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EDITORIAL

Mixed reality for visualization of orthopedic surgical anatomy

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Abstract

In the modern era, preoperative planning is substantially facilitated by artificial reality technologies, which permit a better understanding of patient anatomy, thus increasing the safety and accuracy of surgical interventions. In the field of orthopedic surgery, the increase in safety and accuracy improves treatment quality and orthopedic patient outcomes. Artificial reality technologies, which include virtual reality (VR), augmented reality (AR), and mixed reality (MR), use digital images obtained from computed tomography or magnetic resonance imaging. VR replaces the user's physical environment with one that is computer generated. AR and MR have been defined as technologies that permit the fusing of the physical with the virtual environment, enabling the user to interact with both physical and virtual objects. MR has been defined as a technology that, in contrast to AR, enables users to visualize the depth and perspective of the virtual models. We aimed to shed light on the role that MR can play in the visualization of orthopedic surgical anatomy. The literature suggests that MR could be a valuable tool in orthopedic surgeon's hands for visualization of the anatomy. However, we remark that confusion exists in the literature concerning the characteristics of MR. Thus, a more clear description of MR is needed in orthopedic research, so that the potential of this technology can be more deeply understood.

Key Words: Orthopedic surgery; Mixed reality; Anatomy; Augmented reality; Three-dimensional visualization technologies; Artificial reality technologies

Core Tip: Mixed reality could be a valuable tool in orthopedic surgeon's hands for visualization of anatomy, but a more clear description of this technology is needed in

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INTRODUCTION

In the modern era, surgical planning is substantially facilitated by artificial reality technologies, which permit a better understanding of patient anatomy, thus increasing safety and accuracy[1]. Among artificial reality technologies, virtual reality (VR) has been defined as a technology that completely replaces the user's physical environment with one that is computer generated[2]. Augmented reality (AR) enables specific devices, to fuse digital models with physical objects and allow for interaction with both[3]. MR, like AR, permits fusing of physical with virtual environment, but in contrast to AR, enables users to visualize depth and perspective in the virtual models [2,4]. The models are derived from preoperative images, obtained by computed tomography (CT) or magnetic resonance imaging[5]. Of these technologies, VR and AR allow for adequate visualization of orthopedic surgical anatomy, thus facilitating the performance of several types of orthopedic interventions[5]. The technologies provide surgeons with the ability to visualize patient data in real time, improve preoperative planning, and offer accuracy in performance of interventions, thus leading to upgrades of treatment quality and orthopedic patient outcomes[5]. We aimed to shed light on the role that MR can play in the perception of orthopedic surgical anatomy. We consider that, in contrast with VR and AR, the confusion that exists in the literature impedes the understanding of the value of this technology for the visualization of anatomy in orthopedic surgical procedures.

MIXED REALITY AND VISUALIZATION OF ORTHOPEDIC SURGICAL ANATOMY

In a review of the literature on the implementation of VR, AR, and MR in orthopedics Verhey *et al*[5] stated that similar to AR, an MR system produces stereoscopic images formed by combining the real world with three-dimensional (3D) virtual models[5]. It was also stated that in MR systems, virtual objects are not simply projected on real ones, as in AR, but the user can interact with both the real and digital objects. The definition, provided by Verhey *et al*[5], is different from that provided by Moro *et al* [3], according to which, AR does allow for interaction. Also, Verhey *et al*[5] argued that both MR systems and AR, produce stereoscopic images. Stereoscopic visualization has been defined as the combined view of two digital images seen separately by each eye, using special devices[6]. In contrast, monoscopic visualization comprises digital objects that can be three-dimensionally rotated but are projected on a two-dimensional screen[6]. According to the aforementioned definitions of stereoscopic visualization and AR, it can be noted that stereopsis is not an essential characteristic of AR, thus there is a disagreement with Verhey *et al*[5].

Condino *et al*[7] described an MR-based orthopedic surgery simulator for which hip arthroplasty was chosen as a benchmark for evaluation. The authors performed quantitative tests to "estimate the accuracy of the system by evaluating the perceived position of AR targets". According to Condino *et al*[7], the results of their study supported the use of MR to develop a simulator for orthopedic surgery. However, as can be concluded by the aforementioned purpose of the study, Condino *et al*[7] did not distinguish MR from AR.

Gregory *et al*[8] reported a case of a patient who underwent reverse shoulder arthroplasty performed with the aid of an MR headset. The authors noted that the system enabled accurate visualization of the patient's anatomy, which was beneficial for the safety of the procedure. A postoperative CT scan confirmed the satisfactory position of the prosthesis, and the patient experienced no peri- or postoperative complications

(Table 1). Nevertheless, in the introduction of their article, the authors stated that AR is commonly referred to as MR, thus they did not differentiate the two technologies.

Wu *et al*[9] reported a case of a patient with traumatic high paraplegia who underwent a complicated cervical spine fracture procedure with the use of MR technology. The authors noted that the MR system enabled the surgeon to clearly visualize the anatomy in the operative field, and that CT with 3D reconstruction could not adequately depict neuronal and vascular components around the fracture. However, in the introduction, the authors defined MR as "the merging of the real world and the virtual world," and did not explain the difference between MR and AR.

Wei *et al*[10] evaluated the clinical outcome of MR-assisted percutaneous kyphoplasty to treat an osteoporotic vertebral compression fracture with intravertebral vacuum cleft. It was concluded that percutaneous kyphoplasty assisted by MR provided the surgeon with accurate guidance to the intravertebral vacuum cleft area during the operation. A group of patients who underwent MR-assisted percutaneous kyphoplasty to treat an osteoporotic vertebral compression fracture with intravertebral vacuum cleft was compared with a group who underwent the same procedure with traditional C-arm fluoroscopy instead of MR. Vertebral height improvement, cement diffusion, and pain relief were significantly improved by MR assistance (Table 1). The authors stated that MR is a combination of AR and VR and that it permits accurate combination of virtual objects with the real world, without further explanation.

Wu *et al*[11] assessed the safety and accuracy of pedicle-screw placement in a 3D printed model of an upper cervical spine fracture under MR-based navigation. The authors noted that MR could effectively help surgeons visualize intraoperative anatomy, especially in complex cases involving the upper cervical spine. The authors highlighted the advantages of MR, which "generates computer graphics onto the holographic display of real scenes", and cited a study by Volonté *et al*[12]. However, Volonté *et al*[12] dealt with AR and not MR technology.

A study by Gu *et al*[13] included patients who were randomly divided in two groups. The first with MR-based lumbar pedicle-screw placement and the second with traditional screw placement. The implantation accuracy was significantly better in the first group than in the second one. Also, there was significantly less bleeding, shorter operative time, and faster recovery in the first group. One month postoperatively, the pain scores were significantly better in the first than in the second group (Table 1). The authors defined MR as a technology that combines virtual with physical objects, without further clarification.

Lei *et al*[14] performed a complicated total hip arthroplasty combining 3D printing technology with MR. It was noted that the virtual bone and other anatomical structures were accurately superimposed on the patient's body. Postoperatively, the range of motion for the hip joint was within the normal range, the patient's recovery was reported to be good, and he was discharged without obvious surgical complications (Table 1). The authors stated that "the unsatisfied accuracy of registration in MR technology is an urgent problem yet to be resolved" and cited an article by Fida *et al*[15]. However, Fida *et al*[15] reviewed the use of AR in open surgery, and both Lei *et al*[14] and Fida *et al*[15] used the terms "AR" and "MR" interchangeably.

CONCLUSION

According to the literature, MR can be a valuable tool in the orthopedic surgeon's hands for visualization of anatomy. Although the two technologies are distinct, the interchangeable use of the terms "AR" and "MR" in the orthopedic surgery literature does not permit researchers and surgeons to extract safe conclusions about the possible superiority of AR or MR. Because MR has been defined as a technology that provides depth and perspective in the virtual environment, in contrast to AR[2,4], it seems that the two technologies may have different values in perceiving orthopedic surgical anatomy. The literature suggests that the two technologies may have different anatomy teaching potential[16]. Currently, there is a lack of research to permit comparison between AR and MR in terms of their value in orthopedic surgical practice. The possible difference between the value of two technologies needs further investigation, which should proceed with a clear description of the technology under investigation and with differentiation between AR and MR.

Table 1 Studies of implementation of mixed reality for visualization of orthopedic surgical anatomy, with patient outcomes

Ref.	Operation	Effects of MR on visualization of orthopedic surgical anatomy	Patient outcomes
Gregory *et al*[8]	Reverse shoulder arthroplasty	Accurate visualization of the patient's anatomy	A postoperative CT scan confirmed the adequate position of the prosthesis, while the patient experienced no peri- or postoperative complications
Wei *et al* [10]	Percutaneous kyphoplasty to treat an osteoporotic vertebral compression fracture with intravertebral vacuum cleft	The surgeon could obtain accurate guidance to the intravertebral vacuum cleft area during the operation	Vertebral height improvement, cement diffusion and pain relief were significantly better in the MR group in comparison with the traditional C-arm fluoroscopy group
Gu *et al* [13]	Lumbar pedicle-screw placement	The implantation accuracy with the use of MR was significantly higher in comparison with traditional screw placement	Significantly less bleeding and operative time, faster recovery, significantly better pain scores at 1 month postoperatively with MR, in comparison with traditional screw placement
Lei *et al* [14]	Total hip arthroplasty	The patient's virtual bone, as well as the other anatomical structures, were accurately superimposed on the patient's body	The range of motion for the hip joint was within the normal range, while the patient's recovery was reported to be good and he was discharged without obvious surgical complications

CT: Computed tomography; MR: Mixed reality.

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MINIREVIEWS

Bicruciate-retaining total knee arthroplasty: What's new?

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Abstract

Primary total knee arthroplasty (TKA) is a widespread procedure to address end stage osteoarthritis with good results, clinical outcomes, and long-term survivorship. Although it is frequently performed in elderly, an increased demand in young and active people is expected in the next years. However, a considerable dissatisfaction rate has been reported by highly demanding patients due to the intrinsic limitations provided by the TKA. Bicruciate-retaining (BCR) TKA was developed to mimic knee biomechanics, through anterior cruciate ligament preservation. First-generation BCR TKA has not gained popularity due to its being a challenging technique and having poor survival outcomes. Thanks to implant design improvement and surgeon-friendly instrumentation, second-generation BCR TKA has seen renewed interest. This review will focus on surgical indications, kinematical basis, clinical results and latest developments of second-generation BCR TKA.

Key Words: Total knee arthroplasty; Anterior cruciate ligament; Bicruciate retaining; Knee kinematics; Second generation design; Knee osteoarthritis treatment

Core Tip: Second-generation bicruciate-retaining total knee arthroplasty (BCR TKA) is designed to overcome the historical durability issues of this implant. Recent kinematics studies point out the advantage of this design in mimicking normal knee motion.

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Second-generation BCR TKA is generally associated with a more restrictive indication range in terms of coronal alignment, anterior cruciate ligament integrity, and preoperative range of motion. Available clinical results demonstrate variable outcomes with short-term follow-up.

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INTRODUCTION

Primary total knee arthroplasty (TKA) is a widespread surgery, capable of recovering articular function and relieving pain in end-stage osteoarthritis (OA) of the knee[1]. Once considered a procedure for the elderly, primary TKA is nowadays performed frequently in younger and high-demanding patients. Specifically, in the next years, side by side with an overall consistent increase for this procedure demand, the amount of TKA implanted before 65-years-old will exceed 55% of the total procedures[2]. Moreover, along with those demographic variations, despite technical advancement and a 20-year survival rate exceeding 90%, approximately 20%[3] of patients nowadays remain unsatisfied after surgery[4]. Those results are strictly related to the post-operative ability to perform activities of daily life[5]. Clement *et al*[6] have pointed out that those activities are frequently limited by having a TKA, causing a high dissatisfaction rate (25%) mostly in highly demanding patients that consequently see their expectation not fulfilled[7].

This dissatisfaction may potentially be overcome, improving the abnormal kinematics and proprioceptive instability reported by sacrificing the anterior cruciate ligament (ACL) in posterior stabilized (PS) and cruciate-retaining (CR) design[8,9]. Several reports of studies, in fact, mention the role of the ACL in joint kinematics[10], and the paradoxical anterior femoral motion in contemporary design with cruciate sacrifice as cause of dissatisfaction[8,11]. Thus, bicruciate-retaining (BCR) TKA may represent an effective solution to overcome biomechanical concerns and patients' dissatisfaction reported after implant without ACL.

Over the years, previous BCR TKA generations have not gained widespread popularity because of its being a challenging technique and the tension of retained ligaments, the risk for potential instability from ligament failure or tibial island fracture, and inability to correct major deformities of the knee[12]. Moreover, the U-shaped tibial component may lead to component breakage or mobilization because of reduced tibial coverage area and the thin anterior tibial bar[13]. The latest BCR TKA design was developed to overcome those problems. The aim of the literature review performed for this study focuses on surgical indications, results and latest developments about second-generation BCR TKA.

HISTORICAL NOTES

The first example of cruciate-sparing prosthesis was developed by Gunston[14] in 1960: the "Polycentric Knee". This implant was composed by two semi-circular cemented femoral sliding tracks with two distinct cemented fixed tibial components. Subsequently, the Mayo clinic team created the "Geometric" knee prosthesis, to retain both cruciate, composed of two femoral components linked with a cross-bar and unique polyethylene with a bridge anteriorly to the tibial island[15]. Thanks to Townley[16] in 1972, an anatomic cemented ACL-retaining TKA was created, made of thin, bilobed, horseshoe-shaped femoral components able to limit bone resection and ligaments resection. In 1975, Cloutier *et al*[17,18] developed an anatomic prosthesis with chromium-cobalt femoral component and a U-shaped tibial baseplate with two separated tibial bearing surfaces. The major failure rate on BCR models due to tibial loosening in the early implants, the demanding technique itself and improved clinical outcome of cruciate sacrifice models reduced the interest in development of innovative

design[19]. However, recent studies highlighted the proprioceptive role of the cruciate ligaments, renewing attention in their preservation during knee arthroplasty[20].

In the last years, thanks to advances in technology, saw the introduction of two models of BCR TKA [Vanguard XP Total Knee System (Zimmer Biomet, Warsaw, IN, United States) and Journey II XR (Smith and Nephew plc, Watford, United Kingdom)].

INDICATIONS

There is a growing interest in performing BCR TKA. As reported by De Faoite *et al*[21] from an international survey, 65% of the interviewed surgeons would consider implanting BCR TKA. Despite this, there is a significant lack of knowledge around patient segmentation for this surgery. Available literature on BCR TKA frequently do not specify indications in a precise manner; moreover, there is a significant overlap between recent unicompartmental (UKA) and bicompartmental knee replacement indications that may be confusing (Table 1). BCR TKA may, in fact, ideally combine the expected advantage of UKA in terms of restoring natural knee kinematics and TKA long-term survival rates. Despite this, the available data make it seem reasonable to choose UKA in case of limited unicompartmental knee OA, in contrast to when at least two compartments are involved in the degenerative process, when the choice between bicompartmental knee replacement and BCR TKA is still unclear. Moreover, age is not a barrier to BCR TKA *per se*[22], but the surgeon should preoperatively and/or intraoperatively evaluate the ACL integrity, the coronal alignment and range of motion (ROM) limitations to decide if this implant is the best choice.

Coronal alignment

Management of knee malalignment may be challenging in BCR TKA. A preoperative lower-limb alignment evaluation through long-leg radiographs to evaluate the source of deformity is mandatory. Despite this, the literature is unclear and there is considerable debate regarding the influence of preoperative deformity on BCR TKA outcomes[9]. Second-generation BCR TKA is generally associated with a more restrictive indication range[20,23-25]. Bauman *et al*[20], in his comparative study with UKA, excluded varus–valgus deformity of more than 10°, Christensen *et al*[24] included patients with a "minimal coronal deformity", while Pelt *et al*[25], in his retrospective review of a consecutive series of 175 knees, excluded patients with more than 15° of coronal malalignment. The latter postulate as a possible cause of the low survivorship rate of the BCR TKA reviewed or the pathological variation in knee kinematics that can be introduced with an implant designed to be placed with a traditional mechanical alignment technique within a soft tissue envelope that may not perfectly match after deformity correction. Therefore, exclusion of severe (> 15°) malalignment seems appropriate, but a greater consideration for patient to patient coronal alignment variability and restoration may, with future specifically-designed implants, lead to easier balancing of the ligaments and reduce the tibial component failure rate[26].

