluated the CAM procedure with a Markov decision model and discovered that arthroscopic management was the preferred strategy for patients younger than 47 years, whereas TSA was optimal for patients over 66 years and both treatment strategies may be considered between 47-66 years^[77].

Chondral restoration: Isolated glenohumeral chondral lesions without global or diffuse cartilage involvement may be considered for a restorative procedure. Identification of symptomatic cartilage lesions can be a challenge, as coexistent pathology may be frequently be present and difficult to independently distinguish. As previously mentioned, diagnostic injections may help identify focal areas of pathology masquerading as glenohumeral disease^[78].

Microfracture or other marrow stimulation techniques

have been employed with clinical success in the knee, although only three small case series have been evaluated its role in the glenohumeral joint^[79-81]. The merits of this procedure include that it can be performed arthroscopically without the surgical morbidity associated with an open approach. However, the utility of isolated microfracture is probably limited, and its durability of this procedure is in question due to failure rates approaching 20%^[80]. Additionally, some authors have expressed concerns about the potentially harmful effects that of subchondral bone particularly in the glenoid may be harmful^[82]. Newer modifications incorporating marrow stimulation with orthobiologics are also emerging, but these techniques have not yet been described in the shoulder^[83].

Osteochondral autograft transfer (OATS) or osteochondral allograft transplantation have demonstrated narrow indications in the shoulder, mostly for humeral-based lesions (Figure 6), although the literature is notably limited. Due to the concave geometry of the glenoid vault, centrally located glenoid lesions may be able to accommodate osteochondral transfer, although remains technically challenging^[84]. Only one known series has evaluated the surgical outcomes of 8 patients with OATS from the lateral femoral condyle for Outridge grade IV lesions of the shoulder (7 humeral, 1 glenoid). All patients experienced improvement in both function and pain postoperatively, but two patients experienced mild, persistent shoulder limitations and one patient with donor site knee pain requiring arthroscopic debridement^[85]. In a systematic review of 35 patients with osteochondral allografts of the humeral head at mean 57 mo follow-up, Saltzman *et al*^[86] showed significant improvements in range of motion and American Shoulder and Elbow Society scores. Of note, however, 8.7% demonstrated graft necrosis, 26.7% of patients underwent reoperation, and 35.7% developed secondary arthritic changes. The authors also acknowledged that the majority of grafts were derived from frozen allografts, thereby limiting chondrocyte viability vis-à-vis fresh osteochondral allografts.

Arthroplasty options

Arthroplasty options exist for post-instability arthropathy that incorporates a prosthesis of the humeral head, the glenoid, or both. Survivorship as a concept for surgical treatment is the period of time free from revision surgery. Another way to describe survivorship is durability of outcome or durability of patient satisfaction. Recent literature has highlighted the discrepancy of implant survival with patient satisfaction in shoulder arthroplasty in patients under the age of 50 years^[87].

Partial resurfacing/biologic resurfacing/hemiarthroplasty: Partial humeral head resurfacing with a prosthesis has been suggested as an option for patients with isolated or unipolar humeral disease. Concomitant pathology as well as prior surgical procedures have been found to decrease outcomes and could be considered a contraindication to this procedure^[88]. Soft-

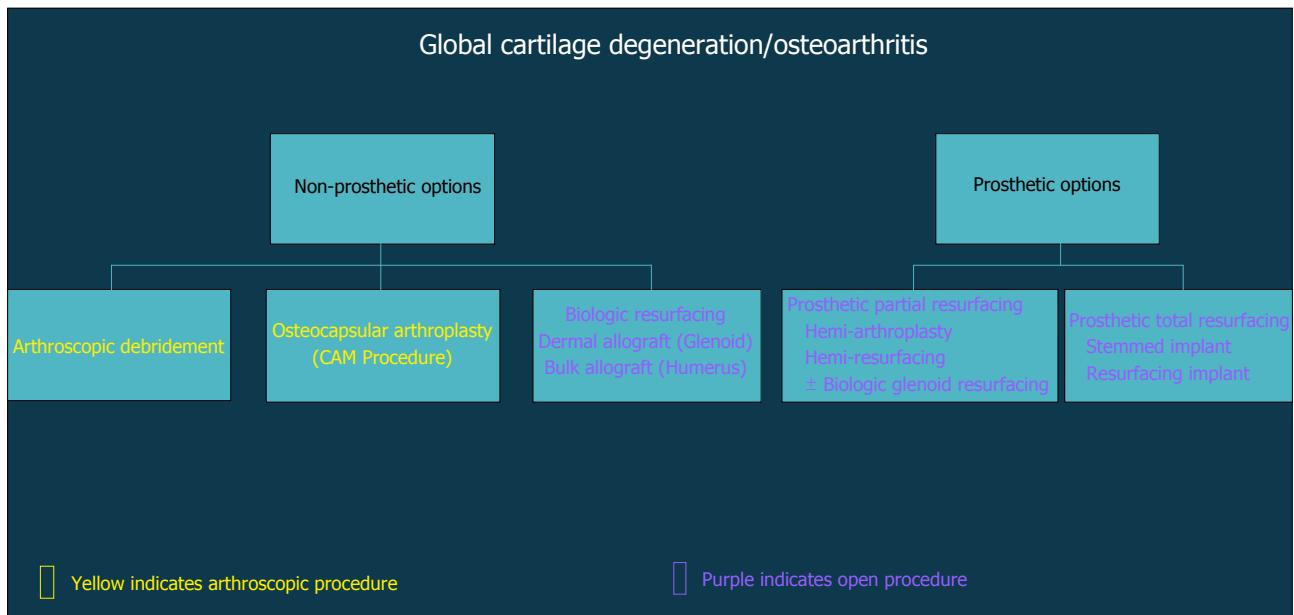


Figure 4 Flow-chart demonstrating decision algorithm for non-prosthetic vs prosthetic treatment options that include arthroscopic and open procedures.

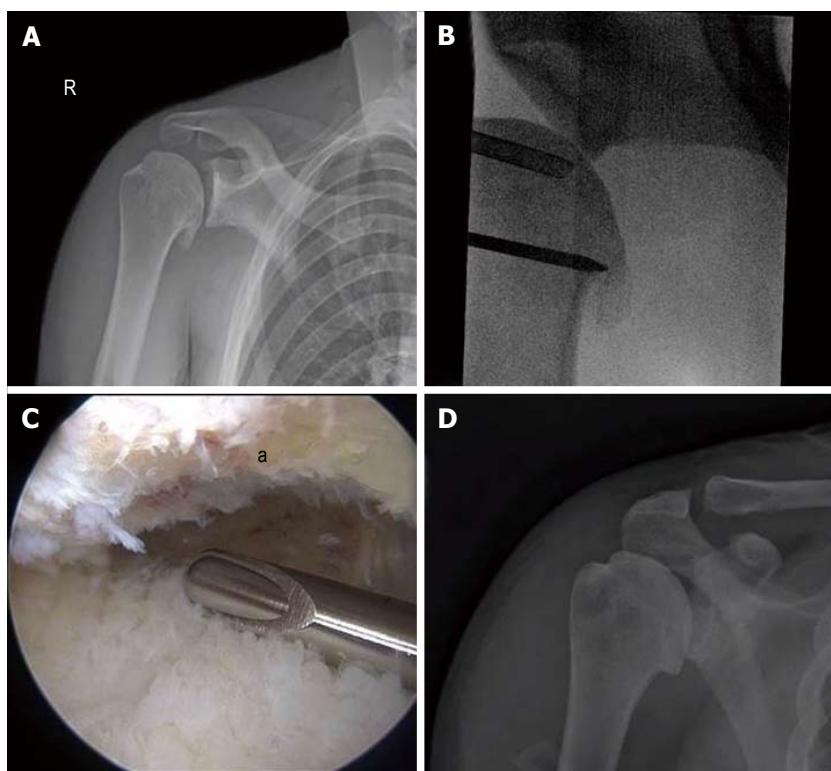


Figure 5 Comprehensive arthroscopy management of glenohumeral arthropathy. A: Images from a 37-year-old male with instability arthropathy demonstrating preoperative anteroposterior radiograph with large inferior humeral head osteophyte and loss of glenohumeral joint space; B: Intra-operative fluoroscopy localization of extent of inferior humeral head osteophyte; C: Intra-operative arthroscopic image viewing from posterior portal, demonstrating inferior humeral neck (a) status post debridement of osteophyte, the arthroscopic shaver is on the inferior capsule; D: Post-operative anteroposterior radiograph demonstrating debridement of osteophyte and biceps tenodesis with a biocomposite screw.

tissue interpositional arthroplasty procedures involve humeral head arthroplasty and then securing soft-tissue to cover the arthritic glenoid in an effort to improve upon the outcomes of humeral hemiarthroplasty (HA) alone. Unfortunately, multiple authors have reported

unacceptably poor outcomes following this procedure^[89-91]. Another option that can be performed with humeral HA is the “ream-and-run” technique popularized by Gilmer *et al*^[92]. This technique provides concentric glenoid reaming with an over-sized reamer with a goal of creating a

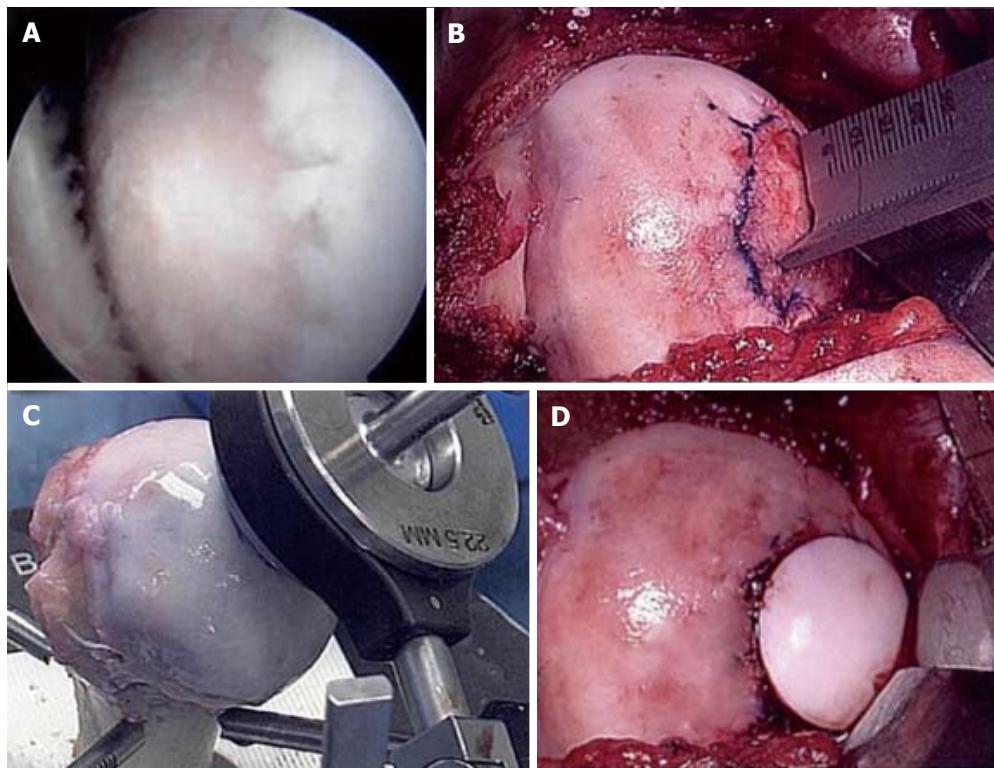


Figure 6 Fresh osteochondral allograft transplantation. A: Intra-operative arthroscopic image of central humeral articular lesion while viewing from a posterior portal in a 39-year-old patient; B: After an open approach, preparation of the central lesion; C: Harvesting a corresponding osteochondral plug from a size-matched, fresh allograft humerus; D: Status post insertion of the osteochondral plug into the defect.

smooth concavity for articulation. This has been shown by the author to be a viable alternative to TSA in the young patient^[93,94], although published series from other institutions are limited^[95]. In the previous studies, the ream-and-run technique utilized in the arthritic shoulder in patients 55 years old or less led to a significant improvement in the Simple Shoulder Test as well as minimal medial glenoid erosion.

HA has been promulgated as an option which theoretically would allow patients to pursue more aggressive/demanding activities and avoid the risk of glenoid component loosening. However, concerns for the durability of pain relief is a concern with glenoid wear over time^[96].

Total shoulder arthroplasty: Total shoulder arthroplasty (TSA) outperforms HA both functionally and in terms of implant survivorship both in the short term and long-term follow-up^[97-100]. Despite initial concerns over the possibility of glenoid loosening, recent studies have shown that patients have a significantly increased return to sports after TSA compared to HA^[101,102]. Large meta-analysis of pooled data has also demonstrated that TSA provides greater pain improvement and increased range of motion compared to HA in young patients with glenohumeral arthritis^[103]. Certainly, the young patient with arthritis is very difficult to treat with any arthroplasty modality, and outcomes in this population are worse than standard arthroplasty patients^[87,104]. Concern over a future

revision procedure can influence the surgeon's choice of the initial arthroplasty procedure, as surgeons worry about medializing glenoid wear with a HA or aseptic glenoid loosening with a TSA. There remains a higher risk of revision surgery in the population of patients under 60 receiving a HA compared to a TSA^[104].

TSA is by no means an operation without complications and adverse effects in this young patient population. In our own experience of treating a young, active military population with instability arthropathy, we have found a high rate of complications to include component failure, neurologic injury, adhesive capsulitis and venous thrombosis. In our series of 26 TSAs in a predominantly male cohort with a mean age of 45.8 years (range, 35-54 years), we experienced 9 patients with 12 complications (46.2%) leading to a 23.1% reoperation rate at an average of 3.5 years follow-up. Nine patients (37.5%) were unable to continue their high-demand activities and underwent a medical discharge for persistent shoulder disability^[105].

CONCLUSION

So-called instability (or dislocation) arthropathy may develop in high-risk patients with a history of recurrent glenohumeral instability, both with and without surgical stabilization. The incidence and rates of arthritic progression may vary widely, with radiographic changes present in up to two out of three patients after primary

Bankart repair. However, the presence of secondary arthrosis does not predict poor patient-reported function. When oral medication, periarticular injections, and physical therapy have failed, surgical options will depend on patient-specific factors, anticipated upper extremity demands, size and extent of articular involvement, and other anatomic factors. A variety of arthroscopic and open non-arthroplasty procedures are available as temporizing measures, and data regarding the efficacy of chondral restoration options are currently limited. Total shoulder arthroplasty remains the most reliable option for the treatment of post-instability arthropathy, although the clinical outcomes, wear characteristics, and implant survivorship remains a concern among active, young patients. Further investigations are warranted to evaluate the comparative efficacy of management options in this challenging, young patient demographic with early arthritis.

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Lower limb stress fractures in sport: Optimising their management and outcome

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common, comprising up to 10% of all of sporting injuries. Around 90% of such injuries are located in the lower limb. This article aims to define the optimal management of lower limb stress fractures in the athlete, with a view to maximise return rates and minimise return times to sport. Treatment planning of this condition is specific to the location of the injury. However, there remains a clear division of stress fractures by "high" and "low" risk. "Low risk" stress fractures are those with a low probability of fracture propagation, delayed union, or non-union, and so can be managed reliably with rest and exercise limitation. These include stress fractures of the Postero-Medial Tibial Diaphysis, Metatarsal Shafts, Distal Fibula, Medial Femoral Neck, Femoral Shaft and Calcaneus. "High risk" stress fractures, in contrast, have increased rates of fracture propagation, displacement, delayed and non-union, and so require immediate cessation of activity, with orthopaedic referral, to assess the need for surgical intervention. These include stress fractures of the Anterior Tibial Diaphysis, Fifth Metatarsal Base, Medial Malleolus, Lateral Femoral Neck, Tarsal Navicular and Great Toe Sesamoids. In order to establish the optimal methods for managing these injuries, we present and review the current evidence which guides the treatment of stress fractures in athletes. From this, we note an increased role for surgical management of certain high risk stress fractures to improve return times and rates to sport. Following this, key recommendations are provided for the management of the common stress fracture types seen in the athlete. Five case reports are also presented to illustrate the application of sport-focussed lower limb stress fracture treatment in the clinical setting.

Key words: Fractures; Lower; Limb; Sport; Management; Stress

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Core tip: This editorial article offers a current perspective on the treatment of lower limb stress fractures in the

Abstract

Stress fractures in sport are becoming increasing more

athlete. The authors focus on the most common "high risk" (Anterior Tibial Diaphysis, Fifth Metatarsal Base, Medial Malleolus, Lateral Femoral Neck, Tarsal Navicular, Great Toe Sesamoid) and "low risk" stress fractures (Postero-Medial Tibial Diaphysis, Metatarsal Shafts, Distal Fibula, Medial Femoral Neck, Femoral Shaft, Calcaneus), highlighting the optimal treatment methods for each, and assessing the most recent evidence which directs this. The value of preventative interventions is also discussed. Finally, five case reports are presented to demonstrate the evidence-based treatment process in clinical practice.

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INTRODUCTION

Stress fractures represent one of the more serious injuries in sport^[1]. Following such injuries, return times to sport are often prolonged, and failure to return to sport, chance of re-injury and persisting morbidity are all distinct possibilities^[2-8]. As a group, stress fractures comprise just over 10% of all sport-related injuries, with this figure as high as 30% within certain sports, such as running^[1,9-12]. The incidence of these injuries is around 1% within recreational athletes, and around 20% within elite level athletes^[1,9-12]. Around 90% of these injuries are located within the lower limb^[12,13]. Given the financial implications of sport within modern society, both with the substantial revenues associated with professional sport, as well as the economic implications associated with injuries to amateur athletes, the effect of such injuries is considerable^[1].

The significance of this injury depends on the location and nature of the fracture^[1]: The tibial diaphysis is the commonest reported location and comprises up to three quarters of all stress fractures^[2]; other common sites include the metatarsals, the femoral neck, the tarsal naviculus, the fibula, the medial malleolus and the calcaneus^[1,14,15]. Until the 1980's, much of the stress fracture research had focussed on military cohorts, overlooking cohorts of sporting individuals^[9,10]. Since then, there has been increasing attention paid to the epidemiology, management and outcome of these injuries in sporting individuals, along with optimisation of rehabilitation techniques and promotion of injury prevention^[1]. However the optimal management plans for many stress fracture locations have still to be determined^[1].

At present, there forms a clear division of stress fractures by those which are deemed "high risk", with a predilection for fracture propagation, delayed union, or non-union^[14]; and those which are deemed "low risk",

with reliable healing patterns and resolution of symptoms when managed accordingly^[15]. Low risk fractures can often be investigated with radiographs alone, and are virtually always managed successfully through conservative management, with rest, activity modification and rehabilitation^[15]. High risk fractures often require specialised imaging to better define and quantify the injury, particularly when first line imaging is equivocal; these injuries also may require surgical management, depending on the location of the injury and the response to initial conservative management^[14]. As a consequence of this, return to sport is often more challenging with high risk injuries, and this proves particularly demanding with the high level professional athlete^[4,7,14]. For individual fracture types, the severity of the injury can be graded from the extent of the radiological changes, using either generic (Fredericson *et al*^[16] or Arendt *et al*^[17]) or site-specific (Saxena *et al*^[18] or Torg *et al*^[19]) classifications^[1,20]; such classifications can further guide management planning as well as provide prognostic information regarding return times to sport^[1,20].

The management strategies of these injuries is constantly developing, and at present, the optimal treatment modality for many stress fracture locations remains unestablished^[1]. Even with similar injuries, management and return to sport times can vary for different sport, with prolonged rehabilitation often required to return to repetitive loading sports such as long distance running and jumping^[1,5]. Regular review of the emerging research in this area, in conjunction with pre-existing treatment protocols, is necessary to determine the best way to manage such athletes, and maximise return to sport^[1]. In addition to this, given the overuse nature of such injuries, often demonstrating prodromal symptoms and resulting from the presence of risk factors, primary prevention programmes provide the best way of managing such injuries^[21,22]. Ongoing research in this field provides continued resources which can benefit both the athlete and the sports medic to fully maximise the potential of such a practice^[21,22].

From the clinical perspective, when defining the optimal method for managing each fracture type, seven major areas require addressing: (1) is the fracture High Risk or Low Risk? (2) what is the optimal imaging modality for the fracture? (3) should this fracture be managed conservatively or surgically? (4) if managed surgically, what is the best technique to employ? (5) if managed conservatively, what is the optimal rehabilitation schedule? (6) how quickly can sporting activities be resumed? and (7) are there any preventative programmes available for this fracture type?

This framework ensures that optimal treatment planning and outcome can be achieved for each individual athlete^[1]. In this editorial, we aim to determine the optimal evidence-based management strategies for the most common "high" and "low" risk sport-related lower limb stress fractures, by reviewing the available literature in this field. With this, we also aim to discuss the areas that require further clarification to provide optimal care for the athlete, as well as to assess the emerging

evidence for preventative strategy programmes that can avert such injuries from developing. To illustrate this treatment process in clinical practice, five case reports assessing the management of sport-related lower limb stress fractures are presented at the end of the article.

HIGH RISK SPORT-RELATED LOWER LIMB STRESS FRACTURES

High risk stress fractures are those which have an increased risk of fracture propagation, delayed union, or non-union^[14]. This is normally because they are located on the tension side of the bone, or because they develop in an area with limited vascularity. The most common high risk stress fractures are those of the Anterior Tibial Diaphysis, the Fifth Metatarsal Base, the Medial Malleolus, the Lateral Femoral Neck, the Tarsal Navicular and the Sesamoids of the Great Toe^[1,14,15,23].

Anterior tibial diaphysis

Common in running athletes, anterior tibial diaphyseal stress fractures (TDSFs) are visualised on radiographs as the "dreaded black line" on the anterior mid tibial cortex^[1,2,14,24]. However, radiographic changes can be absent in up to 85% of cases^[25]; with persisting symptoms and negative radiographs, the recommended second line imaging investigation is now magnetic resonance imaging (MRI) scan^[24].

The severity of the fracture can be graded by presence of changes on each of the MRI sequences, using either the Fredericson^[16] or the Arendt^[17] Scale (Table 1). A higher grade of Fredericson Scale has been shown to be associated with an increased return to running time for TDSFs^[16]. When both cortices of the tibia are involved, with completed fracture lines, this injury needs to be managed as an acute fracture^[1,2,14].

Current treatment protocols advocate a trial of 3 to 6 mo of conservative management, as initial treatment of these injuries^[1,2,14]. Fredericson Grade 1 to 3 injuries are managed with crutch-assisted weightbearing until resolution of pain; bracing serves as a potential adjunct to reduce symptoms^[16]. For Grade 4 injuries, initially casting is recommended for a period of 6 wk^[16].