ACL integrity

Integrity assessment of both cruciate ligaments is crucial when a BCR TKA is performed. As recently reported by Ishii *et al*[27], from their retrospective evaluation of 247 TKA, 94% (233/247) of the evaluated knees had a visually intact ACL (normal or moderately damaged) at time of surgery. However, the ACL integrity in terms of strength and proprioception may be questionable in cases of end-stage OA, even though a visually intact ACL is present. Specifically, Mont *et al*[28] evaluated the histological properties of the ACL during TKA in 173 osteoarthritic knees. They reported mucoid degeneration in 85% of patients, even in visually intact ligaments. The authors linked older age, higher body mass index, and greater osteoarthritic changes to the degree of histological changes.

Moreover, as reported by Kawaguchi *et al*[29], this degeneration may extend to both cruciate ligaments, even when the PCL is intact on preoperative evaluation. Therefore, the author suggests to consider posterior stabilized (PS) TKA in case of ACL mucoid degeneration.

In addition, inflammatory arthritis was not considered as exclusion criteria in several clinical studies[13,18,30,31]. This is of special interest because inflammatory arthritis can impact the ACL integrity. More research is required to improve the understanding of inflammatory arthritis and mucoid degeneration role on ACL preserving arthroplasty. Clinical studies, to define ACL integrity, generally rely on

Table 1 Indications and relative contraindications summary

Indications	Relative contraindication
High-demand patients	Low-demand patients
End-stage bi- or tricompartmental knee OA	Severe coronal malalignment (> 15°)
Coronal malalignment < 15°	Inflammatory arthritis
ACL integrity:	ACL mucoid degeneration/absence
Clinical assessment (Lachman, anterior drawer test, pivot shift test)	Relevant preoperative reduction of ROM (> 10°)
Intraoperative assessment	
Minimal ROM reduction (< 5/10°)	

ACL: Anterior cruciate ligament; OA: Osteoarthritis; ROM: Range of motion.

visual evaluation[13,18,24,25,31] and/or clinical tests, like Lachmann test, the pivot shift test and anterior drawer test[13,18,25,31-34], while very few use radiological assessment in association. Kono *et al*[35] used a pre-operative magnetic resonance imaging (MRI) to determine the integrity of the ACL, while Pelt *et al*[25] used X-ray signs to indirectly assess the ACL status. In order to understand whether radiology may help in ACL status definition, we may refer to Johnson *et al*[36], who used the Lachman test alone, performed under anaesthesia. The investigators reported the test as ineffective in ACL functional integrity evaluation (33% sensitivity), while combination of the Lachman test with MRI scans brought the sensitivity and specificity of the combined tests to 93.3% and 99% respectively. Despite this, the lines of evidence about the role of MRI imaging or X-ray signs as an indicator of ACL insufficiency are limited. Future research should focus on ACL evaluation to select optimal candidates for this surgery.

Preoperative ROM

Restoration of a full ROM from a severe preoperative flexion contracture or a limited extension may be challenging in BCR TKA because of the cruciate ligament integrity and consequent confined surgical space, difficult ligament balancing, and soft tissue release.

There is no consensus in the available literature about acceptable preoperative ROM [9]. Christensen *et al*[24] limited their study to "minimal" contracture BCR indication; Pritchett[37] excluded patients with flexion of less than 90° and a flexion contracture of 20° or greater, while Pelt *et al*[25] included patients with less than 15° of flexion contracture.

Lavoie *et al*[34] conducted a retrospective comparative cohort study of 100 BCR TKAs and 100 PS TKAs, focusing on the influence of the preoperative to the postoperative ROM in the two-implant design. They found that BCR TKA with a preoperative flexion contracture equal or superior to 5° were almost 5-times more likely than PS implant to have a flexion contracture post-surgery and 10-times more likely to have a postoperative flexion contracture when the preoperative flexion contracture was equal or greater than 10°. Therefore, despite no systematic analysis being available with regard to the clinical outcomes in literature for second-generation implants, it seems appropriate to initially limit BCR TKA indications to patients with minimal reduction (< 10°) in ROM because preoperative motion issues are more likely to persist after TKA if both the cruciate ligaments are preserved.

TECHNICAL FEATURES

BCR TKA implies major technical challenges and specific complications resulting from ACL retention and difficult tissue balancing. Moreover, this surgery entails specific design-related issues, such as tibial baseplate stability in absence of a large tibial keel for fixation and reduced tibial coverage.

Second-generation implants are designed to overcome those durability issues; this is obtained through tibia component that comes with an asymmetric perimeter shape, a continuous keel and optimized anterior bridge to provide strength, and reduces historical design concerns related to anterior implant fractures to improve tibial

coverage. Furthermore, because some recent studies[24] found that second-generation BCR TKA with a symmetric, non-anatomical design were associated with an higher complication and revision rate. Newer implants are developed with a dedicated anatomical design that approximates physiological joint geometries to better replicate normal knee motion, allowing more mobility in the lateral compartment, as happens in the screw home mechanism, driven by cruciate ligaments. This is obtained through the tibia component, that includes a metal tibia tray with two independent and differently designed medial and lateral inserts with different radius of curvature of the surface and possibility to set different slope in association with an anatomical femoral component with asymmetrical condylar shape.

This new course adopted finds confirmation in the study conducted by Watanabe *et al*[26]. They investigated the effects of several alignment techniques on BCR TKA biomechanics. The most important finding of this study was that a symmetric BCR model implanted with a mechanical alignment demonstrated non-physiological knee biomechanics resulting from over-tensioning of the joint ligaments, especially the PCL and LCL. The rotational alignment of a symmetric femoral component with mechanical alignment (MA) is, in fact, essentially aligned to the epicondylar axis, and consequently the posterior femoral condyle is often larger than that of the preoperative knee and might excessively compress the lateral tibial plateau, resulting in reduced posterior translation of the lateral femoral condyle due to LCL and PCL tightness during knee flexion. Moreover, although the evaluation of a non-anatomical BCR TKA implanted with a kinematic alignment technique demonstrated a significantly reduced ligamentous tension and sensible improvements in joint kinematic, PCL and LCL tensions were still higher when compared to the normal knee. In view of those findings, they concluded that the non-anatomical shape of the evaluated implant contributed to the abnormal kinematic found and considered as a possible solution to those issues related to the introduction of an anatomical BCR TKA.

Therefore, especially in in the BCR implant, position of the components must be extremely precise to reach proper ligamentous balancing, avoid femoral component impingement on the central bone island, and restore joint line height and slope to obtain optimal ACL and PCL functionality and knee kinematics.

Despite so, as reported by Peng *et al*[38] in his 3D component orientations analysis relevant variations in component position were observed, especially for the tibial component, using standard instrumentation. Moreover, those variations, especially regarding tibial slope, where related to the 1-year clinical outcomes obtained. Because of this, they concluded that since the BCR TKA design aims to preserve both ACL and PCL it requires a higher level of attention to obtain an accurate and precise component orientation in order to restore the native knee biomechanics. This accuracy may ideally be provided by the use of additional surgical navigation guides/robotic assistance. Despite this, to our knowledge, there are no studies that have investigated the possible advantage of navigation guide or robotic assistance on BCR outcomes.

KINEMATIC STUDIES

Physiological knee kinematics are the result of a harmonic relationship between the articular surface, cruciate and collateral ligaments as well as the surrounding soft tissue. Theoretically, retaining both anterior and posterior cruciate ligament in TKA could contribute to restoration of nearly-normal knee kinematics, maintaining the posterior femoral rollback, reproducing medial pivot rotation and preserving proprioception. However, another aspect to consider that could influence kinematics is the implant design, which has been significantly improved with the last anatomic models. Several *ex vivo* studies demonstrated that BCR implants could preserve the screw-home mechanism, maintaining a more anterior femorotibial contact point, increasing the axial rotation and the posterior displacement through flexion in contrast to the ACL-sacrificing design and similar to a native knee[39-42]. However, in addition to ACL preservation, some authors have highlighted the importance of tibial geometry in the restoration of the physiological knee kinematics[41,43].

In their cadaver kinematic study, Hamada *et al*[43] found that normal rotational kinematics were not reproduced using a second-generation BCR TKA (Vanguard XP Total Knee System (Zimmer Biomet, Warsaw, IN, United States). In the same study, the authors showed that the screw-home mechanism was maintained after meniscectomy and femoral replacement but lost after tibial replacement, emphasizing the role of tibial geometry in implant kinematics[43]. Similarly, Wada *et al*[41], in their kinematic analysis of BCR TKA (Vanguard XP Total Knee System (Zimmer Biomet),

demonstrated that the amount of tibial internal rotation throughout knee flexion was greater, and more similar to the native knee, if a medial constrained insert was used compared to a flat insert. *Ex vivo* investigations on BCR TKA kinematics are partially confirmed by several clinical studies focused on daily activities[44-47]. Arauz *et al*[47] analysed the treadmill walking pattern in 29 patients with unilateral BCR TKA (Vanguard XP Total Knee System (Zimmer Biomet) compared to the non-operated contralateral side, using a combination of computed tomography scan and dual fluoroscopic imaging system[47]. The authors found an asymmetrical gait pattern in their unilateral BCR TKA patients: during the stance phase of gait cycle, a higher flexion and internal tibial rotation were observed in the operated knee; moreover, less anterior/posterior and medial/lateral translation were noticed on the TKA side. Nevertheless, the implanted and non-implanted knee had no significant difference in flexion/extension and axial rotation range of motion. They concluded that knee motion symmetry was not completely restored in patients with unilateral BCR TKA [47].

Hennessy *et al*[45] observed that sex could be an influential factor on knee kinematics in BCR TKA during gait. In their kinematic study, the authors found more antero-posterior interlimb asymmetry (BCR TKA *vs* healthy knee) in female patients (2.8 mm *vs* 1.6 mm) than in male patients (2.3 mm *vs* 1.8 mm) and this finding displayed increased posterior femoral translation throughout most of the stance phases of the gait cycle in female patients[45]. In another study, Arauz *et al*[46] investigated the *in vivo* knee kinematics of unilateral BCR TKA, compared to the healthy side, during daily activities, including sit-to-stand, single-leg deep lunge, and steps-up. Performing flexion activities, the BCR TKA side displayed a less posterior contact point on the lateral femoral condyle (from 6° to 100° of flexion). However, the magnitude of the lateral excursion was similar to the non-operated knee, except for the early degree of flexion (0° to 7°). Differently, on the medial side, the extent of femoral translation during knee flexion was inferior and the contact point more variable in BCR TKA compared to the healthy side. In addition, during all the activities, less femoral external rotation during mid-to high flexion was found in the BCR TKA side. The authors concluded that knee kinematics and the screw-home mechanism were only partially replicated with BCR TKA, emphasizing the importance of the implant articular geometry and components positioning[46]. Similar results were obtained in another kinematic study by the same group of authors when investigating strenuous flexion activities in unilateral BCR TKA patients[44].

An interesting *in vivo* biomechanics analysis on cruciate ligament preservation and femoral geometry was provided by Smith *et al*[48]. The authors performed a kinematic evaluation on 50 TKAs with same anatomical femoral geometry (40 Posterior Cruciate Retaining (PCR) – Journey II PCR; 10 BCR TKA – Journey II XR, Smith and Nephew plc, Watford, United Kingdom), during deep knee bending under fluoroscopic surveillance, in comparison to the normal knees (10 subjects). During early flexion, a better restoration of knee kinematics was achieved in BCR TKA subjects compared to PCR TKA, including a more anterior position of both femoral condyles in full extension and more magnitude of posterior-femoral roll back (PFR) in early flexion. However, normal knees showed a more anterior position of the lateral femoral condyle in full extension and more axial rotation compared to both TKA groups. The more posterior contact point of the femoral condyle combined with lesser external rotation shown in BCR TKA was attributed to the differences in femoral geometry between the implant and the native knee. In mid to late flexion, the influence of ACL decreases in favour to PCL, so the differences in kinematics between TKAs become poorer. Nevertheless, the BCR displayed less translational motion compared to PCR, reflecting the importance of balance within ACL and PCL. However, normal knees experienced a continued lateral PFR during flexion, that was only partially achieved in the BCR TKA group[48]. Despite the technical improvement of the second-generation BCR implants, other studies are needed to investigate the biomechanical implications between components design and kinematics.

CLINICAL RESULT

In the literature there are several long-term studies on first-generation BCR TKA, focused on clinical results; all studies have shown a significant improvement in the evaluated scores while ROM assessment indicates varied results (Table 2). Pritchett[31] conducted a longer retrospective study on BCR first-generation implant (Townley Anatomic; Biopro Inc, Port Huron, MI, United States) and reported a significant

Table 2 Second-generation bicruciate-retaining total knee arthroplasty clinical results

Ref.	Follow up in mo	BCR model (*n*)	Pre-op ROM flex, mean	Post-op ROM flex, mean	Pre-op KSS, mean	Post-op KSS, mean	FJS	WOMAC
Alnachoukati *et al* [23]	12	Vanguard XP (146)	116°	121°	48	96		
Biazzo *et al*[49]	33.82	Vanguard XP (24)						8.68 (BCR) *vs* 12.81 (CR)
Baumann *et al*[20]	18	Vanguard XP (34)					53.4 ± 26.4	
Hennessy *et al*[45]	12.7	Vanguard XP (29)			58.1 ± 11.8	86.6 ± 16.7		
Kono *et al*[35]	7.7	Journey II XR	128.7 ± 6.1					
Kalaai *et al*[33]	3.6	Vanguard XP (61)			36.2 ± 8.1	22 ± 10.1	58.4 ± 33.7	
Peng *et al*[38]	12.7	Vanguard XP (29)			58.1 ± 11.8	87.9 ± 16.7		
Pelt *et al*[25]	36	Vanguard XP (141)	121	123				
Tsai *et al*[32]	12.9	Vanguard XP (30)			58.5	86.6		

BCR: Bicruciate retaining; CR: Cruciate-retaining; FJS: Forgotten joint score; KSS: Knee Society score; ROM: Range of motion; WOMAC: Western Ontario and McMaster Osteoarthritis index

improvement in knee flexion, from a mean pre-operative value of 104° to 117° (P = 0.001) and Knee Society Score (KSS) from pre-op mean of 42 to 91 (P = 0.001). The same group collected the patients' preferences in bilateral two-stage TKA; four prosthetic design were implanted (bicruciate retaining, posterior cruciate-retaining, medial pivot, and posterior cruciate-substituting). The mean KSS of BCR implants at 8 years follow-up was 92.6, while the mean ROM was 119°. The conclusion of that study was that, despite the mean ROM, neither the pain score, KSS score nor functional score varied significantly between type of knee prosthesis used; patients with bilateral procedures were more likely to prefer retention of their ACL and PCL or substitution with the medial or lateral pivot prosthesis[37]. Lavoie *et al*[34] conducted a retrospective study, in which 100 BCR TKA (Hermes™ 2C ACR) were compared to 100 PS TKA (Hermes PS). They showed a lower post-op KSS in the BCR TKA cohort compared with the PS design (83.9 *vs* 89.2); moreover, the investigators documented post-operative stiffness at last follow-up in the BCR TKA group (1.5° *vs* 0.7°, P = 0.034). The most important result of the study was the lower maximum passive knee flexion in BCR knees relative to PS knees at every postoperative point, when preoperative flexion was less than 130°.