If symptoms persist following attempted conservative management, surgical intervention should be advised^[1,2,14]. The available surgical techniques include tibial intra-medullary (IM) Nailing, compression plating, or drilling of the stress fracture with bone grafting^[2]. A recent systematic review by Robertson *et al*^[2] found that intra-medullary nailing and compression plating provided the highest return rates and lowest return times of all the surgical treatments available; as such these are the preferred surgical techniques for this injury.

This review also found that conservative management of these injuries resulted in decreased return rates to sport compared to surgical management; return to sports rates were 71% for conservative management and 96% for surgical management^[2]. Thus, clinicians must remain

aware of the benefit of early surgical management in the high level athlete who fails to respond to conservative management^[2]. Reported return times to sports for this injury included 7 mo for conservative management and 7 mo for surgical management^[2].

For completed fractures, current protocols advocate conservative management (casting) for those which are undisplaced, and surgical management for those which are displaced, normally with an IM Nail^[1,2,14]. Reported return times for these injuries included 11.5 mo for conservative management and 7 mo for surgical management, with return rates of 67% for conservative management and 100% for surgical management^[2].

For conservative management, recommended rehabilitation techniques advise activity cessation, with avoidance of heavy loading of the tibia, limited weight-bearing with crutches for between 3 to 6 mo^[1,2,14]. During this time, bracing of the lower limb can be helpful to reduce symptoms^[1,2,14]. Following this, progression of weightbearing and return to loading activities can be allowed as pain permits^[1,2,14]. For surgical management, recommended rehabilitation techniques comprise commencement of a progressive weight-bearing programme, within the first week post-operatively, under the care of physiotherapy, with return to full loading activities between 6 and 8 wk post-operatively^[1,2,14]. With both conservative and surgical management, full level sport should not be commenced until there is clear evidence of clinical and radiological union^[1,2,14].

Validated prevention interventions for this injury type include the use of shock absorbing insoles as well as the optimisation of athlete fitness prior to the commencement of vigorous exercise^[21,22,26].

Fifth metatarsal base

Common in soccer, american football and basketball players, these injuries appear on plain radiographs as a sclerotic or radiolucent line at the proximal aspect of the fifth metatarsal^[1,14,23,24]. However, radiographic changes can be absent in up to 69% of patients^[25]. In such cases, the second line imaging investigation is now MRI scan^[24]. Computed tomography (CT) scan can be of value in assessing fracture union if conservative management is attempted^[24]. These injuries are graded using the Torg Classification^[19] (Table 1), which provides a helpful guide to direct treatment^[13,27].

Torg 1 injuries can be managed either surgically or conservatively^[13,27]. Surgical techniques comprise either percutaneous intramedullary cannulated screw fixation or modified tension band wire; screw fixation is the recommended modality as this has the higher volume of evidence at present^[4,23]. Conservative management comprises non-weightbearing in a below knee cast or moon boot for 6 wk followed by partial weightbearing for a further 6 wk^[27].

There is a growing trend for surgical management of such injuries in high level athletes and athletes in high intensity repetitive loading sports (running, jumping),

Table 1 Classification systems for lower limb stress fractures

	Arendt scale ^[17] (MRI based)	Federicon scale ^[16] (MRI based)	Saxena classification ^[18] (CT based)	Torg classification ^[19] (radiograph based)
Location of use	Generic	Generic	Navicular	5 th Metatarsal Base
Grade 1	STIR signal change	periosteal edema - bone marrow normal	Dorsal cortex involved	Acute fracture line, no intramedullary sclerosis or periosteal reaction
Grade 2	STIR and T2 change	periosteal and bone marrow edema - T2 change only	Dorsal cortex and body involved	Widened fracture line with intramedullary sclerosis and periosteal reaction
Grade 3	STIR, T1 and T2 change - no fracture line present	periosteal and bone marrow edema - T1 and T2 change - no fracture line	Dorsal and Volar cortices involved	Widened fracture line with complete intramedullary sclerosis and periosteal reaction
Grade 4	STIR, T1 and T2 change - fracture line present	periosteal and bone marrow edema - STIR, T1 and T2 change - fracture line	-	-

MRI: Magnetic resonance imaging; CT: Computed tomography; STIR: Short tau inversion recovery.

with a recent systematic review from Mallee *et al*^[4] showing proven benefit of surgical management, in terms of return times and rates to sport. Reported return rates following surgical management ranged from 75% to 100%^[27-31], with return times of 13.8 wk^[28]. Return rates for conservative management ranged from 33% to 100%^[27,28], with return times 19.2 wk^[28]. Conservative management however remains a realistic option for the low level athlete.

As conservative management remains a recognised acceptable alternative to surgery, all athletes being advised to undertake surgical treatment should be fully informed of the available treatment options^[5,14,23]. The risks and benefits for both surgical and conservative should be fully explained: For conservative management the main benefit being the avoidance of surgery, while the main risk being the development of non-union; for surgical management, the main benefit being an improved return rate and time to sport, while the main risk being that of infection and structural damage^[5,14,23].

Torg 2 (delayed union) and Torg 3 (non-union) injuries are advised to be managed with surgical intervention, in the form of internal fixation and bone grafting, to facilitate union^[5,14,23]. A higher Torg grading and a plantar gap greater than 1 mm are predictive of a prolonged return times to sport^[4,29].

For surgical management, current rehabilitation recommendations advise 3 wk non-weightbearing in a short leg cast, followed by progressive weightbearing over the following 3 to 6 wk in protective footwear^[5,14,23]. An over accelerated rehabilitation must be avoided as this significantly increases the chances of treatment failure^[5,14,23]. For conservative management, current rehabilitation recommendations advise 6 wk non weight-bearing in a cast or boot, followed by 6 wk partial weightbearing in a functional splint, and then by a graduated return to sport under the guidance of the physiotherapists^[5,14,23]. With both forms of treatment, full level sport should only be commenced once there is clear evidence of clinical and radiological union^[5,14,23]. There are no validated prevention interventions for this fracture

type at present^[21,22].

Medial malleolus

Common in athletes involved in running and jumping sports, radiographs form the first line imaging of this condition, but can be negative in up to 55% of cases^[25]. With persisting symptoms and no clear radiographic changes, the second line imaging investigation is now MRI scan^[24].

Current management protocols direct treatment based on fracture displacement and the level of the athlete^[1,5,6,14,23]. All displaced fractures should be treated with surgical reduction and fixation to aid fracture union, reduce post-injury symptoms and facilitate return to sport^[1,5,6,14,23]. Undisplaced fractures in the low level athlete are recommended for conservative management, minimal weightbearing with crutches in a short leg cast or moon-boot for 6 to 8 wk^[1,5,6,14,23]. Undisplaced fractures in the high level athlete and in athletes who participate in high intensity repetitive loading sports (such as running and jumping) are, however, now recommended for the surgical fixation, as this has been shown to reduce return to sport times, compared to conservative management^[1,5,6,14,23]. A recent systematic review by Irion *et al*^[6] found similar return to sport rates for surgical vs conservative management of these injuries (both 100%), but the mean return to sport time was three times higher with conservative management (2.4 wk for surgical management vs 7.6 wk for conservative management).

Surgical techniques include cannulated cancellous screw fixation or modified tension band wire technique^[1,5,6,14,23]. The preferred surgical technique is screw fixation, as this has the stronger evidence-base^[1,5,6,14,23]. Any athlete undergoing surgical management, when conservative management form a reasonable alternative, should be fully informed of the benefits and risks of both treatments, particularly outlining the surgical risks involved, which include infection, bleeding, structural damage and requirement for revisional surgery^[1,5,6,14,23].

Recommended rehabilitation for surgical management

comprises 1 to 3 wk limited weightbearing in a cast or moonboot, while that for conservative comprises 6 to 8 wk limited weightbearing in a cast or moonboot^[1,5,6,14,23]. This is then followed by a progressive strengthening, range of motion and proprioception programme under the care of the physiotherapist, with a graduated return to sport^[1,5,6,14,23]. For both forms of management, return to full level sport should only be performed when there is clear evidence of clinical and radiological union^[1,5,6,14,23]. There are no validated prevention interventions for this fracture type at present^[21,22].

Lateral (tension side) femoral neck

Most commonly seen in marathon and long distance runners, plain radiographs form the initial imaging investigation for lateral-sided (tension) femoral neck stress fracture (FNSFs)^[1,5,8,14,24]; however radiographic changes can be absent in up to 80% of cases^[25]. When radiographs are negative, and the history and exam findings are suggestive of the diagnosis, the second line imaging investigation is MRI Scan^[24]. The severity of these fractures can be graded using the Arendt^[17] or Fredericson^[16] Classification; however this type of FNSF is managed universally with surgical fixation, so such gradings have no significant influence on treatment planning^[1,5,8,14,24].

Current management protocols advocate urgent surgical fixation of this fracture type, to prevent fracture displacement and its associated risks of avascular necrosis (AVN) of the femoral head^[1,5,8,14,24]. Surgical fixation is ideally performed with a Dynamic Hip Screw (DHS) (with or without a de-rotation screw) as compared to multiple cannulated screws (MCS), as the DHS confers more stability of fixation for the unstable shear-pattern of these fractures^[1,5,8,14,32-34]. There is limited data for return to sport rates and times for lateral femoral neck fractures, as the majority of studies reported are case reports or series^[1,5,8,14]. In a recent systematic review by Neubauer *et al*^[8], which recorded all published FNSFs in runners, 28 out of 48 patients were noted to return running. Displaced fractures had significantly lower return rates (6/18), than non-displaced fractures (22/30)^[8]; this has been noted by previous authors^[35]. Reported return to sport times varied from 3 to 12 mo^[8].

Recommended rehabilitation techniques advise toe-touch weight-bearing with crutches for 6 wk, followed by partial weight-bearing with crutches for a further 6 wk^[1,5,8,14,36]. Hydrotherapy and upper limb exercises can be commenced 2 wk post-surgery^[36]. Following this, weight-bearing is permitted as tolerated, with commencement of physiotherapy to focus on hip and lower limb muscle strengthening and range of motion exercises, facilitating a graduated return to sport^[1,5,8,14,36]. Full level sport should only be commenced once there is clear evidence of clinical and radiological union^[1,5,8,14,36]. Clinical and radiographic follow-up should be maintained for a minimum of 2 years to ensure delayed post-treatment AVN does not ensue^[1,5,8,14,36].

Validated prevention interventions include education programmes to promote physiological optimisation prior to engaging in rigorous activity, as well performing progressive training regimes (limit training volume increases to 10%,) and limiting training volumes within recommended targets (around 160 km over a 12 wk when starting)^[8,37-39].

Navicular

Common in sprinting athletes, these are visualised on plain radiographs as a sclerotic or radiolucent line extending from the superior tension side of the navicular^[1,3,5,14,23]. However, radiographic changes can be absent in up to 40% of cases^[25]. Thus, with persisting symptoms and negative radiographs, the second line imaging investigation is either CT or MRI Scan^[24]. CT Scanning allows visualisation and quantification of the fracture line, which is useful for management planning^[24]. This enables these injuries to be classified by the Saxena Classification^[18] (Table 1). This can guide management planning, as well as well provide prognostic information regarding return to sport, with a higher Saxena Grade correlating with a prolonged return to sport^[4]. MRI scanning provides a comprehensive picture of the stress injury as well as visualising the surrounding soft tissue structures^[24].

Current management protocols are guided by the extent of the fracture line (Saxena Classification) and displacement of the fracture^[1,3,5,14,18,23]. At present, for partial undisplaced fractures (Saxena Grade 1 and 2), conservative management with short leg cast and non-weight-bearing for 6 wk is recommended^[1,3,5,14,18,23]. In a systematic review by Torg *et al*^[3], such treatment was found to offer superior results over other treatment modalities, with return to sports rates of 96% and return times on mean of 4.9 mo. For displaced or completed fractures (Saxena Grade 3), surgical management, with reduction with internal fixation, is recommended^[1,3,5,14,18,23]. Reported return times following surgical management range from 16.4 wk to 5.2 mo, with return to sport rates of 82%^[3,4]. The available surgical techniques include screw fixation or fracture site drilling, both with or without bone graft^[3,4,18,40]. The preferred technique at present is screw fixation, as this offer improved return times and rates to sport^[3,4,40].

To note, developing evidence suggests that surgical management of all navicular stress fractures may offer improved return to sport times for high level athletes^[4]; however, such evidence fails to stratify outcome by severity of fracture or Saxena Classification, and, as such, further well designed randomised controls are necessary to confirm this^[1,3,5,14,18,23].

Recommended rehabilitation techniques both for conservative and surgical management consist of non-weightbearing in a below knee cast or moon boot for 4 to 6 wk, followed by progressive partial weight bearing for a further 6 wk until painfree^[1,3,5,14,18,23]. This is then followed by a graduated return to sporting activities

under the supervision of the physiotherapists. For both forms of management, return to full level sport should only be performed when there is clear evidence of clinical and radiological union.

Validated prevention interventions include physiological optimisation programmes for the athlete before embarking upon rigorous physical activity as well as performing progressive training regimes and limiting training volumes within recommended targets^[37].

Sesamoids (great toe)

Commonly seen in sports which involve repeated, forced dorsiflexion of the great toe (dancing, gymnastics and sprinting), the medial (tibial) sesamoid is most frequently injured due to its positioning directly beneath the head of the first metatarsal^[1,14,23,41,42]. Radiographs are the first line imaging, though changes can be absent in up to 95% of cases^[25]. In such cases, with persisting symptoms, MRI is the second line imaging investigation^[24]. CT scan can be useful in assessing the progression of union of these fractures^[24].

Current management protocols advocate conservative management as the first line treatment for all such injuries. This comprises activity cessation, with a period of 4 to 8 wk limited-weightbearing in below knee cast, or moonboot^[1,14,23,41,42]. Following this, weightbearing should be progressed, using a forefoot offloading shoe or modified orthotic, as required for comfort^[1,14,23,41,42]. Return rates to sport following successful conservative management include 100%, with return times ranging 3 wk to 1 year^[43,44]. There is however a high rate of delayed union, nonunion, and recurrence with this treatment, so if the patient remains symptomatic after 3 to 6 mo of conservative treatment, surgical intervention should be considered^[1,14,23,41,42]. Conversion from conservative management to surgical management ranges from 33% to 100% in the published studies^[43-45]. There is a variety of surgical techniques available, which include closed reduction and percutaneous fixation, drilling with bone grafting, partial-sesamoideectomy and sesamoideectomy with soft tissue reconstruction^[1,14,23,41,42]. Where possible retention of sesamoids should be performed to preserve joint biomechanics and avoid the development of hallux deformities^[1,14,23,41,42]. If sesamoideectomy is required, soft tissue reconstruction should be performed in conjunction to try restore such biomechanics^[1,14,23,41,42]. The preferred choice of surgical management is guided by the fracture plane (tranverse or longitudinal) and fracture displacement^[44]. Transverse undisplaced fractures should be managed by either by screw fixation or drilling and grafting^[44]. Transverse displaced fractures should be managed by screw fixation when possible, however partial or complete sesamoideectomy can often be required^[44]. Longitudinal fractures are best managed by either drilling and grafting or sesamoideectomy^[44]. Reported return rates following surgery range from 90% to 100% with return times ranging 2.5 to 6 mo^[43-51].

For conservative management, recommended re-

habilitation techniques advise activity cessation and limited weightbearing in a below knee cast or moonboot for 6 wk followed by progressive weightbearing in modified footwear as pain allows^[1,14,23,41,46,51]. For operative management, recommended rehabilitation techniques now advocate a more accelerated recovery with crutch-assisted weight-bearing for 1 wk post-operatively, followed by full unassisted weightbearing as pain allows^[1,14,23,41,46,49-51]. Under guidance of the physiotherapists, running activities can normally be commenced around 6 wk post-operatively, followed by a return to full level sport as symptoms and physical fitness allow^[1,14,23,41,46,49-51]. There are no validated prevention interventions for this fracture type at present^[21,22].

LOW RISK SPORT-RELATED LOWER LIMB STRESS FRACTURES

Low risk stress fractures are those with a low risk of fracture propagation, delayed union, or non-union, with reliable healing patterns and resolution of symptoms when managed accordingly^[15]. This is because they are often located on the compression side of the involved bone, and they develop in an area with robust vascularity. The most common low risk stress fractures are those of the Postero-Medial Tibial Diaphysis, the Metatarsal Shafts, the Distal Fibula, the Medial Femoral Neck, the Femoral Shaft and the Calcaneus^[1,9-12,15].

Postero-medial tibial diaphysis

Common in running athletes, these injuries appear as a sclerotic line on the postero-medial border of the proximal to mid tibial diaphysis^[1,2,15]. However, radiographic changes can be absent in up to 85% of cases^[25]; with persisting symptoms and negative radiographs, the second line imaging of choice is now MRI Scan^[24]. If however, the history and examination findings are high suggestive of the diagnosis, the injury can be managed expectantly, with repeated radiographs alone, due to the benign nature of the condition^[15].

The severity of the fracture can be graded by presence of changes on each of the MRI sequences, using either the Fredericson^[16] or the Arendt^[17] Scale (Table 1). The Fredericson Scale was developed from a cohort of postero-medial stress fractures, within which the severity of grading was shown to be associated with return to running times: Grade 1 injuries took 2 to 3 wk to return to running; Grade 2 injuries 4 to 6 wk; Grade 3 injuries 6 to 9 wk; and Grade 4 injuries 12 wk, with initial cast treatment for 6 wk^[16]. To note, there is growing evidence that "shin splints" or "tibial periostitis" form a continuum with tibial stress fractures injuries, with MR Studies demonstrating periosteal and bone oedema in cohorts of athletes with "shin splints"^[20]. When present, it is advised to treat "tibial periostitis" as Grade 1 injuries, in order to prevent progression and prolongation of the injury^[1,5,15].

Current management protocols advocate conservative management for these stress fractures^[1,2,15].

The standard treatment is cessation of activities, with restricted weightbearing, until symptoms resolve^[1,2,15]. Adjuncts such as ultrasound and pneumatic bracing can improve return to sport times^[1,2,15]. A recent systematic review by Robertson *et al*^[2] found that return rates following posterior TDSFs are universally good with all studies reporting return rates of 100%. Return to sport times averaged around 2 mo: Use of pneumatic bracing reduced return times to 1 mo post-injury; use of pulsed ultrasound enabled return to sport immediately post-treatment. Surgical management is reserved for non-unions, with delayed unions treated expectantly; these however are extremely rare due to the well vascularised nature of the postero-medial tibial diaphysis^[1,2,15].

Recommended rehabilitation techniques advise cessation of activities which provoke symptoms, with weightbearing as per pain allows^[1,2,15]. Some studies advocate immediate return to full weightbearing and sporting activities using an aircast brace, if the patient is completely painfree with the orthotic^[2,52]. This is followed by a graduated return to exercise programmes under the care of the physiotherapists^[1,2,15]. Return to full level sport should only be performed with clear evidence of clinical and radiological union^[1,2,15].

Validated prevention interventions include the use of shock absorbing insoles, as well as physiological optimisation of the athlete prior to the commencement of vigorous exercise, performing progressive training regimes and limiting training volumes within recommended targets^[21,22,26].

Metatarsal shaft

Commonly seen in distance runners and ballet dancers, these most often develop in the second metatarsal, followed by the third and fourth metatarsals^[1,15,23,53]. The first line imaging of these injuries is plain radiographs; however radiographic changes can be absent in up to 69% of cases^[25]. With persisting symptoms, the second line imaging investigation is MRI Scan^[24]; however this injury can initially be imaged with serial radiographs, if the history and clinical exam are conclusive with the diagnosis^[15]. Current management protocols advocate conservative management for these injuries^[5,15,23,53].

This is in the form of activity restriction for 6 to 8 wk, either in a moonboot, short leg cast or fore-foot offloading shoe, with a progressive return to exercise as pain allows^[5,15,23,53]. Further adjuncts, such as a firm-based insoles or midfoot taping, can progress mobility and relieve symptoms during the rehabilitation period^[5,15,23,53]. Occasionally, with delayed union or in the presence of severe pain, protracted application of cast may be necessary, for around 12 wk post injury^[5,15,23,53]. However, most of these stress fractures heal after 4 wk of compliant conservative management^[5,15,23,53]. While, delayed unions can be treated expectantly with prolonged casting, non-unions require surgical intervention in the form of plating and bone graft; this however happens very rarely with compliant treatment^[5,15,23,53]. Reported return to sport

times range from 4 to 12 wk, with second (10 wk) and third (12 wk) metatarsal fractures taking longer to return than 4th metatarsal fractures (4 wk)^[53].

Recommended rehabilitation techniques advise 6 to 8 wk limited weightbearing in a short leg cast, moonboot or forefoot offloading shoe followed by commencement of a graduated activity program once the symptoms have resolved^[5,15,23,53]. Following this, a graduated return to sport programme should be undertaken under the care of the physiotherapist^[5,15,23,53]. Full level sport should only be commenced once there is clear evidence of clinical and radiological union^[5,15,23,53]. Validated prevention interventions include use of viscoelastic insoles, as well as appropriate limitation of training volumes, as athletes who run over 20 m/wk are at increased risk of developing these injuries^[14,21-23].

Distal fibula

These injuries are most commonly seen in running and jumping athletes; the distal third region is the most common site for stress fracture in the fibula^[1,15,23,53]. Standard radiographic changes consist of a sclerotic or radiolucent line at the level of lateral malleolus^[15,23]; however radiographs can be negative in up to 40% of cases^[25]. In such situations, the second line imaging investigation is currently MRI Scan^[24]; however, if the history and clinical exam are conclusive with the diagnosis, the injury can be managed with serial radiographs initially^[15].

Current management protocols advocate conservative management for this injury, with cessation of sports, activity modification and immobilisation in a moonboot, air cast or below knee cast for 6 wk, followed by a graduated return to activities as symptoms allow^[1,15,23,53]. Immobilisation is preferable with a moonboot or air cast, as this allows ongoing physiotherapy exercises to be performed during treatment^[1,15,23,53]. Reported return times to sport are around 13 wk^[53]. Some studies advocate immediate return to sporting activities using an aircast brace, if the patient is completely painfree with the orthotic^[52]. However, the authors advise caution with this as an over-accelerated return to full level sport, particularly in the high level athlete, can prevent adequate healing and provoke development of a delayed or non-union^[1,15,23,53]. Any athlete treated as such should be followed up closely to avoid this occurring^[1,15,23,53]. While delayed unions can normally treated with prolonged casting, non-unions will most often require surgical intervention, in the form of plating and bone graft^[1,15,23,53].

Recommended rehabilitation techniques advise limited weightbearing with crutches for 6 to 8 wk, in a moonboot, air cast or below knee cast, followed by a graduated return to activities, as symptoms allow, under the care of the physiotherapists. If an accelerated return to sport is attempted using an aircast, clinicians must remain vigilant for development of a delayed or non-union^[1,15,23,53]. In order to avoid this, return to full level sport should only be performed when there is clear evidence of clinical and radiological union^[1,15,23,53]. There

are no validated prevention interventions for this injury type at present^[21,22].

Medial (compression side) femoral neck

Most often recorded in marathon and long distance runners, these injuries are visualised on plain radiographs as an area of sclerosis or radiolucency at the medial aspect (compression side) of the femoral neck, perpendicular to the osseous trabeculae^[1,5,8,15,54,55]. However, radiographic changes can be absent in up to 80% of cases^[25]; when radiographs are negative, and the history and examination findings are suggestive of this condition, the second line imaging investigation is now MRI Scan^[24]. This can allow grading of severity of the stress fracture using the Arendt Scale, which has been found to predict return times to sport post-treatment (Table 1)^[17,24,56].

Current management protocols guide management based on the extent and displacement of the fracture, as per the Naval Medical Centre San Diego Classification^[1,5,8,15,54,55]. Compression FNSFs which span less than 50% of the femoral neck width can be treated conservatively, with limited weightbearing followed by a graduated return to exercise programme^[1,5,8,15,54,55]. However, if the fracture line spans more than 50% of the femoral neck width, or if there is displacement, surgery is indicated to stabilise the fracture^[1,5,8,15,54,55]. The compression fracture is oblique in nature, and biomechanically more stable than the tension fracture; so MCS can be used as the preferred fixation method^[32-34]. Other surgical techniques include DHS plus or minus de-rotation screw. With the largest series of sport-related compression FNSFs to date ($n = 27$), Ramey *et al*^[56] reported a return to sport rate of 100% for conservative management, with a mean return to sport time of 14.1 wk. Return times were noted to increase with worsening severity of fracture on the Arendt Scale (Grade 1: 7.4 wk, Grade 2: 13.8 wk, Grade 3: 14.7 wk, Grade 4: 17.5 wk)^[56]. Reports of surgically managed compression FNSFs in the athlete are limited, and none provide formative sporting outcome data^[57].

For both conservative and surgical management, recommended rehabilitation techniques advise 6 wk toe-touch weightbearing with crutches, followed by 6 wk partial to full weightbearing with crutches^[1,5,8,15,54-56]. Hydrotherapy and upper limb exercises can be commenced 2 wk post-immobilisation^[36]. After this, weight-bearing is permitted as tolerated, and return to sport is performed in a graduated manner under the care of the physiotherapy team^[1,5,8,15,54-56]. Full level sport should only be commenced once there is clear evidence of clinical and radiological union. Clinical and radiographic follow-up should be maintained for a minimum of 2 years to ensure delayed post-treatment AVN does not ensue^[1,5,8,15,54-56].

Validated prevention interventions include education programmes to promote physiological optimisation prior to engaging in rigorous activity, as well performing progressive training regimes (limit training volume

increases to 10%) and limiting training volumes within recommended targets (around 160 km over a 12 wk when starting)^[8,37-39].

Femoral shaft

Most commonly seen in running athletes and lacrosse players, these fractures mainly develop on the medial compression side of the femoral shaft, within the proximal and middle thirds of the bone^[1,5,15,24]. Plain radiographs form the first line of imaging; however, radiographic changes can be absent in up to 80% of cases^[25]. With persisting symptoms and negative radiographs, the second line imaging of choice is now MRI Scan^[24].

Current management protocols direct management based on the extent, nature and location of the fracture^[1,5,15,24]. The majority of femoral shaft stress fractures are incomplete, non-displaced and compression-sided, and these can be successfully treated by a period of activity cessation, restricted weightbearing with crutches, for 4 wk, followed by a graduated return to activity^[1,5,15,24]. Return times to sport following such regimes are normally around 12 wk^[1,5,15,24,58]. Surgical intervention should be considered for displaced fractures, tension-sided (lateral cortex) fractures, delayed union, and non-unions^[1,5,15,24]. Surgical techniques available include femoral IM Nailing and lateral sided compression plating. The preferred surgical technique is currently the femoral IM Nail as this provides the strongest biomechanical construct to stabilise the fracture site and allow healing^[1,5,15,24].

For conservative management, recommended rehabilitation programmes advise 4 wk toe-touch weightbearing, with progression to full weightbearing as pain permits^[1,5,15,24,58]. With this injury, it is normally possible to return to light athletic training within 6 wk and to commence full level sport-within 3 mo^[1,5,15,24,58]. Regular follow-up, with interval radiographs, is required to ensure the fracture progresses to union; return to full level sport should only be performed with clear evidence of clinical and radiological union^[1,5,15,24,58]. For surgical management, recommended rehabilitation programmes advise commencement of a progressive weight-bearing programme within 1 wk post-operatively, with return to full-impact loading activities between 6 to 8 wk post-operatively^[1,5,15,24]. This is then followed by a progressive return to activity programme, under the guidance of the physiotherapists, with return to sport often achieved between 12 to 16 wk post-operatively^[1,5,15,24]. Full level sport should only be commenced once there is clear evidence of clinical and radiological union^[1,5,15,24].

Validated prevention interventions include education programmes to promote physiological optimisation prior to engaging in rigorous activity, as well as performing progressive training regimes and appropriate limitation of training volumes^[8,37-39].

Calcaneus

Reported in long distance runners and basketball

players, these fractures most commonly develop on the posterosuperior aspect of the calcaneus, but can also develop on the anterior process or the medial tuberosity of the calcaneus^[15,23,41]. Plain radiographs form the initial imaging investigation, and are often positive when the condition is present, with as many as 87% of cases showing positive X-ray findings^[25]. This is most often seen as an area of sclerosis, which traverses perpendicular to the trabeculae of the postero-superior calcaneus^[15,23,41]. When radiographs are negative, and symptoms persist, MRI scan is the preferred second line imaging investigation, allowing exclusion of associated differential diagnoses such as plantar fasciitis, Achilles tendinosis and retrocalcaneal bursitis^[24].

Current management protocols advocate conservative management for these injuries, in the form of cessation of activity and immobilisation in a moon boot or below knee cast, non-weightbearing for 4 wk, then partial weight-bearing for a further 4 wk^[15,23,41,59]. For conservative management, return rates post injury is 100%, with return times ranging between 11 to 12 wk^[23,59]. Surgical management is reserved for fracture which fail to unite despite prolonged compliant conservative management; the current recommended treatment is drilling of the fracture site, with or without bone graft^[60]. Occasionally the fracture is associated with a Calcaneo-Navicular Coalition; in such cases, if the fracture fails to heal with conservative management, excision of the coalition with fixation of the fracture should be considered^[61,62].

Recommended rehabilitation techniques following conservative management advise 4 wk of non-weightbearing with crutches in a moonboot, followed by 4 wk partial weightbearing, and then a progressive return to exercise programme under the care of the physiotherapy team^[15,23,41,59].

There are no validated primary prevention interventions for the fracture type at present^[21,22]. However, padded heel orthotics and stretching exercises of the calf muscles and plantar fascia have been shown to be valuable secondary prevention measures^[15,23,41].

Case 1: An anterior tibial diaphyseal stress fracture

A 25-year-old professional ballet dancer presented to the Sports Medicine Clinic with a 6 mo history of atraumatic left anterior shin pain. She was otherwise in good health. Radiographs revealed an anterior stress fracture of the tibial diaphysis (Figure 1A). The limb was distally neurovascularly intact and the overlying skin was healthy. Her blood tests (bone profile and biochemistry) were normal and her body mass index (BMI) was 20 kg/m². With the distinct radiographic changes, demonstrating a clear fracture line, MRI scan was not felt to be necessary.

Following an informed discussion in clinic, she was advised that the first line treatment for this injury was conservative management, with activity cessation, cast immobilisation for 6 wk and limited weightbearing for at least 3 mo, followed by progression of weightbearing,

as pain allowed. She was in agreement with this.

After 3 mo of conservative treatment, she was still very painful at the fracture site, with limited evidence of healing on radiographs. She was advised that, given the limited clinical and radiological progress, surgical intervention was now recommended to aid fracture union. Following an informed discussion regarding the risks and benefits of surgery, she decided to proceed with surgical management, and, later that week, underwent a tibial intra-medullary nail uneventfully (Figure 1B).

Post-operatively, she engaged upon a progressive weight-bearing programme over the following 3 mo, under the care of physiotherapy. She returned to light dancing activities 4 mo post-surgery, and returned to full-level dancing 6 mo post-surgery.

At 2 years follow-up, she reports occasional anterior knee pain, but has no pain at the fracture site and radiographs show complete healing of the stress fracture.

Key message: Primary management of anterior tibial diaphyseal stress fractures comprise conservative management with rest, limited weight-bearing and activity modification, with a graduated return to activities as able. However, if, the patient remains symptomatic after 4 to 6 mo of conservative management, with limited evidence of healing on radiographs, surgical management should be considered, with either an intra-medullary nail or a compression plate.

Case 2: A postero-medial tibial diaphyseal stress fracture

A 24-year-old middle distance runner presented to the Sports Medicine Clinic with a 4 mo history of atraumatic posterior right lower limb pain. He was otherwise in good health. Radiographs revealed a posterior stress fracture of the tibial diaphysis (Figure 2). The limb was distally neuro-vascularly intact and the overlying skin was healthy. His blood tests (bone profile and biochemistry) were normal and his BMI was 23 kg/m². An MRI scan showed a Fredericson Grade 3 Postero-Medial Tibial Diaphyseal Stress Fracture.

Following an informed discussion in clinic, he was advised the recommended treatment for this injury was conservative management, with activity restriction and limited weightbearing in a well-padded moonboot, with progression of weightbearing as pain permits. He was in agreement with this.

Following 3 mo of conservative treatment, he was painfree over the fracture site, with clear evidence of healing on radiographs. He had returned to running training at 4 mo post-treatment, and competed successfully in a running race 6 mo post-treatment.

At 2 years follow-up, he reports no symptoms and continues to participate at high level middle distance running.

Key message: Primary management of posterior tibial diaphyseal stress fractures is conservative management with activity modification and limited weightbearing

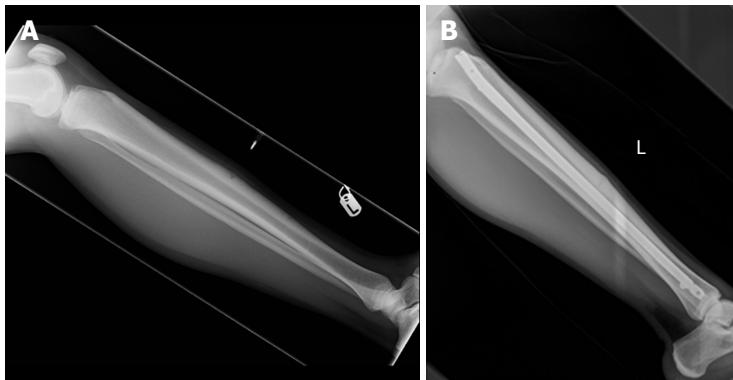


Figure 1 The management of an anterior tibial diaphyseal stress fracture. A: Pre-operative lateral radiograph; B: Post-operative lateral radiograph.



Figure 2 The management of a postero-medial tibial diaphyseal stress fracture. Diagnostic lateral radiograph.

with a graduated return to activities as able. This can be supplemented by pneumatic bracing and ultrasound therapy, both of which has been shown to improve return to sport times.

Case 3: A tension-sided femoral neck stress fracture

A 24-year-old marathon runner presented to the Emergency Department with severe right groin pain after completing a marathon the previous day. She had been training incrementally for this over the last 3 mo and has noted worsening right groin pain for the last month. This was only present during exercise and her coach diagnosed it as ilio-psoas tendinitis. There was no preceding trauma. She was otherwise in good health. Radiographs revealed a minimally displaced tension-sided fracture of the lateral femoral neck (Figure 3A). The limb was distally neuro-vascularly intact and the overlying skin was healthy. She reported pain with full flexion of the hip and with axial compression of the hip. Otherwise her pain was minimal at rest. Her blood tests (bone profile and biochemistry) were normal and her BMI was 19 kg/m². With the distinct radiographic changes, demonstrating a clear fracture line, MRI Scan was not felt to be necessary.

She was admitted as an in-patient and kept on strict bed rest. Following discussion with the on-call consultant in the morning ward round, she underwent Dynamic Hip Screw fixation that day (Figure 3B).

Post-operatively she was kept toe-touch weight-

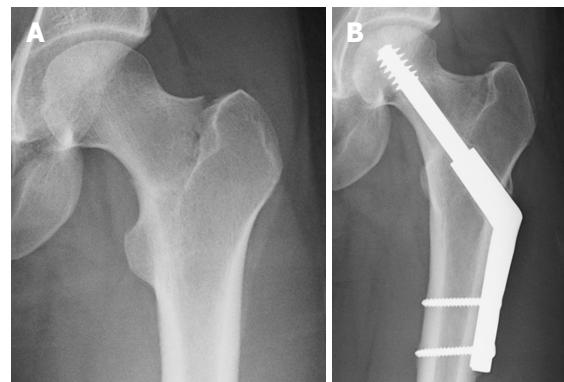


Figure 3 The management of a minimally-displaced tension sided femoral neck stress fracture. A: Pre-operative antero-posterior radiograph; B: Post-operative antero-posterior radiograph.

bearing with crutches for 6 wk, followed by partial weight-bearing with crutches for a further 6 wk. After this, she was allowed to weight-bear as pain permitted, and progressed in a graduated exercise programme under the care of the physiotherapists. Lower limb athletic activity was commenced 18 wk post-surgery, with clear evidence of fracture union radiologically and no pain clinically. With further input from physiotherapy, she returned to running at 6 mo post-surgery, and competed in a marathon again 10 mo post-surgery.

She had dedicated follow-up over 2 years with sequential radiographs to assess that the fracture united and that the fixation did not lose reduction or displace.

At 2 years follow-up, she reports occasional pain at the fracture site with prolonged exercise, particularly in the cold, though her radiographs show complete healing of the stress fracture.

Key message: Primary management of a minimally displaced lateral femoral neck stress fracture comprises of surgical fixation, with a Dynamic Hip Screw, ideally within 24 h of presentation.

Case 4: A compression-sided femoral neck stress fracture

A 20-year-old middle distance runner presented to the Sports Medicine Clinic with a 3 mo history of worsening atraumatic exercise-related left groin pain. He had

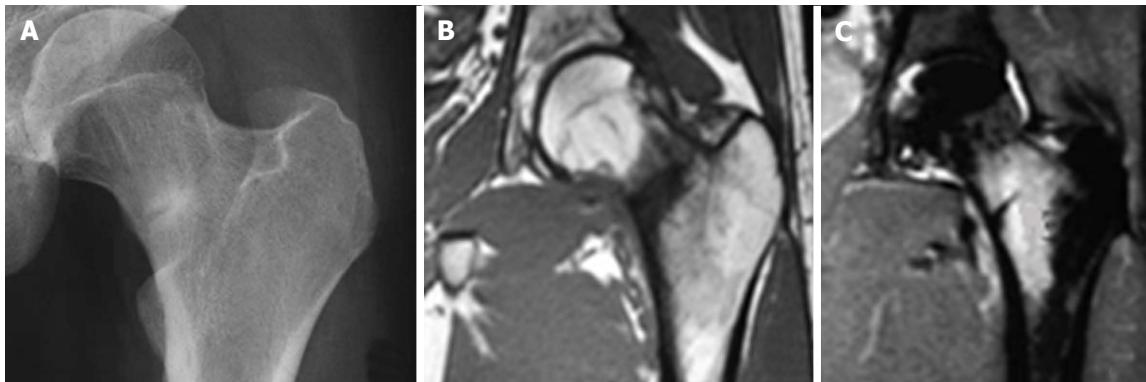


Figure 4 The management of an undisplaced compression sited femoral neck stress fracture. A: Diagnostic antero-posterior radiograph; B: Diagnostic T1 sequence coronal-plane magnetic resonance imaging (MRI) view; C: Diagnostic short tau inversion recovery sequence coronal-plane MRI view.

been training incrementally over the last 4 mo and had noted worsening left groin pain for the last month. This was initially felt to be a groin sprain and treated with analgesia and exercise modification. He was otherwise in good health. Radiographs revealed a compression sited fracture of the medial femoral neck (Figure 4A). The limb was distally neuro-vascularly intact and the overlying skin was healthy. He had mild pain at full flexion of the hip as well on axial compression, but otherwise the hip was painfree. His blood tests (bone profile and biochemistry) were normal and his BMI was 22 kg/m^2 .

He was placed on crutches, non-weightbearing, and underwent a MRI scan which showed a compression fracture which extended 25% across the width of the femoral neck (Figure 4B and C).

Following discussion in clinic, he was advised that the recommended treatment for this was conservative management, with limited weightbearing on crutches, followed by a progressive weight-bearing regime, as pain allows, under the supervision of the physiotherapists.

He was kept partial weight-bearing, with crutches for 6 wk, and then underwent progressive weightbearing as pain allowed. Lower limb athletic activity was commenced in a graduated manner 10 wk post-diagnosis, with input from physiotherapy, as there was clear evidence of fracture union radiologically, and clinically there was no pain. With further guidance from physiotherapy, he returned to running at 6 mo post-diagnosis, and returned to racing 9 mo post diagnosis.

He had dedicated follow-up over 2 years with sequential radiographs to assess that the fracture united and did not displace.

At 2 years follow-up, he reports no symptoms and his radiographs show complete healing of the stress fracture.

Key message: The first line management of undisplaced medial-sided compression femoral neck stress fractures, which extend less than 50% of the femoral neck width, is conservative management, with limited weight bearing using crutches, followed by a

progressive weight-bearing programme and then a return to exercise programme, under the supervision of the physiotherapy team.

Case 5: A medial malleolar stress fracture

A 21-year-old high performance middle distance runner presented to the Sports Medicine Clinic with a 4 mo history of atraumatic medial ankle pain. He was otherwise in good health. Radiographs revealed an undisplaced completed medial malleolar stress fracture (Figure 5A). The limb was distally neuro-vascularly intact and the overlying skin was healthy. His blood tests (bone profile and biochemistry) were normal and his BMI was 23 kg/m^2 . With the distinct radiographic changes, demonstrating a clear fracture line, MRI Scan was not felt to be necessary.

During an informed discussion in clinic, he was advised that both surgical and conservative management were options, with surgical management most likely offering a quicker return time to sport but with the risk of developing surgical complications. Due to a desire to return to sport as quickly as possible, he chose to undergo surgical management of his fracture. The following day, he underwent fixation of his fracture with two 4.0-mm AO cannulated cancellous screws (Figure 5B).

Post-operatively, he was non-weight-bearing for 3 wk, and then he progressed to full weight-bearing in an Aircast cast boot. He returned to light running training 2 mo post-surgery, and to full-level sports 3 mo post-surgery.

At 2 years follow-up, he continues to participate at the same level of running he was at pre-injury. He reports occasional pain at the fracture site, particularly on prolonged running in the cold, but otherwise is asymptomatic and radiographs show complete healing of the stress fracture.

Key message: Primary surgical management of undisplaced completed medial malleolar stress fractures can result in improved return to sport times compared to conservative management, though this exposes the patient to the risk of surgical complications.

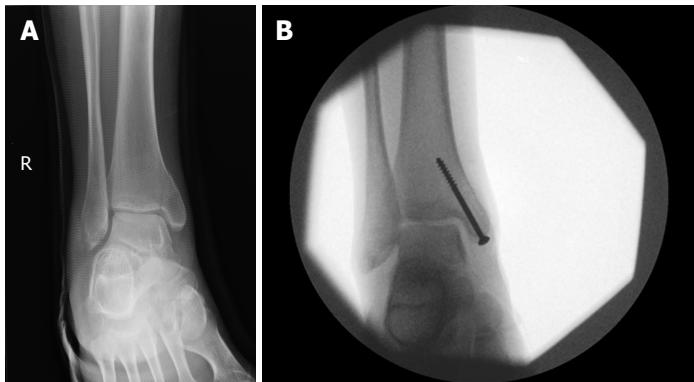


Figure 5 The management of an undisplaced completed medial malleolar stress fracture. A: Pre-operative antero-posterior radiograph; B: Intra-operative antero-posterior radiograph.

DISCUSSION

Within this editorial, we have outlined the currently recommended management strategies for the most common sport-related lower limb stress fractures, determining the treatments which offer the best proven results for the athlete, as well as the proven rehabilitation methods to allow the earliest return to sport possible. This is based on the most recent high quality literature in the field, derived from either systematic reviews or high impact clinical studies on each fracture type. With this, we have also reviewed the current evidence-based preventative interventions for each of the fracture types. Integration of the case studies then provides clinicians with a realistic perspective of how to manage such injuries in clinical practice. From this, we hope to provide clinicians with both a management framework for these injuries, along with, the most up-to-date evidence-based information on their treatment; this should allow provision of a systematic and evidence-based approach to assessing and treating lower limb sport-related stress fractures in their practice.

Areas found to be of particular value in the management of these injuries, were the site specific classifications, which were effective in guiding treatment and prognosis of these injuries^[1,16-19,54]. As such, we recommend the development of further evidence-based classifications for lower limb sport-related stress fractures.

Areas requiring further clarification in the management of these injuries include the role for surgical management of certain high risk injuries, the optimal surgical modality in such cases, and the optimal rehabilitation methods for each fractures type, particularly the role for various adjuncts such as air casts^[1-6,14,15,44]. Further work is required in these areas to better define the optimal treatment methods of these injuries.

The provision of optimal care when managing sport-related stress fractures is vital to maximise return rates to sport, to minimise return times and to limit persisting symptoms and recurrence of injury^[1,14,15,23]. The treatment of these injuries is specific to the location and the nature of the fracture, and a specialist knowledge of the topic

is required to provide optimal management^[1-4,6,8,14,15,23]. It is vital for clinicians to be appropriately informed of the common mode of presentation of these injuries, their optimal imaging modality and the most effective treatment strategies, in order to maximise the care of the athlete^[1,14,15,23,24]. The use of preventative measures against such injuries is an evolving concept, and can be a valuable aid to athletes and sports teams accordingly^[21,22]. Management of the high profile athlete remains a pressurised a situation, as time away from sport can have significant financial and social consequences, so specialist input from experienced personnel should be co-ordinated to ensure optimal care^[1].

In order to maximise the management and outcome of these injuries, it is essential that clinicians continue to participate and support in research in this area^[1,14,15,23]. All treating clinicians should keep documentation of their management and outcome of such injuries, allowing regular publication of relevant case series^[1,14,15,23]. Furthermore, well established specialists centres should co-ordinate more extensive cohort studies and epidemiological studies, to further establish the effects of variations in practice on outcomes^[1,14,15,23]. Where possible, randomised controlled trials in this field should be funded and supported, as these will provide "gold standard" evidence to determine the optimal treatment modalities of sport-related stress fractures^[1,14,15,23].