On the other hand, long-term and comparative studies on second-generation BCR TKA are still not available due to the recent market introduction and few models' availability. Alnachoukati *et al*[23] reported a mean postoperative increase in flexion values (116° preoperative to 121° postoperative) and a mean improvement in terms of KSS (48 to 96). Biazzo *et al*[49] compared functional outcomes between 24 BCR TKA knees [Vanguard XP Total Knee System (Zimmer Biomet)] and 24 CR TKA knees [Vanguard ID Total Knee System (Zimmer Biomet)] in short-term follow up; at the last follow-up, they showed a higher mean Western Ontario and McMaster Osteoarthritis index (WOMAC) score for the BCR group (8.68) than for the CR group (12.81) but no statistically significant difference between the groups (P = 0.33). Baumann *et al*[20] demonstrated the superior proprioceptive function of a bicruciate-retaining implant [Vanguard XP Total Knee System (Zimmer Biomet)] compared to unicondylar knee arthroplasty (UKA) and posterior-stabilized TKA (Genesis II Total Knee Replacement System; Smith and Nephew plc, Watford, United Kingdom) at mean follow-up of 18 mo. The BCR group showed no difference in the Forgotten Joint Score (FJS) relative to the UKA group (53.6 ± 22.2 *vs* 53.4 ± 26.4, P = 0.999). The PS TKA group revealed lower mean score value in the FJS compared to the BCR group (38.9 ± 22.3 *vs* 53.6 ± 22.2, P = 0.035) and UKA group (P = 0.031).

Hennessy *et al*[45] analysed kinematic gait in females and males (15/14) after BCR TKA implantation [Vanguard XP Total Knee System (Zimmer Biomet)]. The authors

demonstrated significant increases in KSS (58.1 ± 11.8 preoperative to 86.6 ± 16.7 postoperative, $P < 0.001$). Kalaai *et al*[33] designed a retrospective study in which 61 BCR TKA were compared to 61 CR TKA; the authors observed no statistical differences in FJS score between BCR TKA and CR TKA but a significant improvement ($P = 0.017$) in the EuroQol (EQ-5D) at 3-year follow-up in BCR TKA group. Kono *et al*[35] matched kinematic data from BCR TKA [Journey II XR (Smith and Nephew plc)], UKA and healthy controls during squatting motion, under fluoroscopic surveillance. There was a lower extension angle of UKA knees than healthy and BCR TKA knees ($P < 0.01$), lower flexion angle of BCR TKA knees than healthy and UKA knees ($P < 0.01$), and lower flexion angle of UKA knees than healthy knees ($P < 0.01$). Peng *et al*[38] examined the relation between component alignment and patient reported outcome measures (PROMs) in 29 BCR TKA implants [Vanguard XP Total Knee System (Zimmer Biomet)]. At 1-year follow-up, they verified a significant overall post-operative improvement in KSS (8.1 ± 11.8 preoperative to 87.9 ± 16.7 postoperative, $P < 0.001$). In that study, the regression analysis demonstrated that the postoperative KSS was negatively associated with a greater posterior tibial slope. Pelt *et al*[25] showed that knee flexion ROM improved from a preoperative mean of 121° to a postoperative mean of 123° after BCR TKA implant. Eventually, Tsai *et al*[32] reported significant improvement from a mean preoperative KSS of 58.5 to a 6-mo postoperative value of 86.6.

COMPLICATIONS AND REVISION RATES

First-generation implants

Pritchett[31] presented the largest and longest-term series on first-generation BCR TKA; the author reported on implant of 214 prosthesis (Townley Anatomic) in 160 patients and the clinical outcomes at a minimum follow-up of 20 years. The Kaplan–Meier survivorship was 89% [95% confidence interval (CI): 82%-93%], with revision for any reason as an endpoint. Twenty-two knees in 21 patients (5.6%) were revised and the most common causes where polyethylene wear, aseptic loosening of the femoral or tibial component (seven revisions) and infection (four revisions)[31]. Ries *et al*[50] showed mechanical failure in 20 first-generation BCR TKAs that required revision; the authors retrieved 16 porous coated cementless Ti-6Al-4V tibial trays (BioPro, Port Huron, MI, United States), 2 cast CoCr tibial trays (BioPro) , and two all polyethylene tibial implants (Geomedic; Howmedica, Rutherford, NJ, United States). Four failure implant ways were identified, namely fracture of the anterior tibial tray or bridge (fatigue fracture), insert dissociation, UHMWPE wear, and tibial component loosening[21].

Second-generation implants

Alnachoukati *et al*[23] reported in a short-term review of 146 BCR TKA implantations [Vanguard XP Total Knee System (Zimmer Biomet)], two revisions (1.4% revision rate) due to anterior arthrofibrosis and tibial component subsidence, and 1 reoperation (0.7% reoperation rate) with manipulation under anaesthesia. Nine out of one hundred and forty-six (6.2%) knees had an intraoperative fracture of the tibial island, which occurred in the beginning of the series, fixated with cancellous screw (Table 3).

A match-paired study with a mean follow-up of 33.82 mo carried out by Biazzo *et al*[49] reported two major and two minor complications after implant of 24 BCR TKA [Vanguard XP Total Knee System (Zimmer Biomet)]. There were two aseptic loosening cases with revisions of the tibial component, on periprosthetic joint infection treated conservatively, and one intraoperative fracture of the intercondylar tibial eminence fixed by cortical screw. That study pointed out the increased surgical time in the BCR design [92.19 min standard deviation (SD) 8.56] when compared to the CR design (76.67 min SD 19.91). Early learning curve experiences may explain the longer operative times and the higher complication rate. A case-control study designed by Kalaai *et al*[33] displayed a survival rate of 98.4% for both the CR and BCR TKA groups; one revision in the BCR group was caused by valgus thrust. Klaassen *et al*[51] presented 2 cases (3 knees) of cyclops lesions after BCR TKA with limited knee extension; these were treated by arthroscopic debridement. Therefore, the knee surgeons should suspect this lesion after BCR TKA implantation if full knee extension is not achieved.

Pelt *et al*[25] in their retrospective study on second-generation BCR implants [Vanguard XP Total Knee System (Zimmer Biomet)] revealed a revision-free survival of 88% at mean 3 years follow-up. The main causes of revision were isolated tibial

Table 3 Second-generation bicruciate-retaining total knee arthroplasty complications

Ref.	Year	BCR model (*n*)	Complication	Follow-up time in mo, mean
Alnachoukati *et al* [23]	2018	Vanguard XP (146)	9 intraoperative tibial island fracture; 1 cyclops lesion; 1 aseptic loosening of tibial component	12
Biazzo *et al*[49]	2020	Vanguard XP (24)	2 Aseptic loosening; 1 periprosthetic infection; 1 intraoperative tibial island fracture	33.82
Kalaai *et al*[33]	2019	Vanguard XP (61)	1 valgus thrust	3.6
Klaassen *et al*[51]	2017	Vanguard XP (3)	2 cyclops lesion (3 knees)	
Pelt *et al*[25]	2019	Vanguard XP (141)	2 Intraoperative tibial island fracture; 11 arthrofibrosis; 1 hematoma; 1 chronic pain	36

BCR: Bicruciate-retaining.

loosening (5/19), ACL impingement (3/19), chronic pain (3/19), unknown reasons (3/19), femoral and tibial loosening (2/19), metal allergy with chronic pain (1/19), ACL deficiency (1/19), and arthrofibrosis (1/19). There were two intraoperative tibial island fractures that were fixed with a screw[17].

CONCLUSION

The renewed interest in BCR TKA, as things currently stand, is mainly rooted on component design improvement and biomechanical and kinematical studies that corroborate the possible significant advantage that retention of cruciate ligaments can offer rather than high-quality long-term clinical trials. The literature on first-generation design has showed good long-term survival rates with satisfying clinical outcomes, while the second-generation-based studies have reported heterogeneous results in short to mid-term follow-ups. Anatomical BCR TKA associated with improved patient selection criteria definition for this surgery and greater consideration for patient-to-patient coronal alignment variability and restoration may improve the results obtained thus far. Further high- quality research will be necessary to investigate those hypotheses, evaluate the long-term clinical results, and define the ideal patient for BCR TKA.

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MINIREVIEWS

Surgical treatment of metastatic bone disease of the distal extremities

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Abstract

Metastatic bone disease of the distal extremities, also known as acrometastasis, is very rare. Thus, there is very limited information regarding the clinical manifestations and methods of surgical treatment. The current available literature shows that acrometastases are often encountered in the context of advanced disease and are thus associated with poor patient survival. As metastatic bone disease is generally uncurable, the goal of surgical treatment is to provide the patient with good function with as few complications as possible. In this article, we discuss the clinical manifestation of acrometastases, the methods of surgical intervention, and the expected clinical outcome. Non-surgically managed pathological fractures generally remain ununited; therefore, conservative treatment is reserved for patients with poor general condition or dismal prognosis. The current evidence suggests that in lesions of the lower arm and leg, osteosynthesis (plate and screw fixation or intramedullary nail) is the most common method of reconstruction, whereas local excision or amputation are more commonly used in cases of more distal lesions (such as ankle, foot and hand). Following surgery most patients receive adjuvant radiotherapy, even though its role is poorly documented. Close collaboration between orthopedic surgeons and medical oncologists is necessary to improve patient care and treatment outcome. Further studies are needed in order to provide stronger clinical evidence and improve decision-making, in an effort to optimize the patients' quality of life and avoid the need for revision surgery.

Key Words: Metastatic bone disease; Surgery; Radiotherapy; Pathological fractures; Distal

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extremities

Core Tip: Metastatic bone disease distal to the elbow and knee is rare, often encountered in patients with spread cancer. Limb-preserving surgery is often possible in the lower arm and leg, and osteosynthesis with plate and screws or intramedullary nails are the most common surgical methods. In the lesions of the ankle, hand and foot, amputation is often utilized.

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INTRODUCTION

Bone is one of the most common organs affected by cancer metastases[1]. Metastatic bone disease (MBD) can be caused by different primary tumors, with the highest prevalence being from breast and prostate cancer[2]. It has been described that the incidence of bone metastases depends on the origin of the primary tumor, although it increases primarily with more advanced disease, regardless of the tumor origin[3,4]. MBD causes a disruption of the bone's normal metabolism and physiology, which eventually could lead to hypercalcemia and bone pain[1,2]. Moreover, the disruption of bone architecture can lead to reduced bearing capacity and microfractures. In turn, this can cause a total loss of the bony integrity and result in bone fractures[1]. The skeleton is not equally affected by MBD, which is more common with metastases in bones consisting of a larger amount red marrow and trabecular bone. Metastatic tumors are also more abundant in the axial skeleton[2]. The most frequently affected long bone is femur, followed by humerus[5].

Diagnosis and treatment of MBD

It is important to diagnose MBD in its early stages so that mortality and morbiditiy can be reduced[6]. Generally, the diagnosis of MBD often starts with conventional radiography (X-ray) or computed tomography (CT), magnetic resonance imaging (MRI) and/or bone scans, depending on the clinical suspicion and origin of the metastasis. Conventional plain radiographs can detect and localize bone lesions, their frequency and size, the occurrence of pathological fractures, and potential soft tissue involvement. Moreover, X-rays can determine whether the bone lesions are sclerotic or lytic. CT scans could be helpful in situations when there is cortical destruction and mineralization[7], and they support the diagnosis process by differentiating benign and malignant tumors[6]. Moreover, CT scanning with 2D frontal-sagittal reconstructions has been proposed as a method for improving the performance of fracture prediction in impending fractures[8]. Although CT scans are proposed as the second step in the diagnosis process, they are most often the primary technique for detecting MBD, as they are part of the routine staging protocol when diagnosing all kinds of cancer[6]. MRIs have an extremely high sensitivity and specificity for assessing tumor spread in soft tissue and the surrounding structures, such as joints and skin. Moreover, MRI has the potential to detect bone marrow engagement even if it is diffuse[6,9]. Although MRI is the gold standard[9], it is inferior to CT scans in cases of small bones, such as the ones in hands, feet and skull[6].

Isotope bone scans are another method that is helpful in the diagnosis of MBD. These scans are useful when detecting obscured bone lesions and mapping tissue characterization. Positron emission tomography (PET) scans are superior to all other imaging techniques in cases of detecting primary lesion sites in the earlier stages of disease. PET scans are highly accurate and can also detect lesions in the distal extremities[10]. Moreover, fine needle aspiration cytology or core-needle biopsy is necessary and should take place in tissue diagnosis[9].

MBD is associated with poor survival, which is mainly due to the primary tumors' type and origin[10]. Generally, MBD is incurable and the treatment options aim to reduce symptoms[11]. Currently, the common treatments include osteoclast inhibition, chemotherapy, radiotherapy, and surgery[11]. Bisphosphonates and denosumab aim to inhibit bone resorption and thereby bone destruction[12-14], while radiation and chemotherapy help to ease pain and control tumor growth. Surgical treatment is needed when the MBD results in impending or pathological fractures[3,11]. However, surgery does not have a cancer-reducing effect nor improve survival[15,16]. Instead, it is the treatment of choice when it comes to stabilizing the bone structure and reducing pain[15].

Pathological fractures managed non-surgically will generally remain ununited[1,17,18]. Therefore, conservative treatment is an option only when the patient is inoperable [18]. Most patients receive radiation therapy following surgery[3], due to its counteractive effects towards pain, local recurrence, and tumor growth[3,19]. However, adjuvant radiotherapy could potentially cause surgical failures when some surgical techniques are used, such as osteosynthesis and un-cemented implants, and lead to wound healing problems and infection[20,21]. Generally, the role of adjuvant radiotherapy is poorly documented[19,22].

GENERAL PRINCIPLES OF ACROMETASTASES

As previously mentioned, the most frequently affected long bone is femur, followed by humerus. Other long bones, such as the ones in hands and feet, rarely harbor metastases[5]. The term acrometastases is used inconsistently[23]; sometimes, it is defined as metastatic lesions distal to the elbow and knee[16] and, other times as lesions distal to the ankle and wrist[23]. Acrometastases are a rare occurrence and the incidence is reported as 7%[17]. Approximately 0.1% of all acrometastases are located distal to the ankle and wrist[16]. The hands are more often affected by osseous metastases compared to the feet[9], with a ratio of 3:1[24]. Significant delay of the diagnosis is common[23], due to its rarity in combination with unspecific symptoms [16]. Associated signs and symptoms are, in general, soft tissue swelling, pain and functional impairment, steering the clinicians' ideas towards more benign conditions, such as gout, ligamentous sprains, osteoarthritis and more[16,25]. In addition, the common practice of metastatic skeletal surveys where whole body CT is used is to exclude the distal extremities, leading to possible under-reporting of these cases[26]. Considering metastatic disease as a differential diagnosis can therefore prevent late diagnosis and delayed treatment. For acrometastases in general, histological examinations have shown that the main tumor type is lung cancer, followed by gastrointestinal tract and genitourinary tract tumors[9].

Complete staging must be performed in order to determine the primary lesion, extension and metastatic count. This information is necessary in order to evaluate prognosis and provide input in determination of the treatment approach[16]. Staging often includes radiology of the lesion, preferably MRI, CT of the chest and abdomen, and bone scans. Tissue diagnosis is of importance. Some authors have recommended fine needle aspiration over incisional biopsies because of the risk of making the lesion extracompartmental[9,27]. When staging has been performed and the patients' prognosis and overall functional status is assessed as sufficient, surgical treatment can be considered[16].

Important elements exist that should be taken into consideration in the surgical planning and reconstruction decision-making. For example, renal metastases are relatively resistant to photon beam radiation therapy, explaining why total resection is recommended. This is in comparison to radiosensitive tumors for which intralesional curettage and stabilization is fitting[28]. Studies have also shown that certain tumor types, such as metastases from renal and thyroid origin, have the best prognosis when totally resected, when local recurrence and disease-free survival are the primary outcome measurements[29]. Nonetheless, prognosis of patients with acrometastatic cancer is poor[30], since most have widespread disease, and their mean survival time has been reported to be less than 6 mo[31].