When managing such injuries, clinicians should remember to provide a holistic approach, performing a detailed assessment of each patient to establish predisposing risk factors, such as abnormal gait biomechanics or nutritional deficiencies, which should be addressed appropriately, to avoid recurrence of the condition. Similarly, when managing the female athlete, clinicians should always consider the female athlete triad as an underlying cause of the condition, assessing and managing this accordingly^[1,14,15,23]. Lastly, it should be noted that all athletes and clinicians should adhere to the established treatment principles that have been developed for these conditions^[1,14,15,23]. Such treatment protocols have been developed from well-organised research within military and sporting populations, both of

which provide robust patient cohorts. Thus any attempt to over-accelerate rehabilitation in the athlete, is likely to result in inadequate treatment and recurrence of the condition^[1,14,15,23]. With appropriate compliance to the recommended treatment, athletes should be reassured that outcomes from these injuries are largely positive, with high return rates to previous level sport and favourable return times^[1,14,15,23]. Given the importance of providing well-informed, individually directed care for such injuries in the high level athlete, it remains important that specialised sport physicians and sports surgeons provide care for these individuals, in order to optimise their management and outcome^[1,14,15,23].

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Basic Study

Spinal alignment evolution with age: A prospective gait analysis study

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Abstract

AIM

To describe, using gait analysis, the development of spinal motion in the growing child.

METHODS

Thirty-six healthy children aged from 3 to 16 years old were included in this study for a gait analysis (9 m-walk). Various kinematic parameters were recorded and analyzed such as thoracic angle (TA), lumbar angle (LA) and sagittal vertical axis (SVA). The kinetic parameters were the net reaction moments (N.m/kg) at the thoracolumbar and lumbosacral junctions.

RESULTS

TA and LA curves were not statistically correlated to the age (respectively, $P = 0.32$ and $P = 0.41$). SVA increased significantly with age ($P < 0.001$). Moments in sagittal plane at the lumbosacral junction were statistically correlated to the age ($P = 0.003$), underlining the fact that sagittal mechanical constraints at the lumbosacral

junction increase with age. Moments in transversal plane at the thoracolumbar and lumbosacral junctions were statistically correlated to the age ($P = 0.0002$ and $P = 0.0006$), revealing that transversal mechanical constraints decrease with age.

CONCLUSION

The kinetic analysis showed that during growth, a decrease of torsional constraint occurs while an increase of sagittal constraint is observed. These changes in spine biomechanics are related to the crucial role of the trunk for bipedalism acquisition, allowing stabilization despite lower limbs immaturity. With the acquisition of mature gait, the spine will mainly undergo constraints in the sagittal plane.

Key words: Sagittal balance; Spine biomechanics; Gait analysis; Thoracic kyphosis; Spine growth

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Core tip: Many postural changes occur during childhood, including the adaptation of the spine to maintain an erect posture. The aim was to describe, using gait analysis, the development of spinal motion during growth. Various kinematic parameters were recorded in 36 healthy children. Thoracic kyphosis and lumbar lordosis were not found to increase during childhood whereas sagittal vertical axis increased with age. The kinetic analysis showed a decrease of torsional constraint while sagittal constraint increased. These changes in spine biomechanics are related to the crucial role of the trunk for bipedalism acquisition, allowing stabilization despite lower limbs immaturity.

Pesenti S, Blondel B, Peltier E, Viehweger E, Pomero V, Authier G, Fuentes S, Jouve JL. Spinal alignment evolution with age: A prospective gait analysis study. *World J Orthop* 2017; 8(3): 256-263 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v8/i3/256.htm> DOI: <http://dx.doi.org/10.5312/wjo.v8.i3.256>

INTRODUCTION

With the acquisition of bipedalism, many anatomical and postural changes occurred in humans^[1-3]. Among these changes, an adaptation of the spine has been necessary to maintain an erect position, in combination with an adaptation of the pelvis and the lower limbs^[4-6]. Although gait acquisition is apparently complete by the age of 3, adaptation to erect posture continues until the end of growth. According to Peterson et al^[7], mature gait patterns are visible in children only from the age of 12.

With the development of modern tools for gait analysis, it is possible to obtain a precise evaluation of the kinematic and kinetic for different segments of the human body. While many of these tools have been developed for lower limbs analysis, various authors have demonstrated

their accuracy for trunk dynamic analysis^[8-10]. Many studies have described the evolution of spinal curvatures with radiological or other methods^[11,12]. Using these tools, it has been shown that thoracic kyphosis and lumbar lordosis increase with age.

To our knowledge, there is no evidence in literature about this development using gait analysis tools. Moreover, gait analysis provides dynamic data such as constraints applied to spinal joints, these parameters having never been discussed in literature before. The hypothesis of this work was that spinal motion changes all along growth. The aim of this study was to describe, using gait analysis, the development of spinal motion in the growing child.

MATERIALS AND METHODS

Study design

To obtain a homogenous pediatric cohort, only healthy volunteers were included in this prospective study after informed consent. Inclusion criteria were children aged from 3 to 16 years old, without known disease and volunteers to participate to the study. Exclusion criteria were every history of orthopedic or neurologic disorders, major orthopedic trauma or allergy to the components used for gait analysis.

Anthropometric data

For each participant, the following anthropometric data were collected for gait analysis: Age, weight, height, lower limb length and knee and ankle diameters.

Gait analysis

All measurements were obtained using an optoelectronic system (Vicon, Oxford, United Kingdom) with six high-resolution cameras with infrared light and a sampling frequency of 100 Hz which recorded the position of passive retroreflective markers and two force platforms (AMTI, United States). This protocol included all the markers necessary to obtain parameters of a standing posture and to calculate the force of external efforts in the different intersegmental centers, as described by Blondel et al^[13], according to the International Society of Biomechanics^[14,15].

Subjects were equipped with a set of 28 retroreflective markers as described in Table 1 and Figure 1. These markers allowed an analysis of different body segments such as head and neck, the scapular girdle, the thorax and thoracic spine, the abdomen and lumbar spine, the pelvis and the lower limbs.

Before the beginning of gait analysis, a short trial was performed to check the good positioning of the markers according to the analysis of knee valgus/varus^[16].

For gait analysis, subjects were asked to walk at a self-selected speed, barefoot, on a flat and straight 9 m-walkway. A minimum of seven trials was recorded to collect kinematic and kinetic data.

The data collected by the 6 high-resolution cameras were converted into a 3D model using NEXUS software

Table 1 Optoelectronic markers placement following anatomical landmarks according to Blondel et al^[13] gait analysis protocol

Parameters	
Head	Vertex: 1 Nasion: 1 Tragus: 2
Trunk - thorax	Acromion: 2 Manubrium: 1 Xiphoid: 1 C7: 1 T6: 1 T9: 1
Trunk - abdomen	T12: 1 L3: 1 S1: 1
Pelvis	ASIS: 2
Lower limbs - thighs	Femoral shaft: 2 Lateral femoral condyle: 2
Lower limbs - legs	Tibial shaft: 2 Lateral malleolus: 2
Lower limb - feet	Calcaneus: 2 2 nd metatarsal head: 2

**Figure 1 Gait analysis model used for trunk motion assessment.** Retroreflective markers were placed according to anatomical landmarks, such as described by Blondel et al^[13] (Table 1). Six markers were used for spine motion.**Table 2 Kinematic parameters measured during gait analysis**

	Frontal	Sagittal	Transversal
Overall balance		SVA Ad	
Shoulders			APA
Thoracic spine		TA	
Lumbar spine		LA	
Pelvis		Pelvic version	
Lower limbs	Knee Varus/valgus	Hip flex/ext Knee flex/ext	

SVA: Sagittal vertical axis; APA: Angle pelvis-acromion; TA: Thoracic angle; LA: Lumbar angle.

Table 3 Kinetic parameters measured during gait analysis

	Frontal moments	Sagittal moments	Transversal moments
Thoracolumbar junction	Lateral bending	Flexion-extension	Torsion
Lumbosacral junction	Lateral bending	Flexion-extension	Torsion

(Vicon Motion Systems, Oxford, United Kingdom) for the lower limbs and data were integrated to MATLAB software for trunk analysis.

The characteristic moments of the beginning and the end of the double stance phase were used to compare subjects.

For kinetic analysis, calculations were made from anthropometric reference tables^[17].

Gait parameters

Kinematic parameters during gait are described hereafter and summarized in Table 2 and Figure 2: (1) Sagittal Vertical Axis Adimensioned (SVA Ad): distance between

the marker "S1" and the vertical line passing by the marker "C7". This value was weighted by the height of the subject to be comparable between subjects, regardless to age and height (SVA Ad=SVA/Height). This parameter reflects trunk position during gait: A great value of SVA indicates that the trunk is leaning forward; (2) angle pelvis-acromion (APA): Angle defined in the transverse plane between the line joining the 2 "Acromion" markers and the line joining the 2 "anterosuperior iliac spine" markers. The APA-rom (range of motion) was calculated as the difference between the maximum and the minimum values of the APA during a gait cycle^[18]; (3) thoracic angle (TA): Angle between the "C7"- "T7" line and the "T9"- "T12" line; and (4) lumbar Angle (LA): Angle between the "T12"- "L3" line and the "L3"- "S1" line.

Kinetic parameters are detailed in Table 3. In frontal plane, moments applied to the spine are relative to lateral bending movements, in sagittal plane they are flexion-extension movements and in transversal plane, they were consecutive to torsional movements. These data were dimensioned (*i.e.*, divided by the weight) to be comparable between individuals, independently from their body mass.

Statistical analysis

Gait data were analyzed to compare subjects in a continuous analysis according to age. A Pearson Product Moment Correlation Coefficient (*r*) was used to determine differences between subjects according to age. Level of significance was set at 5% for every statistical analysis.

RESULTS

Demographic data

From October 2012 to October 2013, 36 subjects were included in this study. Mean age of the population was

Table 4 Details of demographic and anthropometric data

Subject No.	Sex	Age (yr)	Height (cm)	Weight (kg)	Lower limb length (cm)		Knee diameter (cm)		Ankle diameter (cm)	
					Right	Left	Right	Left	Right	Left
1	F	3.3	880	11	420	420	55	55	45	45
2	F	3.4	1060	17	510	510	80	80	60	60
3	M	3.9	935	14	500	500	70	70	44	44
4	F	3.9	1050	19	520	520	80	80	60	60
5	M	4.1	1080	18	550	550	70	70	50	50
6	F	4.6	1090	16	650	650	50	50	45	45
7	F	5.8	1135	19	570	570	70	70	50	50
8	M	6.1	1150	19	575	575	80	80	60	60
9	F	7.0	1345	27	670	670	90	90	65	65
10	F	7.2	1200	21	570	570	70	70	50	50
11	F	7.4	1160	21	585	585	80	80	60	60
12	M	7.7	1370	34	730	730	110	110	70	70
13	F	7.7	1300	31	680	680	95	95	70	70
14	F	7.8	1280	26	650	650	90	90	70	70
15	M	8.0	1340	27	680	680	90	90	70	70
16	M	8.1	1330	28	685	685	95	95	65	65
17	M	8.5	1360	33	710	710	90	90	55	55
18	M	8.8	1400	40	720	720	110	110	70	70
19	F	8.9	1380	37	720	720	100	100	65	65
20	M	9.1	1320	24	680	680	80	80	60	60
21	M	9.2	1420	26	750	760	55	55	50	50
22	F	9.3	1524	38	820	820	100	100	65	65
23	M	9.5	1395	36	750	750	110	105	65	65
24	F	10.0	1360	29	710	710	70	70	55	55
25	F	10.6	1370	39	740	740	95	95	60	60
26	F	10.8	1425	32	750	750	90	90	65	65
27	F	11.0	1530	41	810	810	105	105	70	70
28	M	11.1	1520	51	850	850	100	100	70	70
29	F	11.1	1463	47	740	740	105	105	70	70
30	F	11.3	1610	46	840	840	105	105	70	80
31	M	11.9	1390	34	700	700	85	85	60	60
32	F	12.5	1470	35	740	740	100	100	70	70
33	F	12.7	1570	54	900	900	115	110	75	70
34	F	13.9	1690	47	925	925	100	100	70	70
35	M	15.5	1650	48	830	830	85	85	65	65
36	M	15.6	1770	87	930	930	100	100	70	70

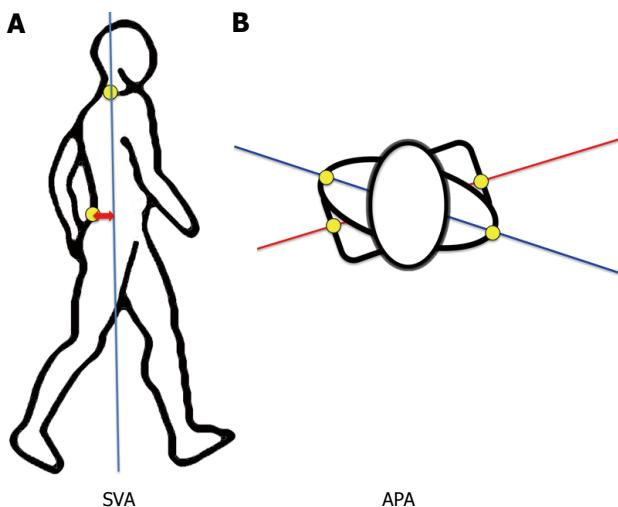


Figure 2 Sagittal vertical axis and angle pelvis-acromion. A: SVA was defined as the distance between the marker "S1" and the vertical line passing by the marker "C7". This parameter reflects trunk position during gait: A great value of SVA indicates that the trunk is leaning forward; B: APA was defined as the angle between the line joining the 2 "Acromion" markers and the line joining the 2 "anterosuperior iliac spine" markers. SVA: Sagittal vertical axis; APA: Angle pelvis-acromion.

8.8 years old (3.3 to 15.6 years old). Demographic and anthropometric data are shown in Table 4.

Gait analysis: Kinematics

Sagittal plane: TA and LA curves were not statistically different (respectively, $r = 0.06$ and $r = 0.023$, $P = 0.32$ and $P = 0.41$, Figure 3).

SVA Ad was significantly correlated to the age ($r = 0.488$, $P < 0.001$), revealing a progressive anterior increase of the projection of the C7 marker with regards to the S1 marker (Figure 4).

Transversal plane: There was a non-significant negative correlation between APA-rom and age ($r = -0.063$, $P = 0.71$).

Gait analysis: Kinetics

Sagittal plane: Results showed that flexion-extension moments at the lumbosacral junction were statistically correlated to age ($r = 0.356$, $P = 0.003$). In other words, mechanical sagittal constraints at the lumbosacral junction increase during growth. At the thoracolumbar

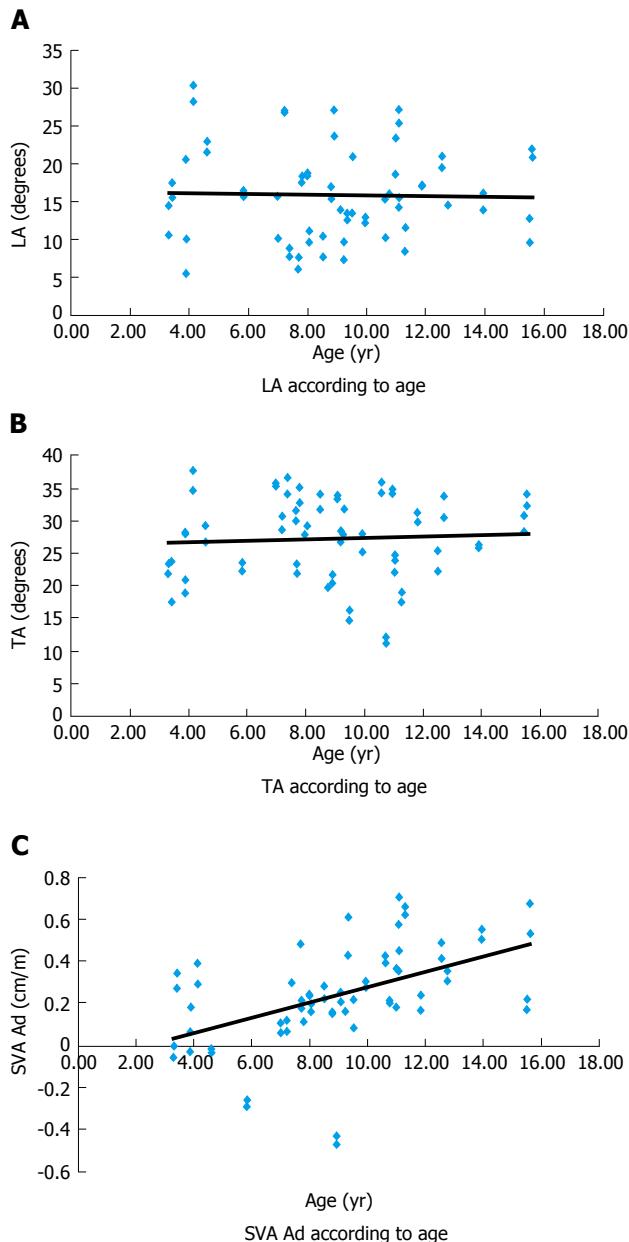


Figure 3 Continuous analysis of kinematic parameters according to the age. A: TA; B: LA; C: SVA. TA: Thoracic angle; LA: Lumbar angle; SVA: Sagittal vertical axis.

junction, sagittal constraints were not significantly correlated to age ($r = 0.189$, $P = 0.13$, Figure 5).

Transversal plane: Results demonstrated that torsion moments at thoracolumbar and lumbosacral junctions were statistically correlated to age ($r = -0.613$ and $r = -0.563$, $P = 0.0002$ and $P = 0.0006$). In other words, transversal mechanical constraints at thoracolumbar and lumbosacral junctions decrease with age (Figure 6).

DISCUSSION

This study is the first to analyze spinal motion in children *via* gait analysis tool. Changes occur in spine motion in children with the acquisition of a mature gait

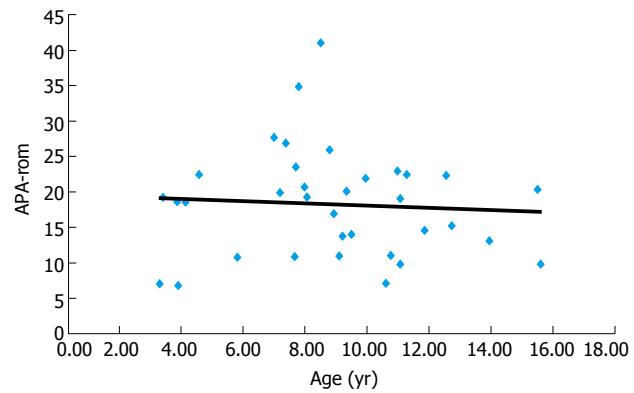


Figure 4 Continuous analysis of angle pelvis-acromion-rom according to the age. APA: Angle pelvis-acromion.

even if dynamic parameters of the spine during growth seem to be established before the age of 3.

So far, only few studies have studied dynamic development of the spine according to age *via* gait analysis^[19]. The studies from Wagner *et al*^[20] and Farfan^[21] showed that the presence of a lumbar spinal curvature concave toward the back is a necessary biomechanical condition for a stable erect posture, enabling an economic muscular functioning despite the posterior position of the spine. Lumbar lordosis thus appears as being a fundamental prerequisite to bipedalism, explaining its early appearance during childhood. Parameters determining bipedalism are acquired very early during growth^[21,22]. However, some skeletal parameters which are not involved in the acquisition of bipedalism are variable and change until the end of growth. Some of these parameters are even found to be genetically predetermined during fetal life. This is, for example, the case of the morphology of the femoral trochlea^[23] or the lumbar lordosis^[24], which are genetically predetermined in humans. Their early kinematic setting is an element explaining the ability to bipedalism.

The spine appears to be of fundamental importance in the adaptation of the skeleton to bipedalism and we can define a real “spinal motor of bipedalism”; the spine being the first skeletal element to adjust its posture and functioning to bipedalism as the main element of locomotion^[25]. The lower limbs adapt secondarily, around the age of 7, with a progressive pelvic anteversion, a progressive extension of the hips and the knees, lately mature.

Some radiographic and morphologic studies have evaluated the development of spinal curvatures during growth^[11,12]. These studies revealed that from the age of 3 years until skeletal maturity, there is a linear enhancement of the thoracic kyphosis and lumbar lordosis. According to us, these changes do not reflect the adaptation of the skeleton to bipedalism, but an adaptation to the major constraints applied to the trunk during growth. In other words, formation of overlying sagittal curvatures to the lumbar lordosis with the appearance of thoracic kyphosis and cervical lordosis is related to biomechanical adaptation to an increase of load on the

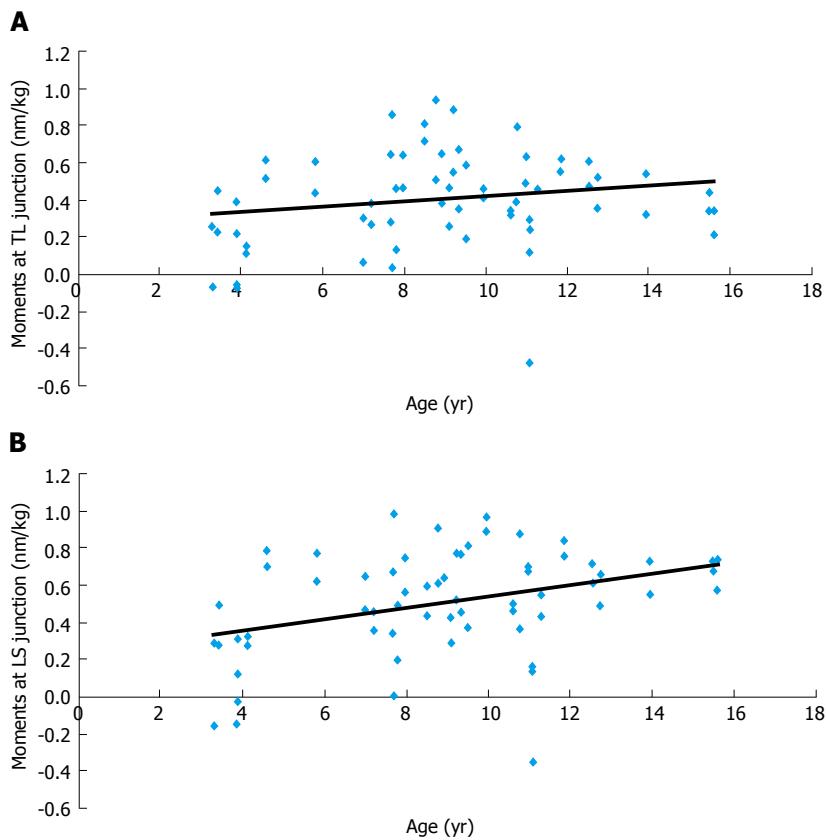


Figure 5 Sagittal kinetic parameters of the trunk according to the age. A: TL; B: LS. Frontal plane constraints are relative to flexion-extension movements. TL: Thoracolumbar; LS: Lumbosacral.

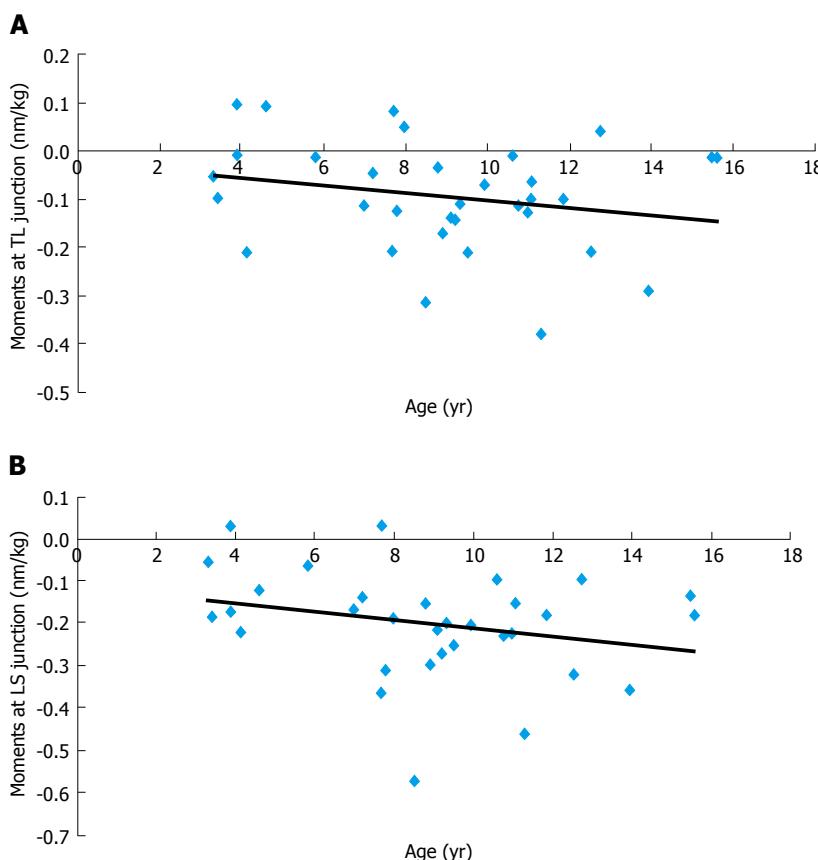


Figure 6 Transversal kinetic parameters of the trunk according to the age (continuous analysis). Transversal plane constraints are relative to torsional movements of the trunk. TL: Thoracolumbar; LS: Lumbosacral.

spine.

Most of the parameters used in this study for kinematic analysis, such as SVA, were chosen according to previous works^[18]. These parameters seemed to be good descriptors because they are the dynamic equivalent of radiographic parameters. Thoracic angle and lumbar angle were meant to be the equivalent of thoracic kyphosis and lumbar lordosis, which are 2 radiographic parameters used in clinical practice.

Results from this study suggest that the sagittal efforts applied on the spine increase significantly with age leading to increased flexion-extension constraints at the lumbosacral junction. This phenomenon can be explained by the accentuation of spinal curvatures with age as a response to the increased load on the spine, deporting the lumbar spine forward and thereby increasing the lever arm and the moment applied to the underlying lumbosacral junction.

With regards to the kinetic parameters in the transverse plane, our results showed a significant reduction in torsional constraints at the thoracolumbar and lumbosacral junctions during growth. Although lumbar lordosis is acquired from fetal life, the central maturation processes coordinating the acquisition of a mature gait for the lower limbs appear only around the age of 7. Before this turning point, the lower limbs do not have a mature kinematics allowing balance and stability for satisfactory and stable erect posture. These results are in line with the posturographic study from Peterson et al^[7] who have shown that sensory systems ensuring a satisfactory balance for maintaining erect station were efficient only from the age of 12. Thus, the spine undergoes greater constraints to compensate this permanent balance research. Large constraints applied to the spine and their reduction with age are a sign of the compensation by the trunk of a lack of stability due to lower limbs and sensory system immaturity. Prior to the acquisition of a definitive and mature bipedalism, the trunk is fundamental for the possibility of early bipedalism.

Furthermore, the significant increase of SVA during growth could be related to the same conclusion. The low value of SVA in young children reflects the need to keep the shoulders over the pelvis to stabilize the erect posture. With maturation and the acquisition of a final biped balance, the subject is projected more forward, then changing the direction of the constraints on the spine from the transverse plane to the sagittal plane.

These findings allow a better comprehension of the importance of constraints in the lumbar spine and can be a source of explanation for specific degenerative disorders of this anatomical region.

The small number of subjects in each age group may be at the origin of a lack of statistical power and may explain the lack of significant difference. However, in similar series, changes in lower limb parameters are clearly established, these parameters being definitively acquired after the age of 7^[26-31]. The protocol used for trunk assessment has been validated before in the study by Blondel et al^[13]. This protocol is designed for clinical use and a low number of markers is a clear advantage

in that case. The authors have demonstrated that 6 markers were sufficient to assess trunk kinematics and kinetics precisely. Moreover, there was a wide amount of variability. Including a greater number of subjects may increase statistical power and allow to highlight differences in sagittal kinematic parameters.

The biomechanical model developed by Blondel et al^[13] in adults has enabled us to achieve the first dynamic study of spine development with age. The comparison of age groups and continuous analysis did not highlight major kinematic evolution of spinal curvatures during skeletal maturation. The acquisition of the lumbar lordosis and thoracic kyphosis is a morphological characteristic that probably appears very early in children, before the age of 3.

The kinetic analysis revealed a progressive decrease in torsional constraints applied on the spine while the constraints in flexion-extension increase with age. These changes allow stabilization of erect posture despite the immaturity of the lower limbs. With the acquisition of mature gait, the spine will mainly undergo constraints in the sagittal plane. These changes point out the major role of the trunk during the acquisition of bipedalism.

COMMENTS

Background

Although gait acquisition is apparently complete by the age of 3, adaptation to erect posture continues until the end of growth. Many studies have described the evolution of spinal curvatures with radiological methods. Using gait analysis tools, it is possible to obtain a precise analysis of the evolution of spinal alignment with age.

Research frontiers

Even if the sample size is quite limited, this study provides interesting information about evolution of spinal dynamics with growth. This study may help to understand changes in gait in spinal disorders.

Innovations and breakthroughs

Results from this study confirm the technical feasibility of the protocol in young children. Using this methodology, it was possible to evaluate net moments applied to spinal junctions. To the authors' knowledge, this is the first study to provide dynamic data of the spine of healthy children.

Applications

By providing normative data, this study may help to understand the changes that occur in children with spinal disorders. It could also help to evaluate the behavior of the spine in children after spinal surgery.

Peer-review

Although the sample size is relatively small, this is an interesting study.

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Retrospective Cohort Study

Results of single stage exchange arthroplasty with retention of well fixed cement-less femoral component in management of infected total hip arthroplasty

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Author contributions: Gollish JD did all the surgeries, designed the research, and critically revised the manuscript; Kazi HA collected the data, analyses the data; Rahman WA collected the data, analyzed the data, wrote the manuscript.

Institutional review board statement: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved with institutional review board of sunny brook health science hospital University of Toronto, Toronto, Ontario, Canada.

Informed consent statement: Informed consent was obtained from all individual participants included in the study.

Conflict-of-interest statement: This study was not funded by any institution. The authors declare that they have no conflict of interest.

Data sharing statement: Technical appendix, statistical code, and dataset available from the corresponding author at dr.waelrahman@gmail.com. Participants gave informed consent for data sharing.

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Abstract

AIM

To investigate success of one stage exchange with retention of fixed acetabular cup.

METHODS

Fifteen patients treated by single stage acetabular component exchange with retention of well-fixed femoral component in infected total hip arthroplasty (THA) were retrospectively reviewed. Inclusion criteria were patients with painful chronic infected total hip. The patient had radiologically well fixed femoral components, absence of major soft tissue or bone defect compromising, and infecting organism was not poly or virulent microorganism. The organisms were identified preoperatively in 14 patients (93.3%), coagulase negative Staphylococcus was the infecting organism in 8 patients (53.3%).

RESULTS

Mean age of the patients at surgery was 58.93 (\pm 10.67) years. Mean follow-up was 102.8 mo (36–217 mo, SD 56.4). Fourteen patients had no recurrence of the infection; one hip (6.7%) was revised for management of infection. Statistical analysis using Kaplan Meier curve showed 93.3% survival rate. One failure in our series; the infection recurred after 14 mo, the patient was treated successfully with surgical intervention by irrigation, and debridement and liner exchange. Two complications: The first patient had recurrent hip dislocation 12 years following the definitive procedure, which was managed by revision THA with abductor reconstruction and constrained acetabular liner; the second complication was aseptic loosening of the acetabular component 2 years following the definitive procedure.

CONCLUSION

Successful in management of infected THA when following criteria are met; well-fixed stem, no draining sinuses, non-immune compromised patients, and infection with sensitive organisms.

Key words: Total hip arthroplasty; Infection; One stage exchange; Complication

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Core tip: Peri-prosthetic hip infection is a devastating complication: We hypothesized that a well-fixed circumferentially ingrown cement-less stem can act as a shield and prevent the spread of pathogens and formation of biofilm around the body of the femoral stem. Therefore, single stage exchange of the acetabular component with retention of the well-fixed femoral component can be a successful option in management of infected total hip arthroplasty, when the following criteria are met; well-fixed femoral component, no draining sinuses, non immune compromised patients, and infection with sensitive organisms.

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INTRODUCTION

Peri-prosthetic hip infection is a devastating complication, up to 2% of primary total hip arthroplasty (THA) and 4%-6% after revision THA are complicated by infection^[1,2]. The goal of treatment is eradication of infection and durable functional reconstruction^[3,4]. There are variable surgical options for management of infected THA. Two-stage exchange arthroplasty has been considered the

gold standard treatment^[5-7]. However, it is expensive and associated with high rates of surgical morbidity^[8-11]. One-stage exchange arthroplasty remains an attractive alternative option since it requires only one operation, and is associated with shorter hospital stay and faster rehabilitation^[12-15]. Previous studies have shown good results of single stage exchange arthroplasty with preservation of a well-fixed cement mantle^[16].

Hypothesis

We hypothesized that a well-fixed circumferentially ingrown cement-less stem can act as a shield and prevent the spread of pathogens and formation of biofilm around the body of the femoral stem. Therefore, single stage exchange of the acetabular component with retention of the well-fixed femoral component can be a successful option in management of infected total hip arthroplasty, when the following criteria are met; well-fixed femoral component, no draining sinuses, non immune compromised patients, and infection with sensitive organisms. Failure of treatment was defined by recurrence of infection that required either further surgical intervention or the use of long-term suppressive antibiotics.

MATERIALS AND METHODS

Research Ethics Board approved this retrospective study at our institution. The Electronic Patient Record was searched for the patients who had single stage acetabular component exchange with retention of a well-fixed femoral component in management of infected THA.

From January 1997 to January 2012, 15 hips in 15 patients (9 females and 6 males) were managed with single stage acetabular component exchange with preservation of well-fixed femoral component. Inclusion criteria were patients with painful chronic infected total hip diagnosed with elevated erythrocyte sedimentation rate (ESR, \geq 30 mm/h) and /or C-reactive protein (CRP, \geq 20 mg/L) and/or elevated white blood cell count $>$ 11000. The patient had the following criteria; radiologically well fixed femoral components, absence of major soft tissue defect compromising wound closure and/or bone defect affecting implant stability, and infection was not associated with culture of polymicrobial or antibiotic resistant micro-organism in the preoperative hip aspiration culture.

Our exclusion criteria were patients presented with a sinus tract communicating with the prosthesis, culture of MRSA or poly-microbial infection, immunocompromised patients, patients treated previously for management of infected THA with either one or two stage exchange arthroplasty, radiological signs of loosening of the femoral component, and if the femoral component was discovered to be loose during the surgical procedure.

All the patients included in the study were consented for single stage acetabular component exchange or two-

Table 1 Patients demographic characteristics and comorbidities

Patient	Sex	Age	Pre ESR	Pre CRP	Re culture	Complication	Revision details	Culture in revision	Failure
1	F	38	NA	NA	Gram negative cocci				No
2	F	44	37	27	Coagulase negative staph				No
3	F	47	33	44	Beta hemolytic street				No
4	F	53	50	46	Beta hemolytic street	Aseptic loosening acetabular component	Revision cup	None	No
5	F	55	50	80	No growth				No
6	F	65	44	57	Beta hemolytic street				No
7	F	68	30	26	Coagulase negative staph				No
8	F	70	55	82	Beta hemolytic street				No
9	M	77	60	130	Coagulase negative staph				No
10	M	58	50	30	Coagulase negative staph	Infection	Debridement and liner exchange	Coagulase negative staph	Yes
11	M	60	65	102	Coagulase negative staph				No
12	M	65	49	86	Coagulase negative staph				No
13	M	65	63	30	Coagulase negative staph				No
14	M	52	25	45	Gram negative cocci				No
15	M	68	24	40	Coagulase negative staph				No

F: Female; M: Male; NA: Not available.

Table 2 Patient details, laboratory results, microorganism, and success of the procedure

Characteristics	n of patients
Hip joints	15
Gender	
Male	6
Female	9
Age at index surgery: Mean, (SD), range	58.93 yr, SD 10.6 (range; 38-76 yr)
BMI kg/m ² , SD, range	30, SD 8.8 (range; 18-51)
ASA INDEX	
I	3
II	5
III	6
IV	1
Smoking	
Non smoker	11
Smoker	4
Comorbidities	
Diabetes mellitus	2
Hypertension	6
Rheumatoid arthritis	1
Hyperlipidemia	2
Patients with previous cardiac history (myocardial infarction)	1

BMI: Body mass index.

stage exchange arthroplasty if there were intra-operative finding of loose femoral component, or highly contaminated hip joint with purulent material and extensive damage of the soft tissue.

Mean age of the patients at operation was 58.93 years (range; 38-76 years, SD 10.6). Patient body mass index averaged 30 kg/m² (range; 18-51 kg/m², SD 8.8). ASA level was I (*n* = 3), II (*n* = 5), III (*n* = 6), and IV (*n* = 1). Eleven patients were non-smokers, while 4 patients were smokers. The patients had the following comorbidities; diabetes mellitus (*n* = 2), hypertension (*n* = 6), myocardial infarction (*n* = 1), hyperlipidemia (*n* = 2) and rheumatoid arthritis (*n* = 1) (Table 1).

Surgical procedures before infection were primary total hip arthroplasty in (*n* = 11), and revision total hip arthroplasty in (*n* = 4); cup revision for aseptic loosening of the acetabular component (*n* = 1), linear exchange for management of poly wear (*n* = 1) and irrigation and debridement for management of acute infection in (*n* = 2). The mean interval between the previous primary total hip arthroplasty and single stage acetabular component exchange was 78.6 mo, SD 75.86 (range; 12-242 mo).

The organisms were identified from the aspirated fluid before single stage acetabular component exchange in 14 patients (93.3%), no organism was identified in 1 hips (6.7%), coagulase negative staphylococcus was the infecting organism in 8 patients (53.3%). Details of the infecting organism are summarized in (Table 2). All the patients included in the study had un-cemented acetabular and femoral components.

During the operative procedure, aggressive debridement of the joint was performed; 5 tissue samples were sent for microbiological analysis. All the patients received intra-operative prophylactic antibiotics after obtaining the soft tissue cultures. All the femoral components were assessed intra-operatively and were well-fixed. Mechanical cleansing with diluted povidone-iodine was used to clean the exposed metal parts of the femoral component. The acetabular components were loose in 6 hips, fibrous ingrown in 6 hips, and well fixed in 3 hips which required use of the Explant system (Zimmer, Warsaw, IN, United States). The acetabular component, liner and femoral head were removed carefully with minimal damage of the bone stock (Figure 1).

A thorough irrigation was done again using 3 L of saline using pulsatile lavage and one liter of diluted povidone-iodine. The instruments were changed and the patients were re-draped before re-implantation. Cement less acetabular component, high cross-linked polyethylene liner, and cobalt chrome femoral head were used in all the patients included in the study. The acetabular components used in the definitive procedure

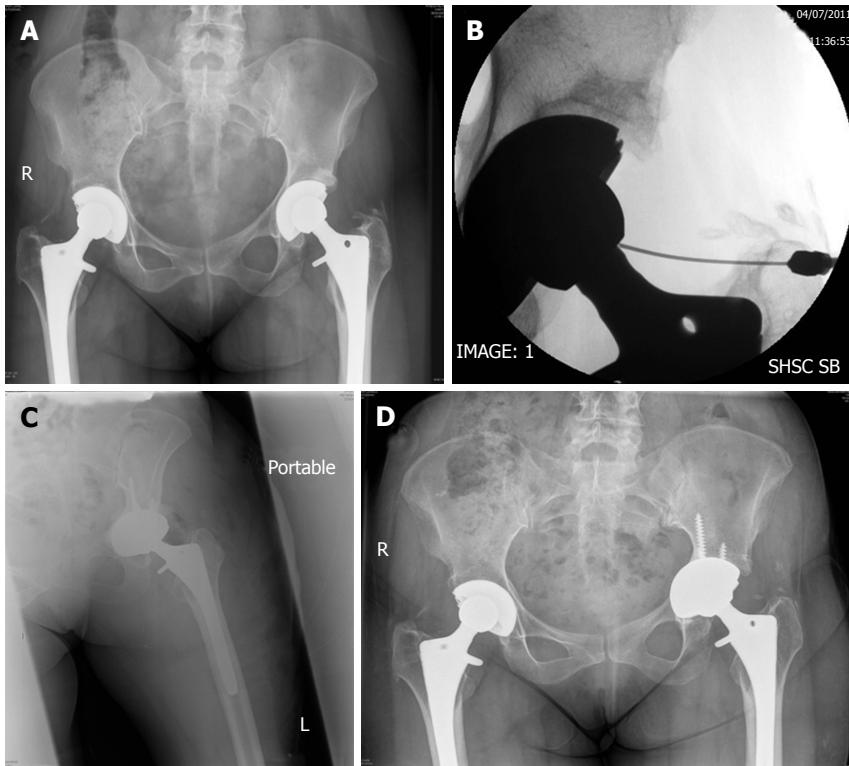


Figure 1 Case demonstration. A: Preoperative X-ray; B: Hip aspiration; C: Post operative X-ray; D: Five-year follow-up.

were as follows; Trilogy ($n = 13$), HGP II ($n = 1$) and Trabecular metal modular cup ($n = 1$) (Zimmer Inc., Warsaw, IN). No drain was used and closure of the hip abductors, Iliotibial band, and subcutaneous tissue were performed with non-absorbable suture (coated VICRYL; Ethicon, Johnson and Johnson, Cornelia, GA), followed by sub-cuticular suture for skin closure. AQUA CELL AG surgical dressing (ConvaTec INC, Greensboro, NC) was used for wound dressing.

All patients were evaluated and managed by the infectious diseases team in our hospital. Postoperatively, the patients were treated with broad-spectrum antibiotics until the results of the culture were available. Organism-specific IV antibiotics were administered for 6 wk. Antibiotics used were cloxacillin ($n = 8$), Vancomycin ($n = 3$), Clindamycin ($n = 2$), cephazolin ($n = 1$) and ceftriaxone ($n = 1$). After discontinuation of the intravenous antibiotics, all the patients continued on oral antibiotics for additional 6 wk, cloxacillin ($n = 12$), and ciprofloxacin ($n = 3$).

At follow-up, the patients were seen at 6 wk, 3, 6, 9, 12 mo and annually thereafter. Clinical, radiological and laboratory evaluation (using serial white cell count, ESR, and CRP) was performed at each follow up.

RESULTS

Mean follow-up was 102.8 mo (36–217 mo, SD 56.4). No patients were lost to follow-up. Fourteen patients had no recurrence of the infection; one hip (6.7%) was revised for management of infection. Statistical analysis

using Kaplan Meier curve showed 93.3% survival rate.

The only failure in our series occurred in a 58-year-old male patient; this patient had acetabular fracture, which was treated by open reduction and internal fixation at the age of 40 then primary THA for management post-traumatic arthritis of the hip joint at age 48. Subsequently the patient underwent revision THA for management of polyethylene wear (liner exchange) at age of 61 years. The patient was diagnosed with chronic infected THA 2 years following revision THA. Eventually, the patient had good result after single stage acetabular component exchange with preservation of the femoral component, but unfortunately the infection recurred after 14 mo. The patient was treated successfully with surgical intervention by removal of the acetabular fixation, irrigation, and debridement and liner exchange. Coagulase negative staphylococcus aureus was the infective organism at all the stages of management.

Two complications occurred in 2 patients. The first patient was 38-year female; the patient suffered from recurrent hip dislocation 12 years following the definitive procedure, this complication was managed by revision THA with abductor reconstruction and constrained acetabular liner, no clinical signs of infection were found during the revision procedure and no organism was grown from the intra-operative cultures. The second complication occurred in a 53-year-old female patient, the acetabular component was revised due to aseptic loosening 2 years following the definitive procedure. No evidence of infection was seen at the revision procedure (Table 2).

DISCUSSION

Infection after THA is a devastating complication; there is no randomized prospective study to evaluate the outcome of different management options. Two-stage exchange arthroplasty is generally felt to be the gold standard method of management. However, this strategy has some drawbacks; long duration of treatment, patient morbidity and high economic cost. The reported failure rates after two-stage hip revision range from 5% to 18%^[6,17,18]. One stage revision is an attractive option for the management of infected hip arthroplasty, with a comparable reinfection rates to two stage exchange and higher functional outcome scores, reduce morbidity, and cost of the management^[7,19-21].

The concept of single stage acetabular exchange arthroplasty with retention of well fixed femoral component in management of chronic infected total hip arthroplasty was brought into attention because removal of well fixed cement less femoral component is a complex procedure, which necessitates extensive soft tissue dissection and femoral osteotomies that can de-vascularize the proximal femur and may result in degradation of the bone stock, and significant post operative morbidity.

Bacterial adherence and subsequent biofilm formation on implant are involved in the origin and chronicity of implant-related infection. Different biomaterials are claimed to differently suffer from microorganism adherence and biofilm formation, justifying partial component exchange in some acute prosthetic joint infection. Experimental studies showed more adherences of microorganisms and formation of biofilm to rough surfaced Ti alloys than polished surfaces^[22].

In a recent study, Gómez-Barrena *et al*^[23] proved that sonification of retrieved implants after prosthetic joint infection showed almost no bacterial adherence to the polished femoral head components in total hip replacement, while knee infections basically seeded on the tibial trays with minimal seeding on the polished femoral component. Theoretically, a well fixed circumferentially ingrown cementless femoral stem can isolate the femoral canal from the infected joint fluid and prevent the formation of biofilm layer on the femoral stem. Therefore, there is high possibility to control infection without the need to remove the well fixed femoral component which seal the femoral canal from the infecting microorganisms.