ACROMETASTASES OF UPPER EXTREMITY

Hand

Acrometastases in the hands are mostly originated from lung cancer[9,32]. The phalanges are the most commonly affected location[10,33], followed by the metacarpal bones[33]. The mean survival for patients suffering from hand metastases have been reported to range from 5 mo to over 1 year[10,24,33]. Although there is no standardized treatment for hand metastases, a variety of treatment options, including radiotherapy, curettage, resection, radical disarticulation of the ray and amputation is available[9,16,33,34]. Most commonly limb salvage surgery is used, including resection and curettage[32]. As the prognosis of acrometastases depends on the characteristics of the primary tumor[10], the approach differs. In cases with poor response to cancer treatments, including radiation and chemotherapy, amputation is a more appropriate method[35]. Moreover, surgical methods, such as local excisions and curettage, could be hard to conduct due to the limited amount of soft tissue in the hands[16,35].

Lower arm (radius and ulna)

MBD in the lower arm is extremely rare. The incidence of metastases involving ulna has been reported as low as 1%[36]. In another small cohort study, the incidence of lower arm metastases was reported as 2 out of 34 fractures (6%)[37]. Because of the rare occurrence of MBD in the lower arm, the literature is sparse regarding these locations. To our knowledge, metastatic bone lesions in ulna and radius are very rarely described in the literature. Our experience is that most lesions can be managed with local excision and osteosynthesis with plate and screws (Figure 1).

ACROMETASTASES OF LOWER EXTREMITY

Foot

Studies suggest that less than 50% of acrometastases involve the feet[38,39]. MBD of the foot occurs in the context of widespread dissemination, which is the main reason why it has a poor prognosis[24]. Lung cancer is the most common primary tumor, followed by breast, kidney and colon/rectum, respectively. The hindfoot (calcaneus and talus) is the most common site, followed by the forefoot (metatarsal bones and phalanxes) and mid foot (cuniforme-, navicular- and cuboid bones)[16]. An average survival of 15 mo for patients with acrometastases of the foot has been reported[30].

Treatments of MBD of the foot vary from simple palliative care or pharmacological treatment, radiation therapy, chemotherapy, and surgery[30,35]. No standard treatment protocols exist because of the rarity of the condition and therefore are often approached on a case-by-case basis. The main goal however should be focused on palliation and improving quality of life[35]. Amputation and local curettage is common practice for these cases, with the former being the most frequent surgical option[16,35]. Midfoot or, more commonly, transtibial amputation can be performed depending on the location and spread of the tumor. If amputation is not acceptable curettage can be an alternative[24]. However, the recurrence rate after curettage has been reported to be approximately 20%[9]. Adjuvant radiation therapy or marginal excision are other options[24].

Lower leg (tibia and fibula)

MBD of the tibia has been reported to account for 3%-4% of MBD, thus being more frequent than metastases in the foot[17,40]. Fibular metastases are very rare and the representation in the literature mainly consists of case reports[41-43]. Due to its rarity, published cohorts of cases are small[17,44]. The somewhat higher occurrence of MBD involving the tibia has resulted in better data. The primary tumors giving rise to bone metastases in the tibia are breast and prostate cancer in women and men respectively, with lung, kidney and colorectal cancers also being represented independent of sex[8, 23,45]. The most common site of metastases in the tibia is the proximal metaphyseal region, followed by the diaphysis[21,23].

Surgery is the primary treatment choice, since the tibia is a major weight-bearing bone. The loading forces affecting the knee and ankle are mainly compressive, and the tensile forces are lower than in the proximal femur, hence decreasing the risk of mechanical failure[20]. The three main surgical management principles for MBD in the lower leg are stabilization after curettage with or without cement or bone graft, endoprosthetic reconstruction after complete resection, and amputation[28]. For

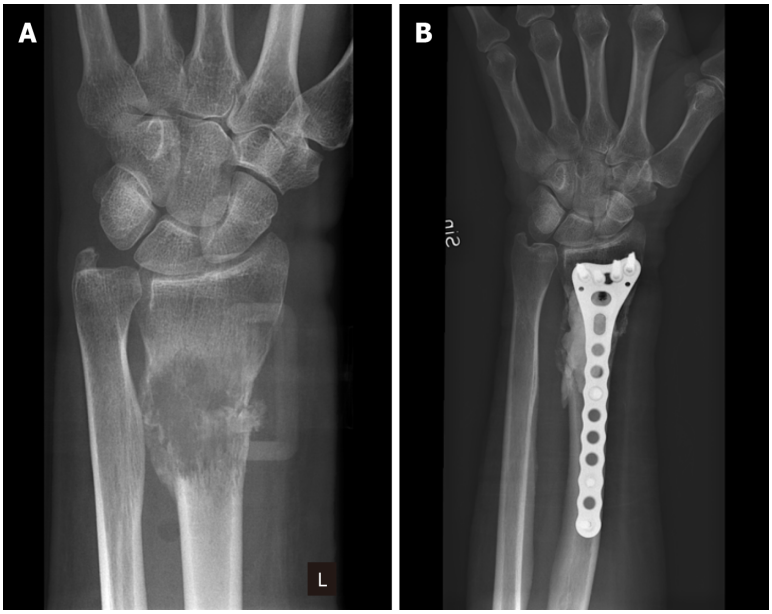

Figure 1 Metastatic bone disease in the lower arm. A: Osteolytic metastasis caused by lung adenocarcinoma in an elderly female patient; B: Treatment with curettage, bone cement and osteosynthesis with plate and screws.

reconstruction, intramedullary (IM) nails, plate and screws with or without cement, and endoprostheses are suitable options[28]. In the cases of proximally located tumors, especially the tibial metaphysis, curettage followed by cementation and stabilization with plate and screws is a good alternative. However, if the lesion is highly destructive and affecting the joint, endoprosthetic reconstruction with a medial gastrocnemius flap can be considered in patients with good prognosis[28]. Closed IM nailing, sometimes with the addition of curettage, and generally followed by radiation therapy, is the preferred method of choice when metastases are located in the diaphysis[8]. IM nail devices typically allow immediate weight bearing, and postoperative radiation therapy is not contraindicated, which is of great importance to the patient (Figure 2).

Metastatic lesions in the distal parts of the tibia are rare[21]. If reconstruction is an alternative, plate and screw fixation could be implemented with or without curettage and bone cement. Since there are no suitable prosthetic devices available after resection of the distal tibia, in cases of large destruction a retrograde IM nail through the calcaneus and talus into the tibia is the main option. Postoperative radiation therapy jeopardizes the fusion of the arthrodesis in these cases[20]. However, due to the poor functional performance of limb-sparing surgery, below knee amputation is a good alternative[28]. This procedure is also suitable in cases in which tumor growth is not controllable by adjuvant therapy, if soft-tissue quality is poor, or if previous surgery or reconstructions have failed[45].

As for the even rarer occurrence of fibular metastases, resection without reconstruction is the most reported procedure in the literature by far[20,28,44]. The fibula, as well as the ribs and clavicle, is an expandable bone, and resection can be performed without any functional impairment[20].

CONCLUSION

MBD in the distal extremities (acrometastases) is a rare condition and very poorly investigated in the medical literature. Patients with acrometastases generally have advanced disease and poor survival. Choosing the proper surgical treatment is important in order to improve the patient's quality of life and avoid implant failure and the need for revision surgery. Osteosynthesis is the most common treatment method in proximal acrometastases (lower arm and leg), with amputation being more common for distal lesions.

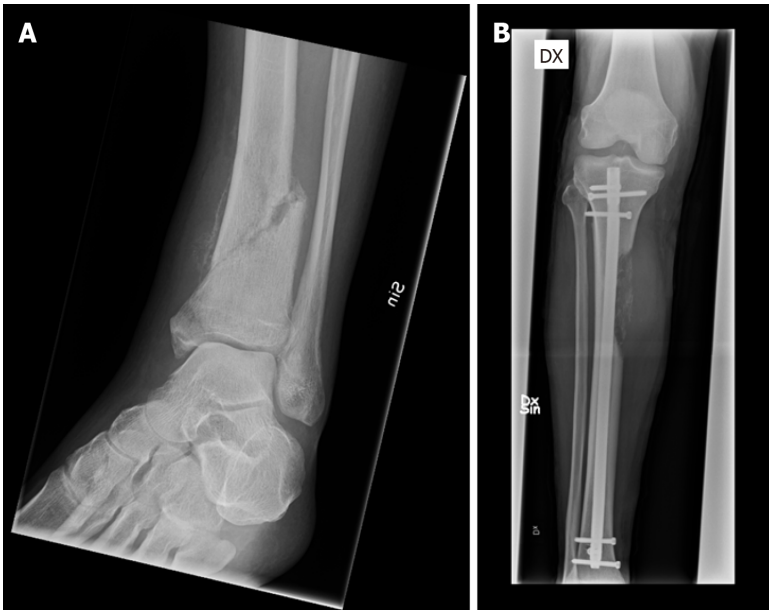

Figure 2 Metastatic bone disease in the lower leg. A: Well-defined osteolytic lesion of the proximal tibia diaphysis in a patient with renal cancer; B: Treatment with intramedullary nailing without any tumor removal.

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ORIGINAL ARTICLE

Case Control Study

SARS-CoV-2 outbreak impact on a trauma unit

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Abstract

BACKGROUND

From February 2020 onwards, our country has been hit by the coronavirus severe acute respiratory syndrome-2 (SARS-CoV-2) infection. At a glance, hospitals became overrun and had to reformulate all the assistance guidelines, focusing on the coronavirus disease 2019. One year after the start of the pandemic, we present the results of a morbimortality study.

AIM

To analyze how our department was affected by the outbreak in terms of morbimortality, and to analyze demographic data, admission to hospital-related data, and subgroups analyses for patients with hip fractures and polytrauma.

METHODS

We designed a study comparing data from patients who were admitted to our unit due to a lower limb fracture or a high energy trauma during the pandemic (from March to April 2020) to those admitted during the same period in 2019 before the pandemic. during the pandemic situation. Both cohorts completed a minimum of 6 mo of follow-up.

RESULTS

The number of patients admitted to hospital in 2020 was nearly half of those in 2019. Hip fractures in the elderly represented 52 out of 73 of the admitted patients. Twenty patients had a positive test result for SARS-CoV-2 infection. Patients with

SARS-CoV-2 infection were admitted to the hospital for a longer time than the non-infected ($P < 0.001$), and had a higher mortality rate during hospitalization and follow-up ($P = 0.02$). Patients with a hip fracture associated with a severe respiratory syndrome were mostly selected for conservative treatment ($P = 0.03$).

CONCLUSION

Mortality and readmission rates were higher in the 2020 cohort and during follow-up, in comparison with the cohort in 2019.

Key Words: Trauma department; COVID-19 pandemic; SARS-CoV-2 outbreak; Hip fractures; Morbimortality; Polytraumatic patients

Core Tip: Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) infection was not a criterion for choosing conservative treatment, unless those patients infected with the virus had a poor general condition that made surgery unadvisable. We did not find a relationship between the employment of anticoagulant therapy and the severity of coronavirus disease 2019 (COVID-19) infection or a different mortality rate. Patients who died during hospitalization due to COVID-19 had higher C-reactive protein levels ($P < 0.001$) and higher urea levels ($P = 0.006$). The mortality rate in 2020 was 13.7% during hospitalization; 19% during the first month after discharge, and 24.6% in the 3 mo after discharge. The mortality rate in the COVID-19 positive patient subgroup was 38.9% after 6 mo of follow-up. Non-operative treatment in hip fractures was related to SARS-CoV-2 infection ($P = 0.03$) and with AO 31.B fractures. Polytrauma patients and high energy fractures were more common in 2019 (24%) than in 2020 (11.5%). The main difference between both periods was the injury mechanism.

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INTRODUCTION

A cluster of atypical pneumonia was identified in Wuhan, China, in December 2019, affecting China first, and rapidly spreading all over the world, starting a pandemic[1]. By the end of February 2020, the first case of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) infection was reported in our community (Madrid, Spain). As a consequence of the outbreak, elective surgeries were suspended. Some of the surgeons were assigned to interdisciplinary teams headed by Internal Medicine, aiding the fight against coronavirus disease 2019 (COVID-19). Surgeries and outpatient appointments were minimized to provide only essential services: emergencies, fractures, some surgical complications, and a few bone or soft tissue tumors.

This study aims to analyze the effect that the SARS-CoV-2 pandemic had on our Orthopedic and Trauma Department. We wanted to evaluate if COVID-19 influenced the decision-making with those patients admitted during the first wave of the SARS-CoV-2 outbreak and if conservative treatment was more frequently chosen. As we noticed that the number of patients admitted and their characteristics varied markedly, we decided to compare the 2020 results with a cohort of patients admitted to our hospital during the same period in 2019, using the same inclusion criteria for both groups.

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MATERIALS AND METHODS

This study consists of a prospective single-center observational study. We selected a cohort of patients under the following inclusion criteria: Patients that came to the Emergency Room (ER) after a traumatic injury, requiring hospitalization because of a lower limb fracture, or polytrauma patients from March 11th, 2020 (date of admission of the first positive case amongst our patients) to April 30th, 2020. Patients presenting a surgical complication were not included if they underwent surgery before the pandemic period. Tumors, upper limb, and spine fractures were omitted (unless polytraumas were presented with them), following the common criteria for admission in our Unit. A minimum of 6 mo of follow-up was required for inclusion in this analysis.

Patients were tested when they arrived in the ER: blood tests, chest AP radiographs and nasopharyngeal swabs. In some cases, if the complementary tests were highly suggestive of SARS-CoV-2 infection but the polymerase chain reaction (PCR) test was negative, a chest computed tomography scan was also performed. Patients with severe acute respiratory insufficiency and bilateral pneumonia were assumed as positives even if the PCR was negative.

Depending on those test results, patients were admitted to the hospital in different areas and operated on in different operating rooms. Postoperatively, we tried to reduce to the maximum the time spent in the hospital, at all times prioritizing clinical status, to avoid nosocomial transmission.

We collected demographic data, lesion mechanism and characteristics, previous functional status, different parameters obtained from chest AP view radiographs, blood tests, or SARS-CoV-2 tests. Time to surgery and average in-hospital stay were recorded. Complications were recorded, as well as readmissions to the hospital due to surgical or medical problems.

Another cohort, with the same characteristics and inclusion criteria, was obtained in the same period in 2019, to compare differences in our unit between a normal period and the pandemic period, the aim being that the only difference between them was the presence of SARS-CoV-2.

Selected data were collected in an electronic database [Microsoft® Excel for Windows® (Microsoft Corp, Redmond, WA, United States)], kept under restricted access in accordance with data protection legislation. All statistical analyses were performed by the Biostatistics Unit at our center. The level of significance was established at $P < 0.05$. The present study was approved by our Hospital's Ethics Committee.

RESULTS

Cohort of patients in 2020

During a period of 50 d, from March 11th, 2020 (date of admission of the first positive case among our patients) to April 30th, 2020 (last day of severe restrictions at the hospital), 73 patients fulfilled inclusion criteria and were included in this study. The most representative descriptive analysis results from the demographic data of the cohort of patients in 2020 are shown in Table 1. The age range was from 17-years-old to 97-years-old. The vast majority of the patients (71%) had a hip fracture, the mean age in this subgroup being 87-years-old (61-97-years-old). Except for those patients classified as polytraumas (11.5%), all patients suffered a fracture due to a low energy traumatism. In this cohort, 14 patients were under anticoagulant therapy and 7 under antiplatelet therapy. The use of these drugs had no relation to COVID-19 development nor the mortality rate. Patients who used them had a longer time to surgery ($P < 0.001$). While admitted to hospital, 3 patients developed a pulmonary embolism despite adequate treatment with low molecular weight heparin; all cases were related to COVID-19. During follow-up, no patients developed complications related to thromboembolic disease (deep vein thrombosis nor pulmonary embolisms).

Wide blood tests were performed systematically on all the patients when they arrived in the ER as part of a protocol to study COVID-19 patients. We noticed that COVID-19 positive patients presented higher values of C-reactive protein ($P < 0.001$). Patients who died during hospitalization had higher C-reactive protein levels ($P < 0.001$) and higher urea levels ($P = 0.006$). Nasopharyngeal swabs were performed systematically when patients arrived in the ER from March 24th onwards, following center protocols; previously it was ordered only in suspected cases. When swabs were not still mandatory, a lower time to surgery was observed ($P = 0.01$).