Two recent reports demonstrate high success rate of two-stage partial exchange with retention of the well-fixed cement less femoral component. In the first report by Lee *et al*^[24], 17 infected THA were managed by two stage exchange arthroplasty; in the first stage irrigation and debridement was done followed by removal of the acetabular components, the femoral component was retained and the exposed metal parts of the femoral stem and femoral head was covered by antibiotic loaded bone cement. The acetabulum was reconstructed in the second stage. At mean follow-up of 4 years, 15 of the 17

(88%) demonstrated no recurrence of infection^[24]. The second report by Ekpo *et al*^[25], reported 19 infected hips treated with two stage partial exchange with retention of the well-fixed cement less femoral component. At mean follow-up of 4 years, 17 of the 19 (89%) demonstrated no recurrence of infection^[25].

The Exeter group reported their outcome of management of infected cemented (THA) by two-stage exchange with preservation of the original femoral cement mantle. The hypothesis was that Osteointegrated cement-bone interface is not part of the effective joint space and is inaccessible to infecting organisms. Fifteen patients were treated with two-stage exchange with retention of the well-fixed cement mantle; infection was controlled in 14 patients at mean follow-up of 82 mo^[16].

The main purpose of this study was to evaluate the success of single stage acetabular component exchange with retention of well-fixed femoral component. To our knowledge, this is the first report evaluating the results of this procedure.

From January 1997 to January 2012, the senior author performed 600-revision Total hip arthroplasty for various reasons, 92 of them were two-stage exchange for infected Total Hip arthroplasty. Single stage exchange with retention of well-fixed acetabular component was performed in 15 cases which represent (14%) of the cases treated for management of infected Total hip arthroplasty.

We defined failure by recurrence of infection that requires either surgical intervention or chronic suppressive antibiotics. Our infection recurrence rate was 6.7% at mean follow-up of 102.8 mo. The results compare favourably with previously published data of two-stage exchange^[6,7,11,17,20-25]. We are comparing the success of the procedure to two-stage exchange arthroplasty as it is considered the gold standard management option of such problem.

Our study has several limitations. First, this study was a retrospective, which can introduce the possibility of selection bias. Second, because of the small number of the patients we could not further analyze data stratifying for virulence of the organism, type of infection, and duration of infection. However, 15 patients treated with this technique for management of infected total hip arthroplasty reflect that strict selection protocol was applied to use this method of treatment and reflect that we are considering this technique when specific criteria are met. Different treatment modalities were utilized when these specific selection criteria for single stage, single component revision were not met. The infecting organism was not identified in one patient prior to the surgery, which raises the possibility that these patients might be infected with virulent microorganisms but in the meantime these patients met all other inclusion criteria. Finally, functional outcomes were not recorded in this study because of the retrospective nature of the study, but we believe that success of eradication of infection is a strong predictor of functional improvement.

In conclusion, our results of management of infected THA with single stage acetabular component exchange with retention of a well-fixed femoral component is encouraging and showed low risk of future recurrence. Retention of the femoral component preserves the femoral bone stock, decreases patients' morbidity, and lessens reconstructive complexity at the time of the revision. Based on our results, success can be achieved with this technique when the following criteria are met: (1) well-fixed femoral component; (2) good patient general health; (3) no draining sinuses; and (4) sensitive microorganisms isolated.

We are not proposing this method of treatment as alternative tool to two stage exchange for management of infected Total hip arthroplasty but it should be considered as one of the management options for treatment of this problem provided strict selection criteria are met. Further randomized controlled trial and trials with large volume of patients is needed to validate the best treatment option.

COMMENTS

Background

Peri-prosthetic hip infection is a devastating complication: The authors hypothesized that a well-fixed circumferentially ingrown cement-less stem can act as a shield and prevent the spread of pathogens and formation of biofilm around the body of the femoral stem. Therefore, single stage exchange of the acetabular component with retention of the well-fixed femoral component can be a successful option in management of infected total hip arthroplasty, when the following criteria are met; well-fixed femoral component, no draining sinuses, non immune compromised patients, and infection with sensitive organisms.

Research frontiers

Preservation of well fixed cementless femoral component in infected total hip arthroplasty cases will decrease the morbidity of management infected total hip arthroplasty patients. This is the only report in their literature up to the authors' knowledge presenting this technique. This study presents long term results of this procedure.

Innovations and breakthroughs

Most of the papers in the literature present results about either one stage or two stage exchange in management of infected total hip arthroplasty. The authors present a very good success rate of our procedure in management of selected patients with infected total hip arthroplasty. The authors' protocol of management can be added to the treatment option of infected total hip arthroplasty.

Applications

This article will encourage other surgeons either to use this technique or present their work if using similar technique in management of infected hip arthroplasty, this can lead to increase the credibility of using single stage exchange with preservation of well fixed femoral stem in management of infected total hip arthroplasty if selected criteria were met.

Terminology

THA: Total hip arthroplasty; CRP: C-reactive protein; ESR: Erythrocyte sedimentation rate; WBC: White blood cell count; BMI: Body mass index; ASA: American Society of Anesthesiologist.

Peer-review

This paper gives readers one of the management options for treatment of infected total hip arthroplasty provided strict selection criteria are met. The manuscript is suitable for the readers.

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Retrospective Study

Role of dynamic computed tomography scans in patients with congenital cranivertebral junction malformations

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Author contributions: The manuscript was written, as well data and measurements were performed by Joaquim AF and da Silva OT; the statistical analysis was made by da Silva OT; the revision of manuscript was performed by Ghizoni E and Tedeschi H; final revision was made by all authors.

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Abstract

AIM

To evaluate the role of dynamic computed tomography (CT) scan imaging in diagnosing cranivertebral junction (CVJ) instability in patients with congenital CVJ malformations.

METHODS

Patients with symptomatic congenital CVJ malformations who underwent posterior fossa decompression and had a preoperative dynamic CT scan in flexion and extended position were included in this study. Measurements of the following craniometrical parameters were taken in flexed and extended neck position: Atlanto-dental interval (ADI), distance of the odontoid tip to the Chamberlain's line, and the clivus-canal angle (CCA). Assessment of the facet joints congruence was also performed in both positions. Comparison of the values obtained in flexion and extension were compared using a paired Student's *t*-test.

RESULTS

A total of ten patients with a mean age of 37.9 years were included. In flexion imaging, the mean ADI was 1.76 mm, the mean CCA was 125.4° and the mean distance of the odontoid tip to the Chamberlain's line was + 9.62 mm. In extension, the mean ADI was 1.46 mm (*P* = 0.29), the mean CCA was 142.2° (*P* < 0.01) and the mean distance of the odontoid tip to the Chamberlain's line was + 7.11 mm (*P* < 0.05). Four patients (40%) had facetary subluxation demonstrated

in dynamic imaging, two of them with mobile subluxation (both underwent CVJ fixation). The other two patients with a fixed subluxation were not initially fixed. One patient with atlantoaxial assimilation and C2 fusion without initial facet subluxation developed a latter CVJ instability diagnosed with a dynamic CT scan. Patients with basilar invagination had a lower CCA variation compared to the whole group.

CONCLUSION

Craniometrical parameters, as well as the visualization of the facets location, may change significantly according to the neck position. Dynamic imaging can provide additional useful information to the diagnosis of CVJ instability. Future studies addressing the relationship between craniometrical changes and neck position are necessary.

Key words: Craniovertebral junction; Dynamic imaging; Basilar invagination; Chiari malformation; Treatment

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Core tip: This study shows the importance of the dynamic image in patients with congenital craniovertebral junction anomalies. A total of ten patients with a mean age of 37.9 years were included. We could demonstrate that 40% of the patients had facetary subluxation demonstrated in dynamic imaging and two of them required surgery for craniovertebral junction due to instability. This study reported the importance of routine dynamic imaging evaluation in patients with craniovertebral junction anomalies even without evidence of instability in static computed tomography scan or magnetic resonance imaging.

da Silva OT, Ghizoni E, Tedeschi H, Joaquim AF. Role of dynamic computed tomography scans in patients with congenital craniovertebral junction malformations. *World J Orthop* 2017; 8(3): 271-277 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v8/i3/271.htm> DOI: <http://dx.doi.org/10.5312/wjo.v8.i3.271>

INTRODUCTION

Basilar invagination (BI) is a congenital craniovertebral junction (CVJ) malformation characterized by the ascension of the upper cervical spine into the skull base and can be associated with other bone anomalies, such as atlas assimilation, Klippel-Feil syndrome, condyle hypoplasia and atlanto-axial instability^[1-4]. BI is generally diagnosed when the tip of the odontoid process is at least 5 mm above the Chamberlain's line (a line traced from the posterior edge of the hard palate to the posterior margin of the foramen magnum)^[5].

Surgical treatment of BI is well accepted in the setting of clinical symptoms^[6,7]. Symptoms are usually caused

by tonsillar herniation, brainstem/upper cervical spine compression and/or CVJ instability, which should be recognized by the surgeon before planning the surgical strategy^[3,7,8].

Increased atlanto-dens interval, atlanto-axial dislocation (AAD), and the tip of the odontoid above the McRae's line (a line drawn from the basion to the opisthotonos), are clear signs of CVJ instability^[8], therefore, in such cases, stabilization concomitant to neural structures decompression is generally recommended^[8,9].

However, some patients may present symptoms of BI with a relative normal or near normal CVJ alignment^[4]. For those patients, dynamic cranovertebral junction computed tomography (CT) scans with sagittal reconstructions can provide detailed information about the facet joints and CVJ alignment, as well as showing abnormal motion of the CVJ suggestive of instability.

Dynamic imaging (such as CT or magnetic resonance imaging in flexion and extension) is commonly used in traumatic spinal diseases, although the literature is relative scarce about its use in CVJ malformations^[10]. Considering the potential benefits of dynamic CT scans in patients with CVJ without clear and evident instability, we proposed to evaluate our experience with this exam in our practice.

MATERIALS AND METHODS

We performed a retrospective study of our database of patients with CVJ who underwent surgical treatment from 2010 to 2016 by the same surgeon (AFJ).

Inclusion criteria

Symptomatic congenital CVJ malformation: Chiari Malformation (CM), characterized by tonsillar herniation through the foramen magnum or BI with or without CM who underwent posterior fossa decompression; age > 15 years old (younger patients have incomplete ossification of the region and were excluded)^[11]; a complete sagittal CT scan of the CVJ in flexion and in extension (a head holder was used to flex the neck and a pad roll was placed below the shoulders for the extended position); non evident AAD or facet subluxation on static radiological exams.

Patients were followed by the same surgeon (AFJ). Neurologic status (pre and post-surgery as well as during the follow-up) was assessed using the Nürick scale (Table 1)^[12,13]. Complications were described in details. Statistical analysis was performed using a paired Student's *t*-test - considering statistical significance a *P* value < 0.05. Analysis was made using the software Stata/MP version 13.0 for Windows (StataCorp/LP®). This study was approved by our Institutional Review Board (CAAE: 49070915.9.0000.5404).

Radiologic measurement

The radiological data were assessed by two authors together (OTS and AFJ). The acquisition of images

Table 1 Nurick score

0	Root involvement. No spinal cord disease
1	Signs spinal cord disease without restriction in walking
2	Difficulty in walking without impact on employment
3	Difficulty in walking with impact on employment
4	Walk only with aid or walker
5	Bedridden or chair bound

was performed in 64-row multidetector CT (Anquilion 64, Toshiba Medical Systems®). The images were reconstructed in 0.5 mm thick slices and analyzed in bone window settings, length 300 Hounsfield and width 2500 Hounsfield.

The measurements were performed in an imaging workstation and all images were downloaded in DICOM format and the measurements were performed using the PACS Aurora 2 (Pixon Medical System, version: 1.9.2)®. The measurements were assessed in both positions (flexion and extension), in sagittal view, following the criteria adopted by the study of Batista *et al*[14], as it follows: Atlanto-dental interval (ADI): Measured from the posterior margin of the anterior arch of C1 to the anterior portion of odontoid; clivus-canal angle (CCA): The angle formed by a line drawn from the posterior line of the clivus and a line marked from the posterior margin of the body of C2; distance of the tip of the Odontoid to the Chamberlain line: The distance from the tip of the odontoid to the Chamberlain's line. Presence or absence of facet joints subluxation of the occipital-lateral masses of the atlas and the atlanto-axial joints; diagnosis of clivus hypoplasia: Adopted when the clivus had less than 36.6 mm (less than 2σ of the mean of the normal population)[1].

RESULTS

Thirty patients with congenital CVJ malformations were operated from 2010 to 2016 by the senior author (AFJ) at our institution. A total of ten patients had complete dynamic exams and were included according our inclusion criteria. The mean age of our population was 37.9 years (ranging from 15- to 56-year-old). Five patients (50%) were male and five were female (50%). Table 2 summarizes the clinical data of the patients.

All patients had some degree of tonsillar herniation (mean of 10.04 mm below the McRae line, ranging from 5 to 15.19 mm). Seven patients (70%) had also the diagnosis of BI (with the tip of the odontoid above at least 5 mm the Chamberlain's line).

The mean pre-operative Nurick grade was 2.8 (ranging from 1 to 5). The mean post-operative Nurick grade was 1.9 (ranging from 1 to 3), after a mean follow-up of 18.1 mo (ranging from 1 to 38 mo).

Treatment consisted in posterior fossa decompression with removal of the posterior arch of C1 in all cases. In all cases, duroplasty was performed, but only two cases had also tonsillar resection due to the severity of the tonsillar herniation. Two patients underwent concomitant

occipito-cervical fixation because they presented a mobile atlantoaxial subluxation on dynamic images, as explained below.

Bone anomalies

The main bone anomaly associated with BI was clivus hypoplasia. Five patients had clivus hypoplasia, four patients had atlas assimilation and two patients had a C2-C3 fusion (Table 3).

Dynamic CT scans measurements

Flexion CT scan: The mean CCA was 125.4° (ranging from 92° to 146°), with a ADI of 1.76 mm (ranging from 0.36 to 5.67 mm) and a mean distance of the odontoid tip to the Chamberlain's line of 9.62 mm above it (ranging from 0 to +22.86 mm). In the group with seven patients that also had the diagnosis of BI, the mean distance of the tip of the odontoid to the Chamberlain's line was +13.32 mm (ranging from +6.6 to +22.86 mm) and the mean CCA was 118.4° (ranging from 92° to 134°). One patient surgically treated at a different institution had a previous posterior fossa decompression and the Chamberlain's line was not accessed.

Extended CT scan: The mean CCA was 142.2° (ranging from 108° to 176°), with the mean ADI of 1.46 mm (ranging from 0.36 to 3.12 mm) and a mean distance from the tip of the odontoid to the Chamberlain's line was 7.11 mm above it (ranging from less than -5 mm to up to 19.34 mm). In the six patients with BI, the mean distance from the odontoid tip to the Chamberlain's line was 11.72 mm above it (ranging from 4 to 19.34 mm above it) and the mean CCA was 135.28° (ranging from 108° to 161°).

Facet dislocation

Four patients had some facet joints subluxation at the atlanto-axial region. Two of these patients underwent a crano-cervical fixation due to their mobile subluxation: One patient had an increased facet subluxation in extension, from 4 to 7 mm, without changing the ADI distance and the other had an increased ADI in flexion, from 2.94 to 5.67 mm (Figure 1). The other two cases were treated initially without occipito-cervical fixation because their facet joints did not change on flexion and extension CT scan (Figure 2).

During the study follow-up, another patient who had BI and a congenital C2-C3 fusion developed latter cervical pain and dizziness when flexing the neck. A new dynamic CT scan was performed two years after posterior fossa decompression who had demonstrated a new atlanto-axial subluxation with dynamic change of 3.7 mm in the atlanto-axial right facet joint from flexion to extension. Additionally, this same patient also had an increased ADI varying from 1.51 mm in extension to 3.86 mm in flexion. We considered that she developed a postoperative instability and surgical fixation was proposed, but she refused it because she had a severe depression and familiar problems (Figure 3).

Table 2 Patients main characteristics according to clinical status, follow-up and radiological parameters analyzed

No.	Gender	Nurick pre	Nurick post	Follow-up (mo)	Pathology	Clivus hypoplasia	Atlas assimilation	Treatment	Tonsillar herniation
1	38	4	2	38	BI + Chiari	Present	Absent	PFD + Duropl	14.95
2	35	3	2	30	BI + Chiari	Present	Absent	PFD + Duropl	15.19
3	15	2	1	21	BI + Chiari	Absent	Absent	PFD + Duropl + Tonsilec	9.4
4	29	2	1	30	Chiari I	Absent	Absent	PFD + Duropl	11.45
5	20	2	2	6	BI + Chiari	Present	Present	PFD + Duropl	11
6	40	2	1	14	BI + Chiari	Present	Present	PFD + Duropl	5
7	48	4	3	28	BI + Chiari	Absent	Present	PFD + Duropl + OCFix	7
8	56	5	3	8	BI + Chiari	Present	Present	PFD + Duropl + OCFix	N/A
9	52	1	1	5	Chiari I	Absent	Absent	PFD + Duropl	9
10	46	3	3	1	Chiari I	Absent	Absent	PFD + Duropl	7.44
M	37.9	2.8	1.9	1654					10.04

M: Mean; BI: Basilar invagination; PFD: Posterior fossa decompression; Duropl: Duroplasty; Tonsilec: Tonsillectomy; OCFix: Occipito-cervical fixation; N/A: Not available.

Table 3 Description of the main radiological characteristics obtained in flexion and in extension sagittal computed tomography scan

N	Flexion position				Extension position			
	ADI	CCA	Facet dislocation	Chamberlain	ADI	CCA	Facet dislocation	Chamberlain
1	1.5	92°	Absent	+22.86	1.25	131°	Absent	+19.43
2	1.72	134°	Absent	+6.6	1.72	155°	Absent	+4.76
3	1.18	115°	Right side - 4 mm	+9.95	1.18	127°	Right side - 4 mm	+10.86
4	1.75	141°	Absent	0	1.75	155°	Absent	-3.7
5	0.5	120°	Absent	+20	0.6	125°	Absent	+19.3
6	3.27	130°	Absent	+12.28	3.12	140°	Absent	+12.11
7	5.67	130°	Left side - 2 mm	+8.26	2.94	161°	Right side - 3 mm	+4
8	1	108°	Right side - 4 mm	N/A	1	108°	Right side - 7 mm	N/A
9	0.36	146°	Absent	+3.97	0.36	176°	Absent	-5
10	0.7	138°	Left site 3.7 mm	+2.67	0.7	144°	Left side 3.7 mm	+2.32
M	1.76	125.4°		+9.62	1.46	142.2°		+7.11

M: Mean; ADI: Atlanto-dental interval; CCA: Clivus-canal angle; N/A: Not available.

Analysis of flexion vs extension

Comparing the differences of the measurements of the clivus canal angle and the distance of the tip of the odontoid to the Chamberlain's line in flexion and extended position were statistically significant ($P < 0.01$ and 0.03, respectively), but for the ADI the difference was not observed ($P = 0.29$).

DISCUSSION

Panjabi *et al.*^[15] defined stability as the ability of the spine to maintain, under physiologic loads, the relationships between the vertebrae without resulting in pain, deformity or neurological compression. When specifically dealing with the mobile and complex CVJ, the criteria for instability are still debated^[4]. According to the most recent studies, in patients with clear AAD, stabilization is mandatory. However, the indications for craniocervical fixation in patients with tonsillar herniation without AAD are controversial^[2,6,8,16].

In congenital CVJ anomalies, instability may be secondary to bone hypoplasia, ligament and musculature laxity, and also by abnormal facet joints configuration that allows abnormal motion^[16,17]. The instability may be not visualized in static radiological exams. In our series of ten patients, four had dynamic changes in the facet joints

and one had late instability also well documented in flexion-extension CT scans, emphasizing the importance of adding this radiological modality in current investigation of congenital CVJ anomalies. Potential advantages of CT scans over plain radiographs include a better visualization of the facet joints and 3D reconstruction that allows better surgical planning and provides detailed anatomical visualization^[18].

Additionally, in this study, we also analyzed the basic craniometry using dynamic CT. The mean CCA was 125.4° in flexion and 142.2° in extended position, with a mean difference of 16.8° ($P < 0.01$). This emphasizes the importance of proper positioning during occipito-cervical fusions. In the plain radiographs era, Smoker *et al.*^[19] had demonstrated that this angle changed about 30° from flexion to extension neck position, also reporting that normal range varied from 150° to 180°. Our limited variation from flexion to extension compared to the reported by Chandra *et al.*^[11] may be explained by the fact that some of our patients had clivus hypoplasia and atlas assimilation which may decrease CVJ motion when compared with normal subjects. Platysmia may lead to a lower CCA and CVJ kyphosis, with brainstem symptoms as well as compensatory subaxial hyperlordosis.

We also reported that the distance of the tip of the odontoid from the Chamberlain's line varies from flexion

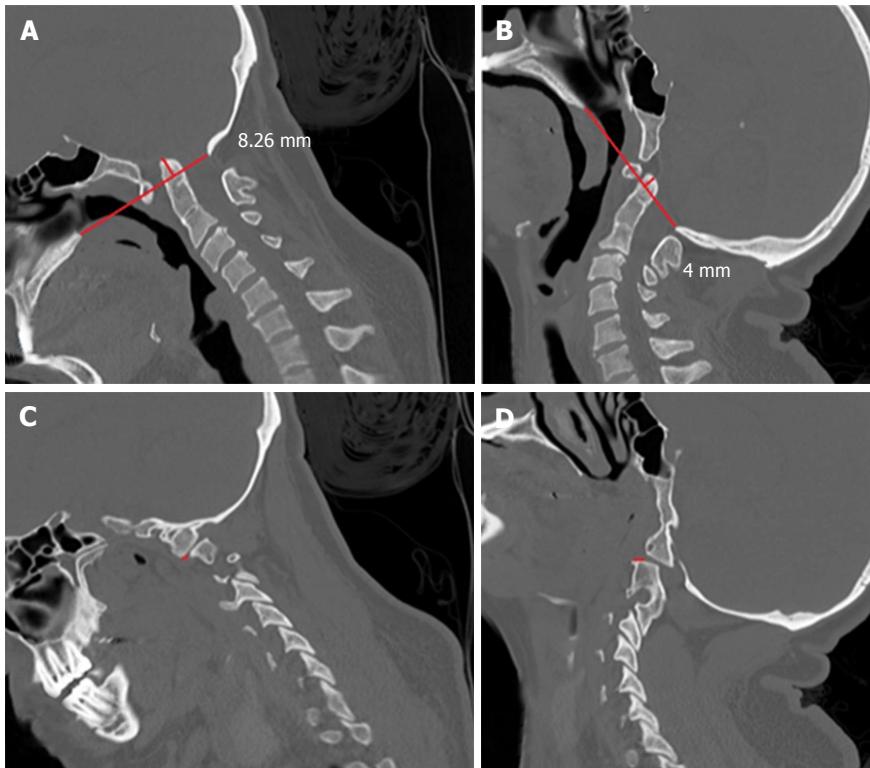


Figure 1 A 18-year-old woman with basilar invagination and tonsillar herniation of 7 mm. She also had atlas assimilation. A: Sagittal computed tomography (CT) scan in flexion shows the tip of the odontoid 8.26 mm above the Chamberlain's line; B: Sagittal CT scan in extended position shows the tip of the odontoid 4 mm above the Chamberlain's line; C: Sagittal CT scan showing anterior dislocation of the facet joint of C1 over C2 facet of 2 mm; D: Sagittal CT scan showing posterior dislocation of the C1 facet joint over the facet of C2 of 3 mm, ranging 5 mm in dynamic exam. This patient underwent a craniocervical fusion concomitant to the posterior fossa decompression.

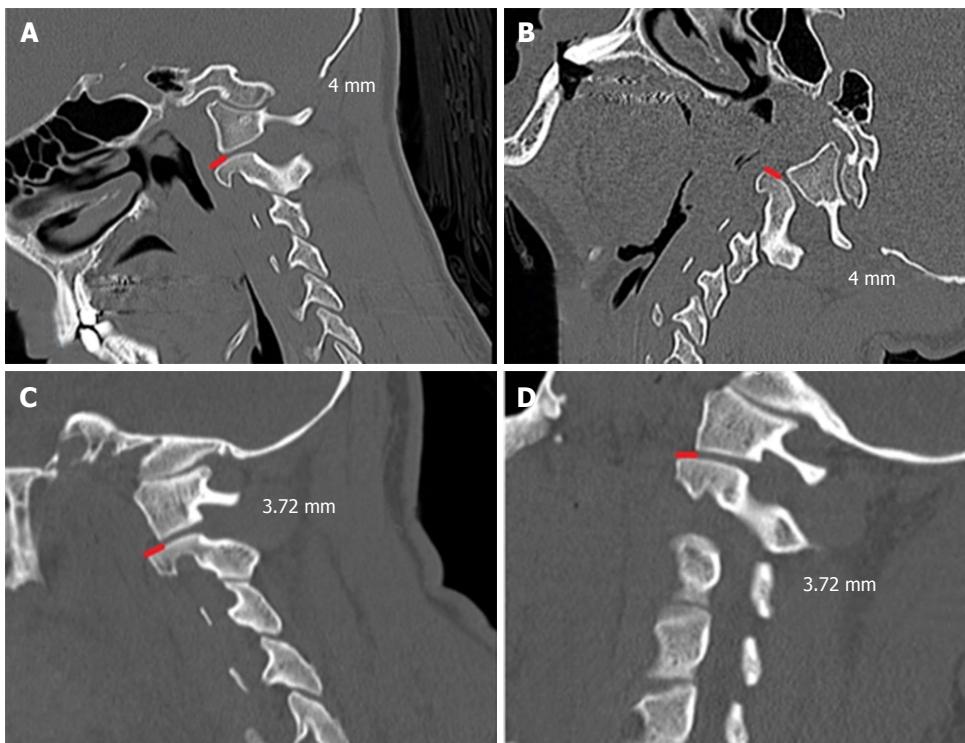


Figure 2 Dynamic sagittal computed tomography scan of 15-year-old boy, which had the diagnosis of a tonsillar herniation of 9.4 mm and basilar invagination. In both A and B positions, the facet dislocation of the C1 lateral mass posteriorly to the superior C2 joints was maintained (4 mm). We opted to perform only posterior fossa decompression without craniovertebral junction instrumentation, obtaining a good clinical improvement; C and D: Dynamic sagittal computed tomography scan imaging - a forty-six-year-old man, with tonsillar herniation of 7.44 mm. In both positions the facet dislocation of the C1 lateral mass over the C2 superior facet joint was 3.72 mm. We also performed only a posterior fossa decompression without fusion in this patient, with a good clinical outcome.

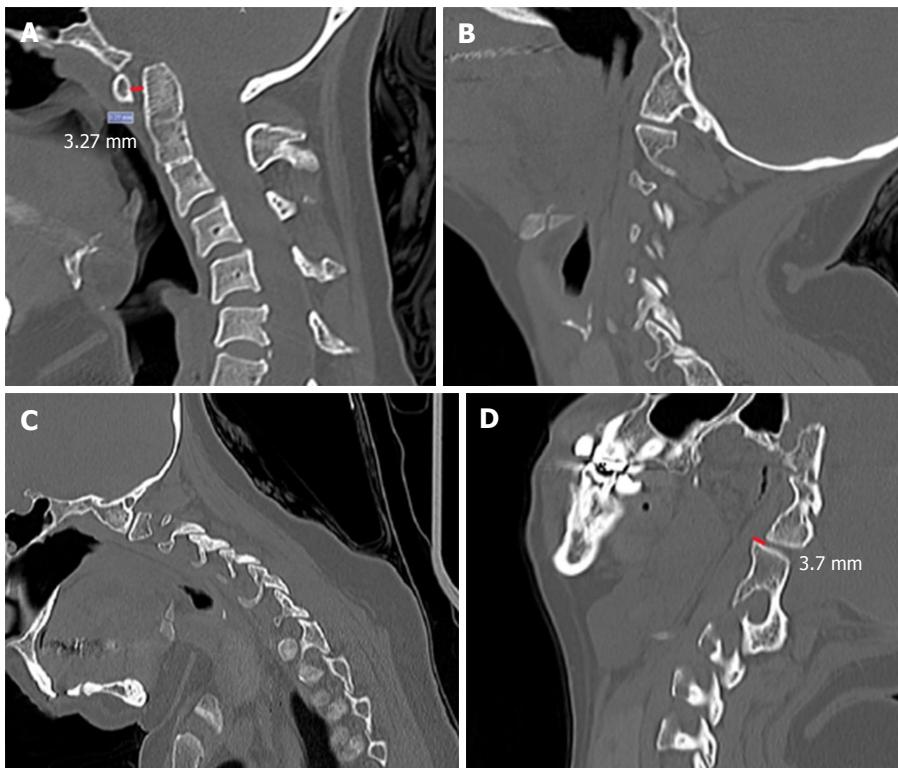


Figure 3 Forty-year-old woman with a tonsilar herniation of 5 mm and basilar invagination. Noted that she also had atlas assimilation and a congenital C2 fusion A, B and C: Pre-operative dynamic imaging, showing a atlanto-dental interval of 3.27 mm, but no signs of facet dislocation in flexion or in extension (B and C); D: Sagittal computed tomography scan obtained after some months after posterior fossa decompression showing an evident facet joints dislocation (the assimilated lateral mass of C1 was dislocated posteriorly over the superior facet joint of C2). She had some symptoms of dizziness and cervical pain when flexing the neck and an occipito-cervical fixation was proposed but the patient declined surgical treatment because she was not doing well with depression and mood disorders.

(mean of +9.62 cm above the tip of the dens) to extension (mean of +7.11 above the tip of the dens) ($P = 0.03$), which may influence the incidence of the diagnosis of BI in patients with Chiari Malformation according to patients neck position when underwent a CT scan.

In the past, Goel et al^[3,8] proposed that patients with BI without AAD required only foramen magnum decompression. In this study, we observed that some patients with tonsillar herniation but without AAD may have instability in about 20% of the cases. Additionally, these patients may develop CVJ instability after surgery (10% of the patients in the present study). Menezes et al^[20] reported that patients with Chiari Malformation, atlas assimilation and concomitant congenital C2C3 fusion may develop atlanto-axial instability after posterior fossa decompression.

Another fact is that not only facet subluxation can be visualized with dynamic exams, but also changes in the ADI, similarly to upper cervical spine trauma or rheumatoid arthritis patients. In two of our patients, we observed an increasing ADI when changing the neck position, suggesting an occult insufficient transverse ligament that may potentially result in atlanto-axial instability, cervical pain and neurological deficits. In these patients, the mean ADI was 3.03 mm in extension to 4.47 mm in flexion, with an increase of about 47.5% after changing the position. However, the differences of the

ADI in our series comparing flexion and extension were not significant ($P = 0.29$), probably because we excluded patients with evident AAD in static exams. The normal ADI obtained using CT scan in neutral position in a series of 100 patients without known CVJ anomalies varied from 0.5 to 1.7, using the exactly same methodology used in our study^[14].

We also noted that some patients (patients 3 and 10) may have mild facet joints subluxation without dynamic changes. These patients were treated with foramen magnum decompression without fixation with an acceptable clinical outcome (both had improvement of their clinical symptoms).

Our study is limited by a small case series and limited follow-up. Additionally, we excluded many patients treated in our institution for congenital CVJ malformations because they did not have a complete preoperative dynamic exam. However, to our knowledge, we could clearly demonstrate the importance of dynamic CT scan evaluation in routine treatment of patients with symptomatic tonsillar herniation. Additionally, we reported that patients with mild subluxation without dynamics change may be considered for foramen magnum decompression alone. Dynamic CT was also useful for evaluating late postoperative instability.

In conclusion, we reported the utility of dynamic CT scans in the evaluation of the best treatment modality for patients with congenital CVJ anomalies. Significant

changes were observed in the CCA and in the position of the odontoid in the cranial base. Prospective studies are necessary to evaluate the role of the radiological findings of dynamic CT scans on patients' outcome.

COMMENTS

Background

Craniovertebral junction (CVJ) congenital malformations are challenging diseases. This study aims to identify which patient has signs of CVJ instability through a dynamic computed tomography scan.

Research frontiers

Diagnostic of CJV instability in congenital disorders is still debated.

Innovations and breakthroughs

This article reported the importance of dynamic imaging evaluation of the CVJ in congenital malformation.

Applications

Decision making for surgical treatment of those patients that had CJV congenital malformations, such as Chiari I.

Terminology

Atlanto-dental interval: Measured from the posterior margin of the anterior arch of C1 to the anterior portion of odontoid; clivus-canal angle: The angle formed by a line drawn from the posterior line of the clivus and a line marked from the posterior margin of the body of C2. Distance of the tip of the Odontoid to the Chamberlain line: The distance from the tip of the odontoid to the Chamberlain's line. Presence or absence of facet joints subluxation of the occipital-lateral masses of the atlas and the atlanto-axial joints; diagnosis of clivus hypoplasia: Adopted when the clivus had less than 36.6 mm (less than 2σ of the mean of the normal population).

Peer-review

Very well designed and honest paper, worth publishing in the present form.

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Observational Study

Relationship between biological factors and catastrophizing and clinical outcomes for female patients with knee osteoarthritis

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Author contributions: Ikemoto T had conceived this research; Ikemoto T and Miyagawa H contributed equally to this work; Ikemoto T, Ushida T and Deie M did the research design; Ikemoto T, Miyagawa H and Akao M participated in the collection of the data; Ikemoto T, Shiro Y, Murotani K and Arai YCP contributed to the analysis and interpretation of the data; Ikemoto T, Shiro Y and Arai YCP prepared a first manuscript and a revised manuscript.

Institutional review board statement: The study received ethical approval from the Research Ethics Committee of Aichi Medical University, Japan (No. 12-101).

Informed consent statement: Prior to study enrollment, each subject was fully informed by the investigator 1: that content of this study and 2: that the personal information of the subject would be kept confidential.

Conflict-of-interest statement: The authors declare that there is no conflict of interest regarding the publication of this paper.

Data sharing statement: There are no additional data available.

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Abstract

AIM

To investigate the correlations between clinical outcomes and biopsychological variables in female patients with knee osteoarthritis (OA).

METHODS

Seventy-seven patients with symptomatic knee OA were enrolled in this study. We investigated the age, body mass index (BMI), pain catastrophizing scale (PCS) and radiographic severity of bilateral knees using a Kellgren-Lawrence (K-L) grading system of the subjects. Subsequently, a multiple linear regression was conducted

to determine which variables best correlated with main outcomes of knee OA, which were pain severity, moving capacity by measuring timed-up-and-go test and Japanese Knee Osteoarthritis Measure (JKOM).

RESULTS

We found that the significant contributor to pain severity was PCS ($\beta = 0.555$) and BMI ($\beta = 0.239$), to moving capacity was K-L grade ($\beta = 0.520$) and to PCS ($\beta = 0.313$), and to a JKOM score was PCS ($\beta = 0.485$) and K-L grade ($\beta = 0.421$), respectively.

CONCLUSION

The results suggest that pain catastrophizing as well as biological factors were associated with clinical outcomes in female patients with knee OA, irrespective of radiographic severity.

Key words: Osteoarthritis; Pain catastrophizing; Knee pain; Physical function; Japanese Knee Osteoarthritis Measure

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Core tip: Plenty of previous studies have focused on biological factors such as aging, gender, body mass index, ethnicity and history of knee injury for knee pain in cases where there was a discordant relationship between radiographic severity and symptoms in knee osteoarthritis (OA). However, in the present study, we found that pain catastrophizing thought was highly associated with knee-related clinical outcomes, irrespective of radiographic severity, for female patients with knee OA, especially pain severity and quality of life.

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INTRODUCTION

Knee osteoarthritis (OA) is a common problem causing knee pain and functional decline and disabilities in the elderly^[1-3]. Although there is a widespread belief of inconsistency between clinical symptoms and radiographic disease severity^[4], recent studies have revealed that knee symptoms were associated with not only disease severity but also female gender, aging, overweight and psychological factors^[5-11], in spite of the fact that these independent variables are sometimes associated with each other.

To establish comprehensive outcome measures relevant to the disabilities, the OMERACT conference first convened in 1992 (OMERACT was originally an

acronym for Outcome Measures in RA Clinical Trials, now it represents the more inclusive scope of "Outcome Measures in Rheumatology"). Several years later, a key objective of the OMERACT III conference was to establish a core set of outcome measures for OA^[12]. A consensus was reached by at least 90% of expert participants that the following 4 domains should be evaluated for knee, hip, and hand OA: Pain, physical function, patient global assessment, and joint imaging.

On the other hand, although a number of previous studies have revealed that radiographic disease severity, female gender, aging, being overweight and psychological factors such as catastrophizing thought were related to knee OA symptoms, it still remains unclear which variables best correlated with clinical disability.

It has been established that women are more sensitive to pain than men^[13], and more likely to complain of chronic musculoskeletal burden compared to men^[14]. Moreover, it has been suggested that women reported greater levels of catastrophizing with more painful symptoms than men^[15]. Recently, pain catastrophizing has been studied in patients suffering from knee OA^[11,16], and Somers et al^[16] have reported that pain catastrophizing rather than radiographic severity appears to be an important variable in understanding pain, disability, and physical function in overweight/obese patients with knee OA. Therefore, it would be important to understand the lack of relationships between the outcomes of knee OA and related variables for female patients with knee OA. Hence, the aim of the present study was to address the correlations between each of the clinical outcomes or between each outcome and relevant variables in knee OA patients with chronic pain or stiffness, limited to female participants using bivariate correlation and multivariate regression analysis. We speculated that pain catastrophizing rather than radiographic severity was a more influential factor for predicting the severity of knee pain, functional capacity, and quality of life for female patients with knee OA.

MATERIALS AND METHODS

Subjects

A previous study found relationships ($pr^2 = 0.10$) between pain catastrophizing and pain severity of knee OA patients^[16]. Based on this finding, the sample size for a power of 0.80 with two-tailed alpha at a 0.05 significance level to run a multivariate regression for seven predictors required a minimum of 74 subjects. After obtaining approval from the ethics committee, we announced research related to knee symptoms in female elderly patients 50 years of age or older from February to August 2015 and recruited participants who were interested in this study through physical-fitness center or orthopedic clinic located within Aichi Medical University. Before investigating their status, each subject was fully informed by the investigator 1: that content of this study and 2: that the personal information of the subject would be kept confidential.

Ninety-five people with chronic knee symptoms were interested in the study and they received a knee X-ray to confirm if they were eligible for the study. The eligibility criteria for this study were as follows: (1) female with knee symptoms persisting for at least three months or more; (2) 50 years old or older; (3) radiographic knee OA with a face of more than grade-2 according to the Kellgren-Lawrence (K-L) grading system on at least a unilateral knee, because most previous studies used grade-2 as a main defining feature for radiographic knee OA; and excluded (4) presence or history of major neurological disorders such as stroke and Parkinson's disease, and history of total knee arthroplasty (TKA).

In the end, we enrolled 77 female patients with knee pain in this study.

Data collection

Demographical background: First, we investigated the age, and body mass index (BMI) of the subjects. The BMI was calculated from weight and height measurements using the formula $BMI = \text{weight} (\text{in kg}) / \text{height}^2 (\text{in m}^2)$.

The K-L grading system

After investigation of the subjects' demographic background (age, BMI), they underwent a radiographic examination of both knees by posterior-anterior view in the fixed standing position by a radiological technician. To avoid assessment error, all radiographs were assessed by two orthopedic physicians together (Tatsunori Ikemoto and Machiko Akao) according to the K-L grading system that uses the following grades: 0, normal; 1, possible osteophytes only; 2, definite osteophytes and possible joint space narrowing; 3, moderate osteophytes and/or definite joint space narrowing; and 4, large osteophytes, severe joint space narrowing, and/or bony sclerosis^[17].

Previous studies related to knee OA have assessed either side, although OA often affects bilateral knees^[18] and this bilaterality may amplify the magnitude of symptoms^[19]. Firstly, we assigned the subjects into either a unilateral group or a bilateral group according to whether radiographic knee OA was observed in one side or both sides. Subsequently, we used the total score of both sides (e.g., if the right side was grade-2 and the left side was grade-1 then the total was 3) as radiographic severity because of the possibility that they have a substantial influence on the outcome measures despite asymptomatic knees^[20].

Japanese Knee Osteoarthritis Measure

The Japanese Knee Osteoarthritis Measure (JKOM) was developed to reflect the specifics of the Japanese cultural lifestyle, which is characterized by bending to the floor or standing up^[21]. The validity and reliability of JKOM has been examined by comparing it with the widely accepted QOL measure, the Western Ontario and McMaster University osteoarthritis index (WOMAC) and the 36-item short-form health survey (SF-36). The JKOM consists

of a pain rating based on a visual analogue scale (VAS) which was a 100-mm line with "no pain" at one end and "worst pain possible" at the other end and scores for a subscale of four symptoms based on a disease-specific questionnaire addressing four dimensions: "Pain and stiffness in knee", "condition in daily life", "general activities" and "health conditions", with 8, 10, 5 and 2 items, respectively. Each item is rated on an ordinal scale from 0-4, with higher scores indicating a symptom or medical condition of higher severity. The four symptom subscales can be scored separately or combined to represent the aggregated total symptoms. Lower JKOM scores indicate better QOL. We assessed the pain severity of participants in accordance with the VAS score.

Pain catastrophizing

Catastrophizing was assessed using the Pain Catastrophizing Scale (PCS). The PCS consists of 13 items that describe an individual's specific beliefs about their pain and evaluates catastrophic thinking about pain^[22].

Participants responded to each item using a Likert-type scale from 0 ("not at all") to 4 ("all the time"). The scale provides a total score and scores on 3 subscales: Rumination (4 items), magnification (3 items), and helplessness (6 items)^[23]. This scale is well known for its reliability and validity in the Japanese version^[24]. Although catastrophizing is known to be a cognitive distortion closely linked to anxiety and depression^[22], we confirmed that no subjects took anti-anxiety drugs or anti-depressants in the present study.

The timed up and go test

Timed up and go test (TUG) measures the time it takes a subject to stand up from a chair (46 cm seat height from the ground), walk a distance of 3 m, turn and walk back to the chair, and sit down^[25]. All subjects performed two trials and the superior time was used. TUG was originally established as an objective measure of physical function in the elderly population. It is also used to assess the risk of falls in older adults^[26].

Statistical analysis

Data were presented as mean and standard deviation and median because each variable resulted in not only parametric but also non-parametric distributions.

We assumed that there were three outcomes, which were pain rating, TUG, and the JKOM score as essential measures for knee OA based on the OMERACT III description. Firstly, we compared the differences in the scores of each outcome between the unilateral group and bilateral group by using the Mann-Whitney *U* test.

Subsequently, we also determined the four independent variables: Age, BMI, K-L grade, and PCS score, which were assumed to influence each clinical outcome. The relationship between each of the variables was analyzed using Spearman's correlation for bivariate regression analysis. Further analysis using a stepwise multiple linear regression was conducted to determine

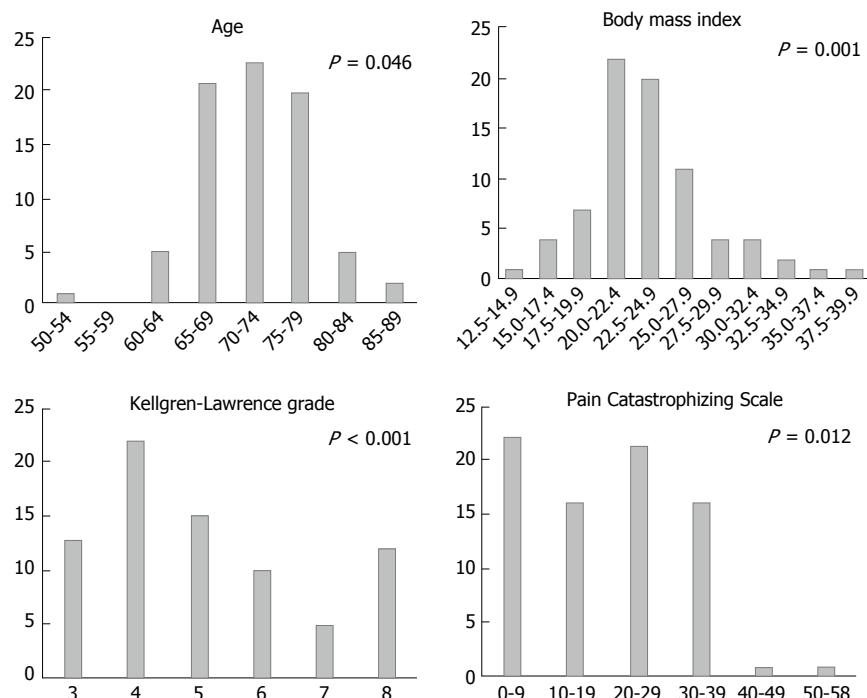


Figure 1 Distributions of the scores of each independent variable. Normality of each distribution was assessed by a Shapiro-Wilk test. The P-value within each variable indicates non-parametric distribution ($P < 0.05$).