Table 1 Demographic data of the cohort of patients from 2020

	Minimum	Maximum	Mean	SD
Age (yr)	17	97	76.99	20.25
FAC	0	5	3.11	1.257
Barthel Index	0	100	71.82	29.649
Pfeiffer mental status	0	10	2.89	3.46
Charlson Comorbidity Index	4	11	6.66	1.75
Body temperature (°C)	35	37.4	36.1	0.5
Blood oxygen saturation (%)	82	100	94.7	3.37
Urea blood levels (mg/dL)	12	219	57.94	37.5
D-dimer (ng/mL)	2010	123070	23939.68	29893.51
Lactate dehydrogenase (UI/L)	152	851	307.66	125.75
C-reactive protein (mg/dL)	0	248	40.7	60.5

FAC: Functional Ambulation Classification; SD: Standard deviation.

Twenty patients obtained a positive test result for SARS-CoV-2 infection. Patients with SARS-CoV-2 infection were hospitalized for a longer time than non-infected ones ($P < 0.001$) and also had a higher mortality rate during hospitalization and follow-up ($P = 0.02$). Of those patients diagnosed with COVID-19 infection, 80% were operated on. The SARS-CoV-2 disease was not a criterion for not performing surgery, although severe respiratory syndrome was ($P = 0.03$).

The in-hospital stay was 11 d (0-61 d). Logically, COVID-19 had an influence on these data: this number varied from 8 d (0-43 d) for the group of negative patients to 18 d (4-61 d) for the group of positive patients ($P < 0.05$). Analyzing the group of patients with hip fractures, COVID-19 positive patients stayed a mean of 17 d (4-61 d) *vs* a mean of 8 d (1-43 d) for negative patients ($P < 0.05$). On the other hand, a longer time to surgery is related to a longer time to discharge ($P < 0.001$). A relationship between a longer time to surgery and the risk of nosocomial SARS-CoV-2 transmission or death could not be demonstrated. Clinical complications during the 3 mo after discharge were more common amongst COVID-19 positive patients (83.3%) than in those without SARS-CoV-2 infection (32.4%) ($P < 0.05$).

The mortality rate in 2020 was 13.7% during hospitalization, 19% during the first month after discharge, and 24.6% in the 3 mo after discharge. Those rates are high and are related to COVID-19. The mortality rate in the COVID-19 positive patient subgroup was 38.9% after a minimum of 6 mo of follow-up.

Hip fractures and SARS-CoV-2

During the period studied in 2020, 52 patients were admitted to the hospital due to a hip fracture, out of 73 patients. We did some analyses in this subgroup, including Functional Ambulation Classification, Barthel Index Score, Pfeiffer Short Portable Mental Status, and Charlson Comorbidity Index. Scores in these scales had no relation to the place where patients lived (home/nursing home) before the fracture, with COVID-19 infection, time of hospitalization, or death ($P > 0.05$). However, patients coming from a nursing home presented a higher rate of SARS-CoV-2 infection ($P = 0.03$), without any relationship between nursing homes and risk of death ($P = 0.1$).

Regarding the type of fracture (classified following AO criteria), we found a correlation with readmission to the hospital ($P = 0.001$), because all the patients who had a 31.A3 or bifocal femoral fractures were readmitted to the hospital due to medical complications.

In our cohort of 52 patients with hip fractures, 7 patients were treated non-operatively and 5 of them developed a severe respiratory insufficiency due to COVID-19. Non-operative treatment in hip fractures was related to SARS-CoV-2 infection ($P = 0.03$) and with AO 31.B fractures (intracapsular fractures) ($P < 0.001$), corresponding to 6 out of the 7 patients treated non-operatively.

Polytrauma patients

The cohort from 2020 includes 5 patients who suffered a high energy traumatism and were defined as polytraumas. The age range was 20-57-years-old with a mean age of 38-years-old. Three of them presented with open fractures. Two of them died during hospitalization due to respiratory failure, but none of them due to COVID-19.

Other fractures

Lower limb fractures, other than hip fractures in the elderly and fracture patients not considered polytrauma, showed a sharp decrease due to the lockdown.

Comparison to a similar cohort in 2019

In the same period of 50 d in 2019, 143 patients were admitted to the hospital and included in analyses following the same inclusion criteria. During the SARS-CoV-2 outbreak, the number of patients admitted to our unit decreased by 49% in comparison with the same period in 2019.

No statistical differences were found between both cohorts (2019 and 2020) regarding demographic data.

The number of patients that were not suitable for surgery was very similar in both periods, 11.5% in 2020 and 12.6% in 2019. In-hospital stay varied from 1 to 32 d (mean 8 d) in 2019, and from 1 to 61 d (mean 11 d) in 2020 ($P < 0.02$). Readmissions to the hospital in the 3 mo after discharge were higher in 2020 (10.8%) than in 2019 (5%) and more frequently due to a medical complication (71.4%). The mortality rate during hospitalization was 2% during the period in 2019, *vs* 13.7% in 2020. Mortality after 6 mo of follow-up was also higher in 2020 (24.6%) than in 2019 (2.8%), ($P < 0.001$).

Hip fractures 2019 vs 2020

The most common type of fracture was pertrochanteric (31.A) both in 2019 and 2020. Despite the sharp decrease in the admissions, the number of patients with a hip fracture increased, compared to 2019, when they represented 53% of the admissions. According to the AO Trauma classification, 31.A2 and 31.A3 fractures were more frequent in 2020 than in 2019, and this could contribute to the higher rate of complications and mortality during hospitalization in addition to SARS-CoV-2 infection (Table 2). Medical complications appeared in 50% of patients in 2020 (52% of them related to COVID-19), and over 20% of patients in 2019 ($P < 0.001$). The surgical complications rate was very similar in both periods (3.8% in 2020 and 5.6% in 2019), and no statistical differences were found.

Polytrauma patients

Polytrauma patients and high energy fractures were more common in 2019 (24%) than in 2020 (11.5%), due to lockdown measures implemented by the National Government. The main difference between both periods was the injury mechanism. In 2019, we recorded traffic accidents and suicide attempts as the most common mechanisms. Polytrauma injuries after car crashes or motorcycle accidents were less frequent in the studied period of 2020. After a few days, lockdown measures were modified and construction work was permitted again. Accidents at work then became one of the main causes of injury, with similar numbers of suicide attempts after falls from height.

Other fractures

The most relevant drop-in was observed in ankle fractures, with 6 cases who needed surgery in 2020 *vs* 26 surgical cases in the same period in 2019 ($P < 0.05$).

DISCUSSION

Continuing to provide health care to fracture patients became a challenge during the SARS-CoV-2 outbreak. As is widely known, hospitals were organized following internal protocols to maximize security and minimize the risk of nosocomial infection [2].

We wanted to study if all those changes had an impact on the results obtained by our patients after hospitalization and surgery, which is why we compared the 2020 results with a similar cohort in 2019, the aim being that the only difference was COVID-19 and its implications.

We observed that patients affected by SARS-CoV-2 infection were older than the non-infected ones ($P = 0.004$), even though age is not a risk factor for acquiring the

Table 2 Incidence of different hip fractures in 2019 *vs* 2020 according to AO trauma classification

	2019	2020
31.A1	18.2%	21.6%
31.A2	33.8%	40.5%
31.A3	6.5%	13.5%
31.B	41.6%	24.3%

infection; some colleagues found similar results[3], and age is a factor to take into consideration during surgery planning.

COVID-19 often presents thrombotic complications[4], which is a reason why some colleagues had hypothesized that patients under anticoagulant or antiplatelet therapy could develop fewer complications or less severe manifestations of COVID-19. We did not find a relationship between the use of these drugs and the severity of COVID-19 infection or a different mortality rate. No patients developed these types of complications during follow-up.

According to this early analysis, our management strategies allowed us to operate on patients safely and early, and in-hospital stay was similar to previous data in our center; except for those patients affected by COVID-19. These results are very similar to others previously published[5].

Sadly, the mortality rate was higher than in other periods and this was associated with SARS-CoV-2 infection, as was the readmission rate in the first 30 and 90 d of follow-up. Mortality rates continued to rise during follow-up, similar to results found by our Italian colleagues[6]; and as many others described, an increase in mortality rate was foreseeable in this group of patients[7].

Hip fractures and SARS-CoV-2

In some cases, COVID-19 pneumonia conditioned the surgeon's attitude. Some colleagues published that surgery could help patients with COVID-19 by stabilizing their respiratory parameters[8]. In our cohort of hip fractures, 7 out of 73 patients were treated non-operatively, patients with an intracapsular femoral fracture and/or SARS-CoV-2 infection were more frequently managed non-operatively ($P < 0.001$ and $P = 0.03$ respectively).

We tend to consider non-operative management as an option for intracapsular fractures when the patient has some comorbidities or a poor ability to perform everyday activities, as it has been demonstrated that they have a higher risk of complications[9]; however during the pandemic, conservative treatment has also been an option for intertrochanteric fractures in some centers[10]. We did not accept conservative treatment as an option for an intertrochanteric fracture except for those patients that were not suitable for surgery due to their medical condition. In our cohort, just one patient with an intertrochanteric fracture was managed under conservative measures, due to a severe respiratory syndrome-related to COVID-19, who in the end died.

Comparing the data from both groups, the number of patients selected for conservative treatment was very similar in both periods, 11.5% in 2020 and 12.6% in 2019 ($P = 1$). We can summarize that COVID-19 did not condition us towards conservative treatment, and this was only chosen when the patient was not suitable for surgery.

While most lower limb fractures decreased in frequency during this period due to lockdown, the number of hip fractures in the elderly rose even more than the normal annual increase, and we would like to emphasize the importance of this public health issue[11] and highlight the need for preventing the apparition of these fractures[12,13].

Polytrauma patients

After reviewing our data, we can conclude that the incidence of polytrauma did not vary drastically during the COVID-19 outbreak, although the incidence of these injuries decreased due to lockdown measures, compared to data from 2019. As other colleagues have described, what varied was the mechanism of injury, and a noticeable increase in work-related accidents was observed[14].

Other fractures

Conservative therapeutic approach had been an accepted alternative during the spread of COVID-19[15]. In our cohort we recorded a large decrease in surgical

treatment for certain types of fractures, particularly ankle fractures; however, their total incidence also fell, so clear conclusions cannot be drawn. Similar results were published by Park *et al*[16].

Our study has important limitations. Firstly, the short follow-up period is limited, and stronger conclusions could be made once the follow-up period is enlarged. Secondly, patients with fractures located in the upper extremities and spine were excluded, as well as surgical complications and tumoral lesions. This is due to an intention to enter into a criteria agreement, as we are a group of surgeons belonging to an Orthopedic Department, made up of a unit that works together, and kept working together during the outbreak. As a team, we all share the same principles of treatment and clinical management.

CONCLUSION

Notwithstanding the difficulties, we consider that protocols established in our center provided satisfactory results according to short times to surgery and in-hospital stay. The number of patients that were not suitable for surgery was very similar in both periods, 11.5% in 2020 and 12.6% in 2019, so we conclude that SARS-CoV-2 infection was not a criterion for choosing conservative treatment, unless those patients infected with the virus had a poor general condition that made surgery unadvisable as we do with any other health condition. The mortality rate during hospitalization and follow-up was higher than the previous year, but this was related to COVID-19. Complications during follow-up were also increased, the vast majority of which were also related to COVID-19. No differences were found in surgical complications between the different periods.

ARTICLE HIGHLIGHTS

Research background

From February 2020 onwards our country has been hit by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection. At a glance, hospitals became overrun and had to reformulate all the assistance guidelines, focusing on the coronavirus disease 2019.

Research motivation

One year after the start of the pandemic, we present the results of a morbimortality study.

Research objectives

The main objective of this study is to analyze how our department was affected by the outbreak, in terms of morbimortality. As secondary objectives, we analyzed demographic data, admission to hospital-related data, and subgroups analyses for patients with hip fractures and polytrauma.

Research methods

We designed a study based on two sections in our tertiary hospital. The first is a cohort prospective study based on data collected on patients admitted to our unit during the pandemic (from March to April 2020, due to a lower limb fracture or a high energy trauma during the pandemic situation). This cohort completed a minimum of 6 mo of follow-up. The second part consists of the study of another cohort of patients, with the same inclusion criteria but selected in 2019, the only difference between them being the presence of SARS-CoV-2 in 2020 and its implications.

Research results

The number of patients admitted to hospital in 2020 was nearly half of those in 2019. Hip fractures in the elderly represented the vast majority of fractures during the outbreak. The incidence of polytrauma did not vary substantively, although the mechanism of injury did. Patients with a hip fracture associated with a severe respiratory syndrome were mostly selected for conservative treatment. Mortality and readmission rates were higher in the 2020 cohort and during follow-up in comparison with the cohort in 2019. Patients with SARS-CoV-2 infection were admitted to the

hospital for a longer time than the non-infected, and also had a higher mortality rate during hospitalization and follow-up.

Research conclusions

The SARS-CoV-2 disease is not a criterion for not performing surgery. Mortality and readmission rates were higher in the 2020 cohort and during follow-up, in comparison with the cohort in 2019. Hip fractures in the elderly represented the vast majority of fractures during the outbreak. The incidence of polytrauma did not vary substantively although the mechanism of injury did.

Research perspectives

The SARS-CoV-2 disease is not a criterion for not performing surgery.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Clinical outcome after surgery on schwannomas in the extremities

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Abstract

BACKGROUND

Schwannoma is a benign, encapsulated and slowly growing tumor originating from Schwann cells and is rarely seen in the peripheral nerve system. Typical symptoms are soreness, radiating pain and sensory loss combined with a soft tissue mass.

AIM

To evaluate pre- and postoperative symptoms in patients operated for schwannomas in the extremities and investigate the rate of malignant transformation.

METHODS

In this single center retrospective study design, all patients who had surgery for a benign schwannoma in the extremities from May 1997 to January 2018 were included. The location of the tumor in the extremities was divided into five groups; forearm, arm, shoulder, thigh and leg including foot. The locations of the tumor in the nerves were also categorized as either; proximal, distal, minor or major nerve. During the pre- and postoperative clinical evaluation, symptoms were classified as paresthesia, local pain, radiating pain, swelling, impairment of mobility/strength and asymptomatic tumors that were found incidentally (with magnetic resonance imaging). The patients were evaluated after surgery using the following categories: Asymptomatic or symptomatic patients (radiating and/or

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local pain) and those with complications. The follow up period was from the time of surgery until last examination of the particular physician. Multivariate logistic regression analysis was performed to identify independent prognostic factors for postoperative significant symptoms at follow-up.

RESULTS

We identified 858 cases from the institutional pathology register. We excluded cases with duplicate diagnoses (n = 407), pathology not including schwannomas (n = 157), lesions involving the torso, spine and neck (n = 150) leaving 144 patients for further analysis. In this group 99 patients underwent surgery and there were five complications recorded: 2 infections (treated with antibiotics) and 3 nerve palsies (2 involving the radial nerve and one involving the median nerve) that recovered spontaneously. At the end of follow-up, 1.4 mo (range 0.5-76) postoperatively, we recorded a post-operative decrease in clinical symptoms: Local pain 76% (6/25), radiating pain 97% (2/45), swelling 20% (8/10). Symptoms of paresthesia increased by 2.8% (37/36) and there was no change in motor weakness before and after surgery 1% (1/1). Multivariate analysis showed that tumors located within minor nerves had a significantly higher prevalence of postoperative symptoms compared with tumors in major nerves (odds ratio: 2.63; confidence intervals: 1.22-6.42, P = 0.029). One patient with schwannoma diagnosed by needle biopsy was diagnosed to have malignant transformation diagnosed in the surgically removed tumor. No local recurrences were reported.

CONCLUSION

Surgery of schwannomas can be conducted with low risk of postoperative complications, acceptable decrease in clinical symptoms and risk of malignant transformation is low.

Key Words: Schwannoma; Extremities; Surgery; Removal; Symptoms; Outcome

Core Tip: Schwannoma is a benign slowly growing tumor which is most common in the central nerve system. Peripheral schwannomas can give symptoms as numbness, local- and radiating pain. Recent studies proves surgical excision can be made with low expectations for complications and a high rate of remission. Never the less, some patients show up with consisting and significant symptoms after surgery. Our study showed that location of tumor on the nerve is of importance when evaluating patients' clinical symptoms post-operatively.

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INTRODUCTION

Schwannomas are one of the most common benign tumors in the peripheral nervous system. They originate from Schwann cells and account for about 5% of all tumors in the upper extremity. The most common presentation of a schwannoma is as a slowly growing, non-invasive single mass with a diameter ranging from 10–250 mm[1]. Patients present most commonly in their third to fifth decades of life with no racial and gender difference[2-5]. Symptoms described in the literature are mainly sensory as radiating pain, local irritation and sensation of a heavy mass. Primary motor involvement has also been described leading to paresis and eventually paralysis[6].

Schwannomas is commonly diagnosed using magnetic resonance imaging (MRI) but ultrasound and clinical examination is also well described[7,8].

Malignant peripheral nerve sheath tumors are rarely reported to have arisen from a primary schwannomas but when this occurs the reason ought to be malignant transformation of Schwann cells[9]. There are few studies documenting the malignant transformation of schwannomas[10,11]. The aim of our study was to describe the pre- and postoperative symptoms in patients treated surgically for benign schwannomas and examine whether tumor size, anatomical location or specific nerve location had an impact on the clinical symptoms prior to and after surgery. We also investigated the rate of malignant transformation.

MATERIALS AND METHODS

In this single center retrospective study design, all patients who had surgery due to benign schwannoma from May 1997 to January 2018 were included in the study. Patient data were collected both from our institutional pathology database and patient files.

To make sure no schwannomas were missed in the patients' data files for the study, we conducted a search in the pathology register that included all nerve sheath tumors. We found 858 cases including schwannoma, neurofibroma, neuroma and malignant schwannoma (ICD Codes D36.10; D36.11; D36.17; C47).

We excluded the following: Duplications of patients (n = 407), pathology other than solitary schwannoma (Schwannomatosis, Neuromas and Neurofibromas) (n = 157), surgery performed in the torso, spine, neck, pelvis and retroperitoneum (n = 150) and conservatively treated schwannomas (n = 45) thus leaving 99 patients treated surgically for further analyses (Figure 1).

By using data from patient files, we analyzed age, sex, data on nerve involvement including site and branch involved, pre- and postoperative symptoms and complications. We measured the size of the tumor by examining the patient's pre-operative MRI. Post-operative symptoms and objective findings were recovered from patient records. Patients were not followed up further if they were symptom free at the first postoperative examination at two weeks. Symptoms were classified as either paresthesia, local pain, radiating pain, swelling, motor involvement and no symptoms (incidental MRI-finding).

The patients who were symptomatic at end of follow-up were followed up with a custom-made questionnaire January 2018 investigating symptoms before and after surgery.

Those patients who reported new symptoms, recurrence of a mass or unsatisfactory results were offered an MRI-scanning and a follow-up to rule out a recurrence or malign transformation of the schwannoma.

The location of the tumor in the extremities was divided into five groups; forearm, upper arm, shoulder, thigh and leg (including foot). The location of the tumor in the nerve was categorized as either proximal, distal, minor nerve or major nerve. Proximal locations were defined as upper arm, thigh and shoulder and distal locations as leg and forearm. Nerve branches were classified as follows: Minor nerve was defined as schwannoma on muscular or terminal branch and major nerve as tumors located on either ischial-, femoral-, peroneal- or tibia nerves in the lower limb and axillary-, radial, ulnar- or median nerves in the upper limb.

Surgical complications were categorized as infection (superficial or deep), transient paresis and reoperation (all causes). Symptoms categorized as significant were motor paresis and pain (both local and radiating).

The study was cleared by the National Patient Safety Authority (Case numbers 3-3013-1550/1 and 3-3013-1550/2) and by the Data Protection Agency of the Capital Region of Denmark (number: RH-2016-144, I-Suite number.: 04677).

Surgical procedure

A preoperative MRI was used to plan excision and surgical approach. The affected nerve was exposed visualizing the tumor in the center with the proximal and distal healthy nerve ends. By using loupe magnification, nerve fascicles passing outside the tumor were identified and tested with a nerve stimulator and protected. The capsule of the tumor was incised away from nerve tissue. With a blunt dissector the tumor was loosened and removed when possible. If the tumor was attached to nerve tissue a swab was used to loosen the tumor under testing with the nerve stimulator. After removal, the tumor was sent to pathological examination. Hemostasis was secured and the wound closed with vicryl suture in fascia and subcutaneous layers and skin (intracutaneous). All patients were mobilized immediately and discharged from the

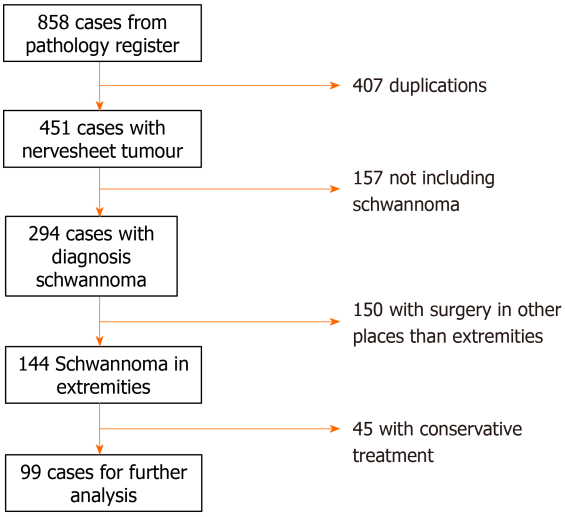

Figure 1 Flow chart for exclusion.

hospital within 24 h.

Statistics

All data are presented as median values together with total range.

Univariate logistic regression analysis was carried out in order to identify predictable factors for significant symptoms at follow-up. Patients with significant symptoms at follow up were compared with those without symptoms. Median values were defined as cut off for both size (24 mm) and age (53 years). The parameters compared were anatomical location and location on a minor or major nerve. A multivariate analysis was performed to identify independent prognostic factors for significant postoperative symptoms. In multivariate analysis no elimination of parameters was performed.

We assumed variables mentioned above were normally distributed. No substitution was made for missing data points. The results of the logistic regression analyses were presented as the odds ratio (OR) together with the 95% confidence intervals (CI) and *P* values below 0.05 are considered significant.

RESULTS

We included 99 patients with the baseline characteristics shown in Table 1. There were 51 men and 49 women. Median age was 53 (17-89) years and median postoperative follow-up was 0.5 (0.5-76) mo.

Preoperative symptoms were observed in 86% (85/99) of the operated patients, the remaining tumors were found incidentally on an unrelated MRI.

We recorded 5 complications: 1 superficial infection (treated with oral antibiotics), 1 reoperation (attempted arthroscopic excision was unsuccessful), and 3 transient nerve palsies (two involving radial and one involving median nerve).

At the end of follow-up, we registered a post-operative decrease in symptoms: local pain 76% (6/25), radiating pain 97% (2/45), swelling 20% (8/10). Symptoms of paresthesia increased by 3% (37/36) and there was no change in motor weakness before and after surgery 1% (1/1). One patient with schwannoma diagnosed by needle biopsy had malignant transformation to Neurofibrosarcoma verified after final surgery (Figure 2). No local recurrences were reported.

Univariate analysis showed a tendency (OR: 2.19; 95%CI: 0.97-5.09; $P = 0.063$) towards a higher degree of significant postoperative symptoms if a minor rather than a major nerve was involved. Multivariate analysis showed that tumor location on a minor nerve had a statistically significant higher risk of having significant symptoms after surgery (OR: 2.63; 95%CI: 1.22-6.42; $P = 0.029$) (Table 2).

Tumor location (proximal or distal), size (24 mm cut off) and age (53 years cut off) had no influence on the surgical outcomes.

Our letter with the questionnaire was sent out to 98% (97/99) of the patients and in total 44% (44/99) replied. Out of these 18 got a second MRI and one patient had an

Table 1 Baseline characteristics (*n* = 99)

Category	
Age, median (range)	53 (17–89)
Male, *n* (%)	51
Tumor size (range) (mm)	24 (5–175)
Preoperative symptoms	Local pain 25%
	Radiating pain 45%
	Swelling 10%
	Motor weakness 1%
	Paresthesia 36%
Nerve branch	Major 51 %
Anatomical localization of tumor	Distal 44%

Table 2 Predictive factors for consisting symptoms after surgical removal of schwannomas

	Univariate		Multivariate		Reference
	OR (CI)	*P* value	OR (CI)	*P* value	
Localization	1.48 (0.65-3.40)	0.354	1.61 (0.69-3.85)	0.276	Proximal
Nerve	2.19 (0.97-5.09)	0.063	2.63 (1.22-6.42)	0.029	Minor
Size	0.84 (0.37-1.90)	0.680	0.91 (0.39-2.13)	0.828	< 24 mm
Age	0.65 (0.29-1.46)	0.301	0.57 (0.23-1.35)	0.205	< 53 yr

OR: Odds ratio; CI: Confidence interval.

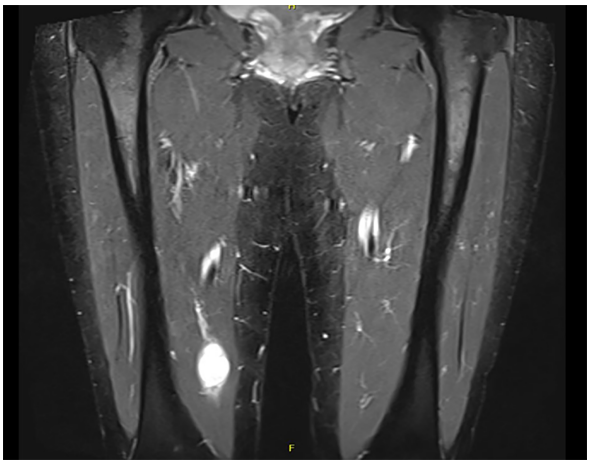

Figure 2 Patient with needle biopsy first diagnosed with schwannoma and after final biopsy showed to have a neurofibrosarcoma.

ultrasound examination as she had contraindication against MRI (because of an ICD-unit). None of the patients who had a second scan had local recurrence or malignant transformation. All the patients whom reported symptoms had scar tissue and adherence mass around the operative field on MR scanning.

DISCUSSION

Our report investigated symptoms and remission rate after surgical removal of peripheral benign schwannomas in the extremities. The most significant finding was

that surgical removal of tumors involving terminal nerve branches showed an increased risk of getting significant symptoms (local or radiating pain) compared to tumors originating from major nerve branches.

We decided to exclude those who had more than one schwannoma and Schwannomatosis as these patients often have many operations, larger operation area, multiple affected nerves and clinical results regarding symptoms after operation can be difficult to categorize. Gosk *et al*[12] included patients with more than one schwannoma[12]. Four of their patients had a total of 14 tumors removed and due to the reasons mentioned above, we believe this complicates analysis of the clinical outcome and could contribute to bias regarding the post-surgical evaluation.

Other articles have investigated complications after surgery of schwannomas and have reported numbers as high as 76.6%[13] and 42.7%[14] where they define loss of sensibility immediately after operation as a complication, even though it is often just transient.

We choose not to include loss of sensibility after surgery as a complication, as we do not consider it to be an adverse effect when studies showed that loss of sensibility had a remission rate of 73%-100%[6,13,15,16]. This difference in the definition made our rate of complications remarkably lower.

Several studies have shown an incidence of neurological deficits after surgery ranging between 1.5% and 80%[6,13,15,17-20]. One reason for this may be the vast variation in follow-up periods. Another contributing factor could be the differences in the definition of neurological deficits. We did not define neurological deficits as a combined group but instead divided it into either local pain, radiating pain, paresis and/or paresthesia. The first two subgroups (local pain and radiating pain) showed a decrease in symptoms with time but the last group (paresthesia) actually showed an increase after surgery. This highlights the importance of recording different components of preoperative deficits before comparing this to changes of neurological status after surgery. Combining sensory and motor deficits could compromise evaluation of outcomes.

Previous reports have shown that the incidence of postoperative complications was significantly higher in patients with larger tumors, tumors on the upper extremities[6,13,15], younger age[6] and tumors originating from the ulnar nerve[21], but these features were not found to be risk factors in our study.

Other studies report that surgery for schwannomas originating from unidentified terminal branches in the muscle or in the skin does not cause postoperative neurological symptoms[22]. Our study proved that this might not be the case as many of our patients who had excisions of tumors involving terminal nerve branches had significant postoperative symptoms.

One possible reason for our finding of higher risk of symptoms after surgery in terminal branches, may be due to the lower soft tissue coverage distally than proximally. Adani *et al*[17] described this phenomenon but found that tumors lying distally and in the upper limb gave more symptoms after surgery, something we could not conclude in our report.

The limitations of our study are inherent in its retrospective design. Also data files show a vast number of surgeons operating schwannoma, and also a great discrepancy in the charts describing clinical symptoms at final exam. The follow-up period was varying among patients and most were relatively short.

CONCLUSION

The authors of this study found evidence for reduction of pre-operative symptoms especially regarding local pain and radiating pain after surgical excision of solitary schwannomas of the extremities and opine that this balances the risks of operative treatment.

ARTICLE HIGHLIGHTS

Research background

Schwannomas are one of the most common benign tumors in the peripheral nervous system and symptoms described in the literature are mainly sensory as radiating pain, local irritation, and sensation of a heavy mass, while primary motor involvement leading to paresis is uncommon.

Research motivation

Surgical removal of schwannomas in the peripheral nervous system is by many surgeons considered a high risk procedure with surgery directly on peripheral nerves and since the literature regarding the clinical results that can be expected after this procedure is relatively sparse, we found it of interest to examine the postoperative results after this procedure.

Research objectives

To evaluate the pre- and postoperative symptoms in patients treated surgically for benign schwannomas and examine whether tumor size, anatomical location or specific nerve location had an impact on the clinical symptoms prior to and after surgery. Finally, we also aimed to investigate the rate of malignant transformation.

Research methods

All patients who had surgery due to benign schwannomas from May 1997 to January 2018 at our institution were identified and included in the study. We registered preoperative baseline data and postoperative symptoms and objective findings were recovered from patient records and a questionnaire. Patients that reported new symptoms, recurrence of a mass, or unsatisfactory results were offered an magnetic resonance imaging-scanning and a follow-up to rule out a recurrence or malignant transformation of the tumor.

Research results

At the end of follow-up we recorded a significant post-operative decrease in clinical symptoms such as local pain and radiating pain. Multivariate analysis showed that tumors located within minor nerves had a significantly higher prevalence of postoperative symptoms compared with tumors in major nerves. One patient with schwannoma diagnosed initially by needle biopsy was diagnosed to have malignant transformation diagnosed in the surgically removed tumor. No local recurrences were reported.

Research conclusions

Surgery of schwannomas can be conducted with low risk of postoperative complications, acceptable decrease in clinical symptoms and risk of local recurrence and malignant transformation is low.

Research perspectives

Future studies should provide prospective data and especially give more detailed information for those few patients who got worsening of their pre-operative symptoms and give further information about the specific characteristics of the patient and the tumor that may affect the outcome of the surgical tumor removal.

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ORIGINAL ARTICLE

Retrospective Study

Osteolysis in total hip arthroplasty in relation to metal ion release: Comparison between monolithic prostheses and different modularities

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Abstract

BACKGROUND

Among the various complications associated with total hip arthroplasty (THA) periprosthetic osteolysis and wear phenomena due to the release of metal particles, are two of the most common and have been reported to be correlated because of inflammatory responses directed towards released particles that generally activate macrophagic osteolytic effects. Therein, new masses known as pseudotumors can appear in soft tissues around a prosthetic implant. To date, there is paucity of reliable data from studies investigating for any association between the above mentioned adverse events.