Table 1 Characteristics of study subjects

Variables	n = 77
Age (yr)	72 (50-86)
BMI (kg/m ²)	23.7 (14.5-41.7)
K-L grade (Rt + Lt)	5 (3-8)
PCS	20 (0-50)
Pain rating (VAS)	26 (0-99)
TUG (s)	6.0 (4.1-16.5)
JKOM	18 (1-81)

Data are shown as the median (range). BMI: Body mass index; K-L grade: Kellgren-Lawrence grading system; VAS: Visual analogue scale; TUG: Timed up and go test; JKOM: Japanese Knee Osteoarthritis Measure; PCS: Pain Catastrophizing Scale.

which independent variables best correlated with the severity of each outcome measure.

For a priori power analysis, we used G*power3 software^[27] to determine sample size for study destination. Bivariate correlation analysis and multivariate regression analysis were performed with SPSS software (version 20.0J; SPSS Inc., Chicago, IL, United States). Differences were always considered significant at a level of $P < 0.05$.

RESULTS

The subject characteristics are presented in Table 1 and Figure 1 shows the distributions of the scores of each independent variable.

The subjects were assigned as follow: 17 subjects (22%) in the unilateral group; and 60 subjects (78%) in the bilateral group. Comparisons of the dichotomous groups revealed that there were no significant differences

Table 2 Comparison of each outcome between unilateral and bilateral knee osteoarthritis

Variables	Unilateral (n = 17)	Bilateral (n = 60)	P-value
Pain rating (VAS)	24 (0-95)	26 (0-99)	0.51
TUG (s)	5.5 (4.4-7.2)	6.3 (4.1-16.5)	0.02
JKOM	13 (2-35)	18 (1-81)	0.23

Data are shown as the median (range). The Mann-Whitney U test was used to compare differences between two groups. VAS: Visual analogue scale; TUG: Timed up and go test; JKOM: Japanese Knee Osteoarthritis Measure.

in severity of knee pain and JKOM scores between the unilateral group and bilateral group, while TUG was significantly faster in the unilateral group than in the bilateral group (Table 2).

The correlation coefficients (ρ) between each of the clinical outcomes or between each outcome and relevant variables using a bivariate regression analysis are shown in Table 3. Each outcome measure was significantly associated with each other. The pain rating showed significant positive correlations with K-L grade and PCS. TUG showed significant positive correlations with BMI, K-L grade, and PCS. The JKOM score showed a significant positive correlation with K-L grade and PCS.

In addition, the results of a stepwise multiple linear regression analysis for each outcome measure are shown in Table 4. We found that the significant contributor to a pain rating was PCS ($\beta = 0.555$) and BMI ($\beta = 0.239$), to TUG was K-L grade ($\beta = 0.520$) and PCS ($\beta = 0.313$), and to a JKOM score was PCS ($\beta = 0.485$) and K-L grade ($\beta = 0.421$), respectively.

Table 3 Spearman's correlation coefficients between each variable

	Age	BMI	K-L grade	PCS	Pain rating	TUG	JKOM
Age	1.000	-0.144	0.100	-0.023	-0.079	0.170	-0.017
BMI		1.000	0.322 ^b	0.084	0.212	0.257 ^a	0.046
K-L grade			1.000	0.182 ^d	0.281 ^a	0.587 ^d	0.467 ^d
PCS				1.000	0.574 ^d	0.404 ^d	0.594 ^d
Pain rating					1.000	0.487 ^d	0.721 ^d
TUG						1.000	0.588 ^d
JKOM							1.000

Value (ρ): Correlation coefficient. Small letters show the statistical significance: ^a $P < 0.05$, ^b $P < 0.01$, ^d $P < 0.001$. BMI: Body mass index; K-L grade: Kellgren-Lawrence grading system; PCS: Pain Catastrophizing Scale; TUG: Timed up and go test; JKOM: Japanese Knee Osteoarthritis Measure.

DISCUSSION

In the present study, although there is some disagreement regarding our speculation, pain catastrophizing has been highly associated with knee-related clinical outcomes for female patients with knee OA, especially pain severity and QOL score. To our knowledge, this is the first report that comprehensively investigates the relationships between knee OA related outcomes and related factors limited to female samples.

Knee pain with OA is known as a cause of disabilities among older adults as well as low back pain^[28,29]. Knee pain is also an important outcome for patients with knee OA. However, previous studies have focused on biological factors such as aging, gender, BMI, ethnicity and history of knee injury for knee pain in cases where there was a discordant relationship between radiographic severity and symptoms^[4,30]. On the other hand, recent studies have suggested that there were apparent relationships between pain catastrophizing and physical disabilities as well as pain severity in both pediatric and adult patients with musculoskeletal disorders^[11,31,32]. Moreover, Forsythe *et al*^[33] have reported that preoperative PCS scores predicted the presence of postoperative pain in patients who received TKA for primary knee OA.

In the present study, we found no interrelationships between pain catastrophizing and age, BMI and radiographic severity, while pain catastrophizing was a significant predictor which correlated with pain severity, and disease-specific QOL scores in female patients with knee OA, irrespective of disease severity. This finding is not only consistent with a previous report^[16], but also suggests that pain catastrophizing is an important factor rather than aging, and body weight associated with physical disabilities in female patients with knee OA, if radiographic severity is progressive.

The term catastrophizing was originally introduced by Ellis^[34] and subsequently adapted by Beck *et al*^[35] to describe a mal-adaptive cognitive style employed by patients with anxiety and depressive disorders. Keefe *et al*^[36] found a high test-retest correlation between catastrophizing thought during a 6-mo period in patients

with rheumatoid arthritis, and suggested it was invariable. Three prospective studies of TKA have included measures of catastrophizing in their test batteries^[31,37,38]. In these studies, catastrophizing scores did not significantly decline over time despite reduced pain in study participants and therefore it could be a personality trait such as neuroticism. By contrast, Wada *et al*^[39] recently reported that a change in pain intensity was associated with a change in catastrophizing for patients with TKA during a 6-mo follow-up. Furthermore, a number of studies have examined whether pain catastrophizing is an active cognitive process variable in multidisciplinary pain treatment settings, and have shown that pre-to post-treatment reductions in pain catastrophizing are associated with reductions in pain severity^[40-42]. Indeed, Marra *et al*^[43] have reported that multidisciplinary intervention for knee OA was superior to usual care with an educational pamphlet in terms of overall improvements, pain and function scores according to the Western Ontario and McMaster Universities' Osteoarthritis Index.

Besides, in the present study, TUG as an index of moving capacity was associated with not only disease severity but also pain catastrophizing after adjusting for BMI. We found that a correlation coefficient between TUG and K-L grade was higher than that between TUG and pain rating. This indicates that an assessment of bilateral knees may predict the moving capacity in female patients with knee OA, irrespective of pain severity. While a significant relationship between moving capacity and catastrophizing was consistent with a report by Somers *et al*^[16], the underlying mechanism, which can explain the correlation between them, is still unknown. Perhaps, pain-related fear may be related to physical performance with effort (*i.e.*, walking fast) in chronic pain^[16,44].

Taken together, this study suggests that clinicians should make sure to include an assessment of radiographic severity bilaterally and pain catastrophizing to explain the outcome measures in female patients with knee OA. This is because they may be able to improve both functional capacity and symptoms even at a progressive stage without knee arthroplasty by psychological intervention, which ameliorates mal-adaptive cognition in patients with high catastrophizing thought.

Several limitations should be taken into account when interpreting our data. Firstly, this was a cross-sectional study, therefore causal relationships between each outcome score and related variables could not be identified. Further longitudinal investigation is necessary to identify the interactions between the chronology of outcome measures and changes in variables. Secondly, the severity of radiographic OA was only assessed by posterior-anterior view in this study, although knee joints consisted of three components. Lanyon *et al*^[45] have reported that 24% of patients with radiographic knee OA was missed by not visualizing the patella-femoral joint. Thirdly, although we assess biological and psychological factors as influential variables on the outcome in knee OA, we didn't evaluate the strength of the quadriceps, which has been consistently associated with knee pain

Table 4 Multiple linear regression analysis of factors associated with each outcome

Outcome	Independent variables	R ²	Unstandardized coefficients: B	95%CI for B	β	P-value
Pain rating	BMI	0.397	0.162	0.039-0.284	0.239	0.010
	PCS		0.139	0.093-0.184	0.555	< 0.001
TUG	K-L grade	0.431	0.638	0.419-0.856	0.52	< 0.001
	PCS		0.053	0.023-0.082	0.313	0.001
JKOM	K-L grade	0.492	4.556	2.737-6.374	0.421	< 0.001
	PCS		0.719	0.470-0.968	0.485	< 0.001

TUG: Timed up and go test; JKOM: Japanese Knee Osteoarthritis Measure; BMI: Body mass index; K-L grade: Kellgren-Lawrence grading system; PCS: Pain Catastrophizing Scale.

and disabilities^[46]. Furthermore, we didn't evaluate the patient's background such as underlying disease, educational level and previous treatment which might be associated with clinical outcome. Finally, we have emphasized catastrophizing for the outcome and mentioned the possibility of improving catastrophizing thought in patients with chronic pain by a multifaceted intervention. However, there is little consensus on the effectiveness of a cognitive-behavioral intervention for knee OA pain^[47]. Hence, we must attempt to ameliorate these limitations and conduct a further investigation into whether an intervention to catastrophizing in relation to knee pain can improve the clinical outcomes for the female patient with knee OA.

This study showed that pain catastrophizing was a significant predictor which correlated with pain severity, physical function, and disease-specific QOL scores in female patients with knee OA, irrespective of disease severity. This finding suggests that pain catastrophizing is an important factor to explain knee symptoms and disabilities in female patients with knee OA.

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COMMENTS

Background

There is a widespread belief of inconsistency between clinical symptoms and radiographic disease severity in knee osteoarthritis (OA). Recent studies revealed that knee symptoms were associated with not only disease severity but also female gender, aging, overweight and psychological factors. However, there is little evidence reporting comprehensive relationships between biological and psychological factors and severity of symptoms in female patients with knee OA.

Research frontiers

Although a recent study has suggested that pain catastrophizing thought, as a psychological factor for pain symptoms, was associated with functional capacity as well as severity of knee pain in patients with knee OA, to what extent this psychological factor contributes to the severity of symptoms in female patients with knee OA, is still poorly understood. The research hotspot is to introduce

the contributing degrees of both biological and psychological factors to the severity of symptoms in female patients with knee OA.

Innovations and breakthroughs

Knee pain is an important outcome for patients with knee OA. However, previous studies have focused on biological factors such as aging, gender, body mass index (BMI), ethnicity and history of knee injury for knee pain in cases where there was a discordant relationship between radiographic severity and symptoms. On the other hand, the study revealed that pain catastrophizing has been highly associated with knee-related clinical outcomes for female patients with knee OA, irrespective of disease severity, especially pain severity and QOL score. To our knowledge, this is the first report that comprehensively investigates the relationships between knee OA related outcomes and related factors limited to female samples.

Applications

This study suggests that clinicians should make sure to include an assessment of pain catastrophizing as well as radiographic severity to explain the outcome measures in female patients with knee OA, because they may be able to improve both functional capacity and symptoms even in a progressive stage without knee arthroplasty by psychological interventions which ameliorate maladaptive cognition in patients with high catastrophizing thought.

Terminology

The term "catastrophizing" was originally introduced by Albert Ellis and subsequently adapted by Aaron Beck to describe a mal-adaptive cognitive style employed by patients with anxiety and depressive disorders. In the present study, catastrophizing was assessed using the Pain Catastrophizing Scale (PCS) invented by Sullivan et al (1995). The PCS consists of 13 items that describe an individual's specific beliefs about their pain and evaluates catastrophic thinking about pain.

Peer-review

The authors investigated the factors associated with clinical outcomes in female patients with knee OA. They concluded that pain catastrophizing scores well correlated with ADL scores and gait ability. The manuscript was concise and well written.

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Hip resurfacing arthroplasty complicated by mismatched implant components

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Abstract

Metal-on-metal hip resurfacing has gained popularity as a feasible treatment option for young and active patients with hip osteoarthritis and high functional expectations. This procedure should only be performed by surgeons who have trained specifically in this technique. Preoperative planning is essential for hip resurfacing in order to execute a successful operation and preview any technical problems. The authors present a case of a man who underwent a resurfacing arthroplasty for osteoarthritis of the left hip that was complicated by mismatched implant components that were revised three days afterwards for severe pain and leg length discrepancy. Such mistakes, although rare, can be prevented by educating operating room staff in the size and colour code tables provided by the companies on their prostheses or implant boxes.

Key words: Hip resurfacing; Mismatch; Revision

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Core tip: The authors present a case of a man who underwent a resurfacing arthroplasty for osteoarthritis of the left hip that was complicated by mismatched implant components that were revised three days afterwards for severe pain and leg length discrepancy. Such mistakes,

although rare, can be prevented by educating operating room staff in the size and colour code tables provided by the companies on their prostheses or implant boxes.

Calistri A, Campbell P, Van Der Straeten C, De Smet KA. Hip resurfacing arthroplasty complicated by mismatched implant components. *World J Orthop* 2017; 8(3): 286-289 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v8/i3/286.htm> DOI: <http://dx.doi.org/10.5312/wjo.v8.i3.286>

INTRODUCTION

Metal-on-metal hip resurfacing has gained popularity as a feasible treatment option for young and active patients with hip osteoarthritis and high functional expectations. This procedure is more technically challenging than routine total hip replacement, mainly for surgeons new to the procedure and it should only be performed by surgeons who have trained specifically in this technique. The learning curve is known to be longer than in other hip arthroplasty procedures and is expected to be more than 50-70 surgeries^[1,2]. During the learning curve the surgeon should follow the technique thoroughly. Preoperative planning is essential for hip resurfacing^[3]. This step is important to help the surgeon perform a successful procedure and preview any technical problems.

The correct placement of both acetabular and femoral components is critical for the optimal functioning of the bearings. A smooth surface and perfect clearance are the key factors for the bearing, but equally important is the need for optimal placement to ensure good clinical results. High abduction angles and impingement will lead to early wear of the metal-on-metal articulation^[4]. The problem of malpositioned components is becoming increasingly recognized as the cause of premature failure. An unusual cause for failure is the accidental implantation of mismatched components^[5]. One such case is described below.

CASE REPORT

In July 2007, a 51 years old man was admitted at the ANCA Medical Centre in Gent with a mismatch of implants. Three days prior, at another hospital, the patient underwent a resurfacing arthroplasty for osteoarthritis of the left hip, with a posterior approach assisted with computer navigation (Brainlab®). A Birmingham Hip Resurfacing (Smith and Nephew, Memphis, Tennessee) was used. In the recovery room, the patient complained of severe pain and a rigid immobility of the hip that did not disappear the day after surgery. The patient at clinical examination presented a flexion contracture on the right side and pain in the groin. X-rays confirmed a mismatch between the femoral and the acetabular component diameters (Figure 1). A size 56-mm cemented femoral component was combined with a size 62-mm cementless

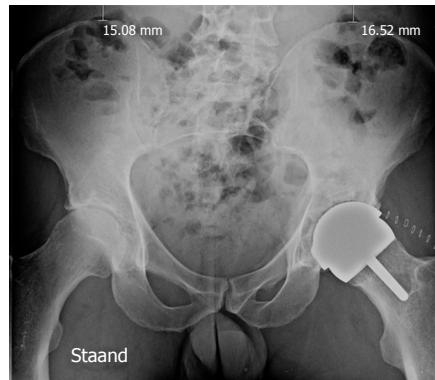


Figure 1 The post-operative X-ray, showed a mismatch between the femoral and the acetabular component diameters.

acetabular component thick shell that should have been applied with a 54-mm head instead of a 56-mm head.

The patient was treated with a revision to total hip arthroplasty two days later with the same posterolateral approach. The femoral component was revised with a Profemur L stem (Wright Medical Technology, Arlington, Tennessee, United States) and the socket was replaced by a Pinnacle™ Acetabular Cup System (DePuy Orthopaedics, Inc., Warsaw, United States) with Delta on Delta Biolox Ceramic couple 36 mm. Routine post-operative thrombo-prophylaxis was carried out. He experienced no pain and was allowed full weight bearing the day after revision surgery. The patient experienced an ordinary postoperative course and was habitually followed up in outpatient clinic.

The implants were analysed using a coordinate measuring machine to measure both components. This confirmed the size mismatch; the femoral component was 55.75 mm while the acetabular component was 54.054 mm. The coordinate measuring machines (CMM) map indicated damage to the femoral component (Figure 2). The effect of the mismatched sizing is demonstrated by comparing the removed components to a correctly sized set using a 54-mm femoral component obtained from the retrieval lab (Figure 3).

DISCUSSION

There is a decreasing demand and interest from orthopaedic surgeons for hip resurfacing arthroplasty. Consequently, from a peak of 14 implant manufacturers, currently only 8 different MOM hip resurfacing implants are available for use in clinical practice in Britain and Europe. For each design, there can be special sizes with different increments.

To help operating room staff to select the appropriately matched implants, some manufacturers provide a colour chart to show the size of the femoral head that the surgeon can match with the corresponding different acetabular sizes, with the same colour code.

In this present case report, despite various colour codes, the improper components were selected during

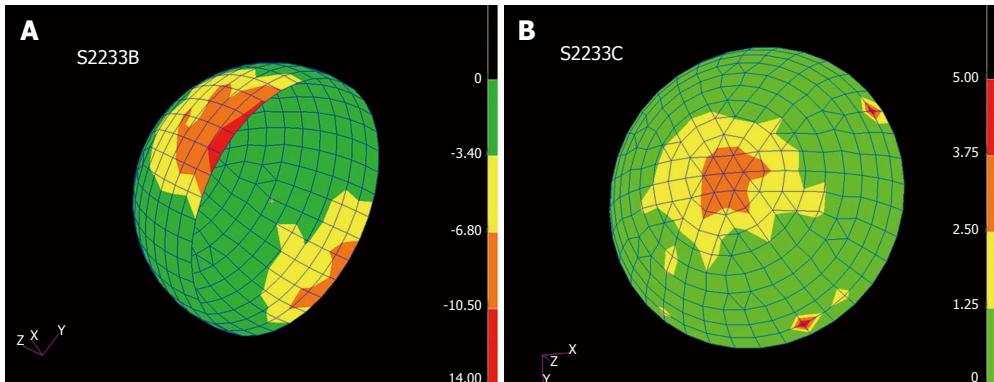


Figure 2 Coordinate measuring machines wear measurement of the mismatched couple showed that the femoral component had already been damaged.

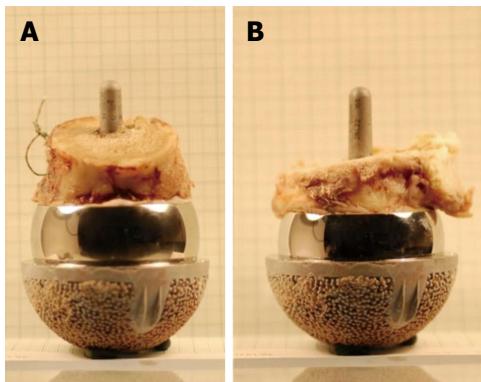


Figure 3 The 62-mm cup mismatched with a 56-mm head and but correctly matched with a 54-mm head. A: Mismatched couple with 62-mm cup and 56-mm head. Note how the femoral head was not fully seated in the socket by 3 to 4 mm. Compared to B; B: The same 62-mm thick shell cup correctly matched with a 54-mm head.

the case. The thin shell component, cup size 62-mm was requested but the 62-mm thick shell which can be used only with a 54-mm head was mistakenly provided instead. This thick shell is a special acetabular component that can be used for particular cases of head/neck mismatch or hip articulation deformity such as coxa profunda and protrusion acetabuli.

In the literature, Hanks *et al*^[6] reported this technical complication in total hip arthroplasty; in two cases the head size of the femoral component was larger than the corresponding inner diameter of the acetabular cup. The author suggests that the error can be prevented with a careful preoperative planning and appropriate selection of implants.

Morlock *et al*^[7] published on a mismatched zirconium/aluminium oxide couple with high wear in a total hip arthroplasty in a patient that had a squeaking noise but with good clinical function. No signs of loosening were detected on the radiograph. The revision was performed 42 mo after the first surgery. The analysis of the retrievals showed that the cup had large deviations from an ideal sphere but minor wear signs and the head revealed heavy local damage in the articulation zone resulting in high stress concentrations and increased wear of the zirconium head.

One of the advantages of hip resurfacing is an easier conversion to a secondary procedure if failure occurs^[8]. In this case an early revision was necessary for the pain and leg length difference the patient was experiencing. The retrieval analysis of this case revealed no clear damage to the acetabular component but there was damage to the femoral component. More importantly, lack of proper contact between the ball and the cup presented the risk of high wear with metallosis if the mismatched components had been allowed to be used. It has also been established that wear and degradation particles are released into the periprosthetic tissues and transported systemically throughout the body^[9]. Furthermore, there was also a risk that the increased torque between the mismatched bearings could have compromised fixation and stability.

Operating room staff needs to be reminded to pay careful attention to component size markings, particularly in the designs where more acetabular component sizes exist for one femoral component size. Implants also only can be matched if they are from the same manufacturer. The tight clearance specifications that make these implants work well can be dramatically mismatched if implants from different manufacturers are mixed. As seen in the present case, some implants labelled or marked as 55-mm head (nominal size), are in reality 55.5-mm. If these are matched with a real 55 mm internal diameter cup from another design we would have an equatorial mismatch with all of the attendant complications and high wear.

Care should be taken in the theatre to provide the surgeon with the correct implants. Mistakes only can be prevented by a well trained team of nurses and assistants, and they must be familiar with the size and colour code tables provided by the company on the prostheses or implant boxes. All companies should provide the surgeons with a chart that shows all different increments of the femoral head and cup sizes that can be matched together.

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COMMENTS

Case characteristics

A 51-year-old man was admitted at our institution with a mismatch of implants.

Clinical diagnosis

The patient at clinical examination presented a flection contracture on the right side and pain in the groin.

Laboratory diagnosis

Coordinate measuring machines (CMM) wear measurement of the mismatched couple showed that the femoral component had already been damaged.

Imaging diagnosis

X-ray.

Treatment

The patient was treated with a revision to total hip arthroplasty two days later with the same posterolateral approach. The femoral component was revised with a Profemur L stem (Wright Medical Technology, Arlington, Tennessee, United States) and the socket was replaced by a Pinnacle™ Acetabular Cup System (DePuy Orthopaedics, Inc., Warsaw, United States) with Delta on Delta Biolox Ceramic couple 36 mm.

Term explanation

CMM is a technique that has been widely used for dimensional inspection of complex shaped objects both for evaluating their shape which can be used to estimate wear distribution over the surface.

Peer-review

The authors reported a case of a patient underwent a hip resurfacing arthroplasty for osteoarthritis of the left hip that was complicated by mismatched implant components. They also reported the results of the patient treated with a revision to

total hip arthroplasty two days later. As a typical case report, it could be accepted for publication.

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