AIM

To investigate for the existence of any association between serum and urine concentrations of metal-ions released in THA and periprosthetic osteolysis for modular neck and monolithic implants.

METHODS

Overall, 76 patients were divided into three groups according to the type of hip prosthesis implants: Monoblock, modular with metal head and modular with ceramic head. With an average f-up of 4 years, we conducted a radiological

appendix, statistical code, and dataset available from the corresponding author at francesco.manfreda@libero.it. Participants gave informed consent for data sharing.

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evaluation in order to detect any area of osteolysis around the prosthesis of both the femur and the acetabulum. Moreover, serum and urinary tests were performed to assess the values of Chromium and Cobalt released. Statistical analysis was performed to determine any association between the ion release and osteolysis.

RESULTS
For the 3 study groups, the monolithic, modular ceramic-headed and modular metal-headed implants had different incidences of osteolysis events, which were higher for the modular implants. Furthermore, the most serious of these (grade 3) were detected almost exclusively for the modular implants with metal heads. A mapping of the affected areas was performed revealing that the highest incidences of osteolysis were evidenced in the pertrochanteric region at the femur level, and in the supero-external region at the acetabular level. Regarding the evaluation of the release of metals-ions from wear processes, serum and urinary chromium and cobalt values were found to be higher in cases of modularity, and even more so for those with metal head. Statistical linear correlation test results suggested positive correlations between increasing metal concentrations and incidences areas of osteolysis. However, no cases of pseudo-tumor were detected.

CONCLUSION
Future studies are needed to identify risk factors that increase peri-prosthetic metal ion levels and whether these factors might be implicated in the triggering of local events, including osteolysis and aseptic loosening.

Key Words: Total hip arthroplasty; Peri-prosthetic osteolysis; Metal-ions; Monolithic total hip arthroplasty; Modular ceramic headed total hip arthroplasty; Modular metallic headed total hip arthroplasty

Core Tip: In this study a rigorous and statistically proven correlation was made between the release of periprosthetic metal ions in hip arthroplasty and the phenomenon of osteolysis, for severity and localization. A novel aspect of this study was that these evaluations were classified according to the types of prostheses: Monolithic, modular with ceramic head and modular with metal head. This was done so to conduct a contextual comparison between them. In fact, the results appeared quite clear, although further randomized trials and studies of higher scientific evidence will be needed.

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INTRODUCTION

The introduction of total hip arthroplasty (THA) was one of the most important achievements in medical landscape over the last century. It led to an improvement in the quality of life of patients by reducing pain and improving hip functionality. Additionally, surgeons and engineers sought to improve upon the surgical technique and the design of the prostheses, with the aim of reproducing the natural biomechanics of the hip, to improve functionality and longevity of the implant. Likewise, as the technology improved the lifespan of the implants, issues with debris from joint surfaces were encountered.

The advent of modularity in THA brought to orthopedic surgery a great potential gain for restoring biomechanical parameters. In fact, the use of the modular neck prosthesis has the advantage of restoring the offset, the length of the limbs and the neck version, compared to a mono-block prosthesis[1]. The major disadvantages

associated with the modular neck prothesis have been reported to be corrosion, adverse reactions of tissue spaces and increased blood metal ions release[1,2], often leading to mechanical failure of the implant and a possible systemic toxicity. In addition, these adverse events derive from the higher contact-surfaces of implants. In fact, a larger number of elements in a modular system correspond to a larger amount of stress-forces of the implant surfaces.

The active corrosion process of metallic surfaces and the particles released due to wear are a source of soluble metal ions[3] As stated above, orthopaedic implants generate ions and metal particles, most of them of Cobalt and Chrome (CoCr), predominantly of nanometric dimensions[4]. CoCr particles are generally smaller than 50 nm[5], while larger particles can be formed from the smaller size particles agglomeration[6]. Within periprosthetic tissues, particles larger than 0.1 μm are degraded by macrophages, where they are subsequently eliminated from the joint[6]. However, nanometric particles are not able to stimulate phagocytosis by macrophages[7,8]. Ultra-fine particles are generally more inflammatory than fine particles of the same material[9]. The precise mechanism underlying this increased activity is currently unknown. However, it is thought to be the result of a complex series of biological reactions, which depend on particle size, shape, and chemistry and surface properties. Generally, the inflammatory response to the accumulation of particles and ions within periprosthetic tissues is considered one of the major causes of aseptic mobilization and implant failure[10]. In many cases, a thin fibrous membrane develops at the interface between the implant and the bone. This measures 0.1-0.3 mm in width at the femoral component, increasing with implant survival, and > 0.1 mm at the acetabular component. This may be considered a normal response to a foreign body and does not necessarily indicate a damaging inflammatory reaction. However, whenever excess debris is produced and/or macrophages are unable to phagocytize it all, there is a dramatic increase in particles in the periprosthetic tissue[7]. The accumulation of these debris particles tends to increase the infiltration of inflammatory cells (macrophages and mononuclear giant cells) into the tissue. These cells drive the subsequent inflammatory reaction by creating fibrin deposits at the interface. Activation of macrophages leads to the release of inflammatory mediators such as interleukin-6 and tumor necrosis factor-α. In some cases this histiocytic reaction may cause a progressive destruction of the surrounding bone, known as osteolysis, which is mediated by a complex series of biological interactions between activated macrophages, osteoclasts and osteoblasts[8,11]. Osteolysis may depend on the composition and shape of the debris particles. Experimental evidence suggests that osteolysis, that is caused by CoCr particles, may be due to a direct action of inflammatory cytokines, in contrast to osteolysis caused by titanium and polyethylene[12]. With regard to periprosthetic tissues, a significant amount of macrophage cells and a dramatic perivascular accumulation of T-cells and/or B-cells as well as plasma cells were found[13-16].

In addition, a relation between the phenomenon of osteolysis and a pseudotumor has been well described in literature.

It would be worthwhile to investigate for an association among the amount of metal-ion release, the potential consequent osteolysis as a direct response, and the presence of pseudotumors.

To date, few studies have compared modular and monoblock implants clinically, radiographically and tribologically. In this paper, we sought to investigate for the presence of any association between serum and urine concentrations of metal-ions released in THA and periprosthetic osteolysis for modular neck and monolithic implants

MATERIALS AND METHODS

Type of study: Comparative retrospective. Level III Evidence.

The inclusion and exclusion criteria we chose were the following.

Inclusion criteria: (1) Diagnosis: Primary hip OA; (2) Age under 86 years old; (3) First implant prostheses; (4) Use of implants: ABG II Stryker® Modular Neck metal or ceramic ones, and ABG II Stryker® with metal head; and (5) Polyethylene head-acetabulum interface

Exclusion criteria: (1) Patients not present at 2-year follow-up; (2) Septic loosening; (3) Contralateral hip or other prosthetic implants; and (4) Occupational Hazard for metals (Metallic industries; chemical/pharmaceutical industries; textile industries; glass processing; paint processing; photographic processing).

Because of the severe criteria, we could enroll only 81 patients, of which 5 were lost over follow-up (76): 23 monoblock prostheses with metal heads (Group A, Table 1), 21 modular prostheses with ceramic heads (Group B, Table 2), 32 modular prostheses with metal heads (Group C, Table 3). The hip surgical approach adopted was the same for all the patients: Kocher-Langebeck posterior approach. The mean age for Group A was 71.08 years, for Group B it was 71.2 years, and for Group C it was 70.9 years. The mean follow-up period for Group A was 46.10 mo; for Group B it was 39.19 mo; for Group C it was 47.05 mo.

Although we did not conduct any invasive procedures, all patients included in the study signed an informed consensus.

For each patient, we conducted anterior-posterior weight-bearing and axial radiographs on the operated hip. Both of the x-ray-projections were evaluated by the Authors, who looked for possible osteolytic processes and periprosthetic aseptic detachment, and whenever localized, both the site and degree of osteolysis were recorded. The assessment of osteolysis was conducted by revealing the presence of radiolucent areas or lines around the implant in all the zones described by Gruen for the femur and DeLee for the acetabulum[17] (Figures 1 and 2).

As suggested in literature, we quantified grades of osteolysis by measuring radiolucent signs in mm with the software for viewing the radiographs (Figure 3).

The degree of osteolysis was established as follows: Grade 0 no osteolysis; grade 1 osteolysis of 1-2 mm; grade 2 osteolysis between 2.1-3 mm; grade 3 osteolysis > 3 mm [17].

We also measured serum and urinary levels of Cr and Co for each patient, as shown in Tables 1-3. Patients underwent blood and urinary analyses for the study of Cr and Co values at the laboratory of Occupational Diseases of the University Clinic of Perugia. Presently, normal ranges in serum for Cr and Co are defined as 0.1-0.5 μg/L and 0.05-0.1 μg/L, respectively. While normal ranges in urine for Cr and Co are 0.05-0.35 μg/L and 0.1-1.5 μg/L[18].

We investigated for graphical and statistical correlations between levels of Cr and Co in blood and urinary exams, in order to estimate the hypothetical direct effect of higher metallic levels on the processes of osteolysis. For this, we used the statistical test of linear regression.

Finally, in all the cases of either high levels of metallic ions or painful-symptomatic, we recommended an magnetic resonance imaging (MRI), so to exclude for the presence of a pseudo-tumor around the prosthesis or other tissues-lesions.

RESULTS

As stated above, in the radiological evaluations we determined the site and grade of the osteolysis, finding that only Group C presented a grade 3 osteolysis (Figure 4) while grade 2 was prevalent in THAs with a modular neck (16 cases), compared to monoblock THAs (2 cases).

In Figure 4, we present the final report on the observed processes of osteolysis for each group, while in Table 4 we report the localizations of the osteolysis in the peri-prosthetic field along with relative severity (Figure 4 and Table 4).

We calculated the mean values for each group: Serum Cr was 0. 54 (SD 0.56) μg/L (normal range 0. 1-0.2 μg/L) for Group A, 0.67 (SD 0.60) μg/L for Group B and 0.91 (SD 0.69) μg/L for Group C; the mean value of serum Co was 3.59 (SD 3.46) μg/L (normal range 0.05-0.3 μg/L) for Group A, 3.05 (SD 1.76) μg/L for Group B and 5.29 (3.46) μg/L for group C; the mean value of urine Cr was 1.41 (1.33) μg/L (normal range 0.05-0.35 μg/L) for Group A, 2.34 (SD 1.66) μg/L for Group B and. 95 (SD 1.75) μg/L for Group C; the mean value of urine Co was 10.06 μg/L (SD 10.19) (normal range 0.1-1.5 μg/L) for Group A, 14.42 (SD 9.18) μg/L for Group B and 21.73 (SD 12.64) μg/L for Group C (Tables 1-3).

We observed that in the modular THAs groups (B and C) there were higher serum and urinary Cr and Co levels and higher prevalence of osteolysis.

Table 5 reports on the correspondence between mean values of metal-concentration and cases of osteolysis.

Linear regressions conducted in order to quantify a direct relation between ion-release and osteolysis revealed a positive result (where positivity corresponds to $P > 0$ at linear regression) for every test; though there were varying degrees of significance for each test.

Cr levels from blood exams showed a coefficient of linear regression equal to 0. 048 for grade 2 of osteolysis and 0.101 for grade 3 osteolysis.

Table 1 Patients with monolithic total hip arthroplasty

Group A					
Patient	**Age**	**Cr serum (μg/L)**	**Cr urine (μg/L)**	**Co serum (μg/L)**	**Co urine (μg/L)**
1	58	0.53	0.69	3.9	6
2	63	0.14	0	0	0.76
3	69	0.92	2.71	3.22	14.53
4	76	0.8	2.14	11.1	34.9
5	77	0.07	0.11	0.1	0.1
6	65	no	1.48	5.03	14.9
7	71	0.1	0.4	0.82	0.2
8	74	0.08	0.61	0.73	2.1
9	75	0.5	1.13	4.3	9.6
10	78	0.77	2.94	10.65	27.5
11	79	2.05	4.36	7.92	17.4
12	75	0.7	1.7	4.6	9.4
13	65	0.37	2.3	7.84	26
14	75	1.14	3.86	6.38	24.2
15	70	0.1	0.1	0.1	0.1
16	69	0.3	1.25	1.77	7.1
17	72	0.34	0.04	0.1	0
18	71	0.76	1.07	2.06	9.3
19	74	0.1	0.09	0.67	0.1
20	65	0.1	0.22	1.34	3.9
21	64	0.1	0.52	0.34	0.2
22	72	1.87	3.69	7.25	12.38
23	78	0.1	1.02	2.41	10.7
Mean	71.08	0.54	1.41	3.59	10.06
ST.DEV		0.56	1.33	3.46	10.19

Coefficients for Cr in urine resulted being 0.21 for grade 2 osteolysis and 0.37 for grade 3; resulting in a stronger correlation, compared to the Cr in the blood.

Coefficients for Co in the blood resulted being 0.17 for grade 2 of osteolysis and 0.66 for grade 3 (both stronger than Cr). Whereas, coefficients for Co in the urine resulted being 1.51 for grade 2 of osteolysis and 3.16 for grade 3.

Graphs below (Dispersion graphs) show that, although there having been a variability in coefficients of linear regression for the different exams, every test result exhibited a regular tract of linear correlation, except for the serum cobalt values (Figure 5).

As for pseudotumors, of the few MRI tests we were able to carry out, there were no diagnosed cases. Additionally, all patients with loosening of the THA met exclusion criteria, so we could not conduct a correlation between the levels of metals and loosening of THA.

DISCUSSION

Corrosion at the stem-neck junction was first described in 1980[19]. Neck-to-stem wear is more significant than the head-to-neck junction, due to the higher mechanical stresses and an increased lever arm in the former[20].

Table 2 Patients with modular/ceramic head total hip harthroplasty

Group B					
Patient	**Age**	**Cr serum (μg/L)**	**Cr urine (μg/L)**	**Co serum (μg/L)**	**Co urine (μg/L)**
24	68	1.56	3.9	4.19	19.2
25	71	0.1	2.34	2.09	21.15
26	69	0.38	1.59	2.3	15.2
27	70	0.67	1.91	0.61	0.2
28	71	2.25	7.52	5.6	17.7
29	75	0.77	2.36	6.33	19.5
30	55	0.44	1.55	3.76	19.9
31	74	0.53	1.9	3.4	23.9
32	76	0.55	1.94	2.95	29.4
33	74	0.18	0.24	1.83	4.7
34	69	0.11	1.54	0.85	0.2
35	81	0.2	1.28	1.79	2.1
36	78	0.5	0.49	3.93	12.5
37	65	0.38	3.89	1.44	12.4
38	74	1.03	2.59	6.28	26.4
39	79	0.73	3.19	2.55	4.7
40	72	0.35	1.57	1.93	16
41	73	0.24	0.78	2.19	5.3
42	55	1.13	1.97	1.93	7.2
43	71	0.1	1.41	0.46	27.2
44	77	1.96	3.48	3.63	24.4
Mean	71.28	0.67	2.34	3.05	14.42
ST.DEV		0.60	1.66	1.76	9.18

Our study suggester this condition, highlighting a greater degree of osteolysis for the proximal portion of the femur (zones 1 and 7).

The choice of materials have been reported to affect the durability and survival of the implant. In current-day hip prostheses, the physical properties of CoCr provide an ideal surface for supporting the load and movement with minimal degradation over a long period. The CoCr Mo neck has increased rigidity and wear resistance compared to Ti6Al4V[21]. One possible cause of corrosion is the failure of the stem, due to a loss of tension of soft tissues, that creates micromovements of the neck; also inappropriate neck orientation on the stem creates a stress concentration on the neckline; impingement between the femoral neck and the acetabular cup, osteolysis and fretting are other possible causes of dissociation[21,22]. In addition, the formation of pseudotumors is a known complication of modular neck prostheses, even though there is no widely held consensus regarding a possible correlation with urinary and blood metal ions levels[23]. The pathophysiology of these lesions is not known, although it is assumed to be a consequence of local chronic inflammation, due to the release of metal particles causing necrosis and cell cytotoxicity[22-26]. Some authors have reported that patients with pseudotumors have higher chromium and cobalt serum levels, compared to patients without pseudotumors[27]. Furthermore, over the last decade, physicians have described additional adverse effects beyond osteolysis, including pseudotumors and loosening caused by metallosis. In fact, several studies have described how Metal-on–Metal prostheses may be a potential cause of ALVAL lesions[28]. ALVAL is short for "Aseptic Lymphocyte-Dominant Vasculitis-Associated Lesions" a histological entity denoting a chronic inflammatory response to metal particles, as a T-lymphocyte-mediated type IV hypersensitivity reaction. Specifically, the particles activate cytotoxic T-lymphocytes and macrophages, which in turn leads

Table 3 Patients with modular/metallic head total hip arthroplasty

Group C					
Patient	**Age**	**Cr serum (μg/L)**	**Cr urine (μg/L)**	**Co serum (μg/L)**	**Co urine (μg/L)**
45	84	1.78	4	7.02	27.7
46	73	0.9	4.89	9.8	28.9
47	67	2.19	8.4	5.1	19.1
48	73	0.27	2.56	4.43	24.9
49	69	1.26	5.04	8.56	40.1
50	68	0.26	0.8	3.01	15
51	73	0.32	3.18	3.2	18.2
52	74	0.1	1.96	2.7	3.5
53	62	0.84	2.96	3.5	12.3
54	79	0.81	3.27	4.45	19.7
55	71	0.55	2.72	3.86	18.6
56	78	2.5	1.9	5.22	14.8
57	73	0.84	1.99	0.46	7.5
58	59	1.31	3.8	4.77	25.3
59	75	0.19	2.99	4.03	22.5
60	59	0.39	0.88	0.76	7.89
61	74	0.9	3.5	4.56	24.7
62	52	0.55	0.98	5.55	19.8
63	64	0.7	2.21	4	14.5
64	85	0.59	7.19	5.72	41.6
65	72	1.94	4.69	7.14	41.9
66	77	0.15	1.94	2.17	16.1
67	71	0.1	1.58	1.33	7.9
68	72	1.4	3.57	8.84	35.4
69	85	1.24	2.07	13.78	60.2
70	32	2.65	1.77	7.03	16.7
71	79	1.27	3.28	2.09	18.2
72	79	0.84	1.7	4.52	17
73	74	0.96	3.89	15.47	36.8
74	60	0.14	1.05	4.94	11.16
75	79	0.49	2.41	1	6
76	78	0.75	1.5	7.22	18
Mean	70.93	0.91	2.95	5.29	21.73
ST.DEV		0.69	1.75	3.41	12.64

to tissue damage[29].

Joint prostheses in CoCr are not subject to standard biological monitoring and the acceptable levels of CoCr in the blood and urine have yet to be established. To date, it is uncommon practice to measure CoCr serum and urinary levels in patients who had undergone prosthetic implant surgery. There is no standardized assessment for maximum levels, either for either blood or urine levels, which might assist surgeons in patient management; instead surgeons can rely upon only clinical symptoms and/or adverse reactions. Therefore, although there is no currently held agreement on what

Table 4 Localization of osteolysis in peri-prosthetic field

	Group A	Group B	Group C
Site of osteolysis			
Gruen zone 7	2	2	4
Gruen zone 1	2	6	12
DeLee zone 1 and 2	5	3	3

Table 5 For every group mean values of blood and urinal concentration of Chrom and Cobalt are related to cases of osteolysis

	Cr Serum (μg/L)	Cr urine (μg/L)	Co serum (μg/L)	Co urine (μg/L)	Cases of Gr. 2 osteolysis	Cases of Gr. 3 osteolysis
Group 1	0.54	1.41	3.59	10.06	2	0
Group 2	0.67	2.24	3.05	14.42	7	0
Group 3	0.91	2.95	5.29	21.73	9	3

Cr: Chrom; Co: Cobalt.

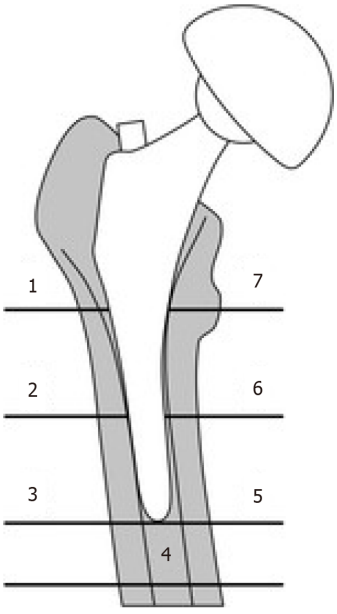

Figure 1 Gruen's classification for femural osteolysis.

the possible decision limits could be for increases in blood and urine metal levels, any elevation should always be considered relevant and worthy of attention.

While there have been studies that have analyzed these events from a pathophysiological perspective, it is evident that in literature there have been few studies that have been designed with a clinical, radiological and tribological approach for patients with modular and monoblock prostheses, regardless of the coupling of metals and non-metallic material (ceramic, polyethylene) used in their modularity.

For the most part, most studies have statistically evaluated ion elevations relating to the type of prostheses, whereas few have correlated osteolytic events and/or conducted clinical follow-up. Another limitation of past studies concerns their short follow-ups, with only a few studies planning periods longer than 40 mo.

In 2007, Daniel *et al*[30] conducted a four-year follow-up after THAs in young and active patients. Like in our study, the authors reported significant increases in the levels of metal ions at 1-year follow-up, compared to pre-operative times. At 4-year follow-up, the same Authors observed a progressive reduction in these levels; statistically significant for Cr but not for Co[30].

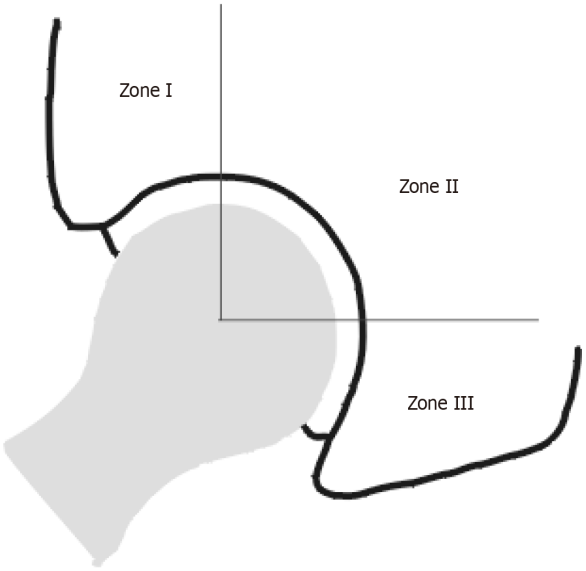

Figure 2 DeLee-Charney's classification for acetabular osteolysis.

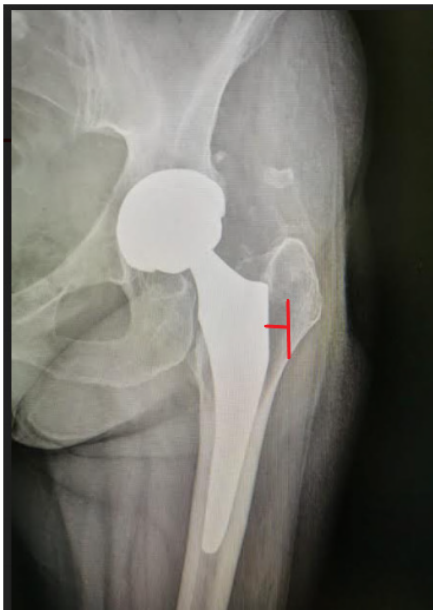

Figure 3 Measurement of grades of osteolysis.

In 2020, Pozzuoli *et al*[31], were able to perform a 7-year follow-up, from which they reported a revision-rate for MOM prostheses where they conducted clinical and radiographic evaluations in relation to metal-ion release[31].

For our study results, we saw how the release of metal ions could, either directly or indirectly, set off the activity of the osteoclasts, and might, therefore, have been responsible for periprosthetic bone resorption, and in some cases for aseptic loosening of the implant itself. From our radiogram findings, it is evident (Graph I) that the cases of marked osteolysis were only in Group C, which was also the group with the most cases of grade-two osteolysis. We can therefore affirm that, in our study, a greater release of metal ions corresponded to a greater number of osteolysis cases.

The statistical tests of the linear regression used, generally showed positive correlations between detected increases in the values of metal ions and the severity of osteolysis.

However, these results need to be challenged by further investigations. Our sample of patients underwent investigations that could not be complete, including biomechanical tests and/or longer follow-up. Unfortunately, MRI was not performed on all the patients in this series, and when done so, it could not be performed in a standardized

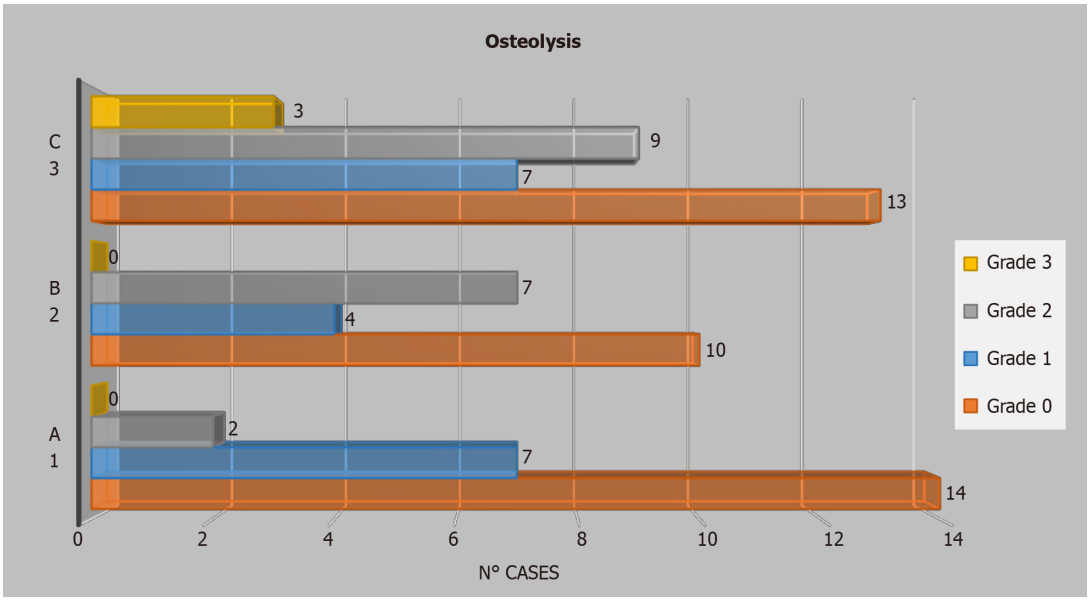

Figure 4 Cases of osteolysis and relative severity for every group.

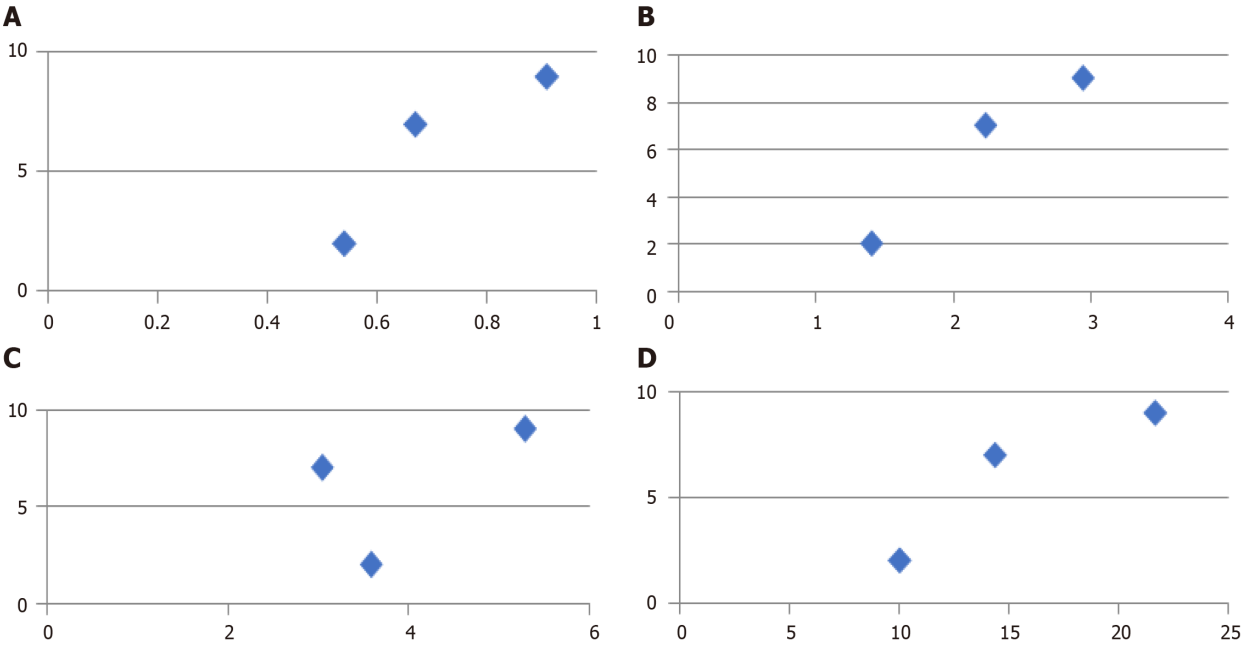

Figure 5 Relation between serum chrome, urine chrome, serum cobalt, urine cobalt and osteolysis. A: Serum chrome and osteolysis; B: Urine chrome and osteolysis; C: Serum cobalt and osteolysis; D: Urine cobalt and osteolysis.

manner. This made those few examinations, neither clinically nor statistically comparable. So, it was not possible to hypothesize on a relationship between either the phenomenon of inflammatory lesions and the degree of metal release or the severity of periprosthetic osteolysis.

CONCLUSION

Periprosthetic osteolysis in total hip replacement is one of the most significant mid- and long-term adverse events that has been described over the years. The cause of this event has been widely debated, with a wide consensus on a macrophage inflammatory response due to the presence of metal ions released from the implants caused by wear mechanisms. Our study results indicate a direct quantitative, as well as qualitative relationship, between the release of the most common periprosthetic metal ions in

THAs (Cr and Co) and the presence of periprosthetic osteolysis. Furthermore, our results showed how modularity in THAs has irrefutable biomechanical advantages but is, however, associated with both a higher degree of metal ion release and greater prevalence of osteolysis events. These increases were even greater when metals rather than ceramic components were detected in the modularity.

To obtain a robust level of evidence, future randomized and controlled trials should be designed to identify further risk factors that could affect the levels of metal ions, which could also be associated either systemic adverse effects or local events, such as osteolysis, aseptic loosening and/or tissues-lesions.

ARTICLE HIGHLIGHTS

Research background

Osteolysis is one of the most common and important adverse reactions to total hip arthroplasty (THA). Therefore it's important to define if there are conditions that facilitate its occurrence.

Research motivation

There is a lack of works studying the correlation between metal ions levels and osteolysis and its different prevalence between modular THA and monolithic prostheses.

Research objectives

Studies analyzing these topics would help the surgeons in the choice of the implants and in the in a correct patients' follow-up. So that we designed this work aiming to have a comprehensive vision of a complication, such as the osteolysis, in THA.

Research methods

We enrolled 76 patients who underwent an operation of first implant of THA, with no other prosthesis and no Cobalt and Chrome (CoCr) work exposure. We divided them in three groups: Patients with monoblock prosthesis with metal head (Group A,), patients with modular prosthesis with ceramic head (Group B), patients with modular prosthesis with metal head (Group C). We analyzed the presence, if any, of osteolysis, its localization and the serum and urinary metal ions levels (Cr and Co).

Research results

We found out a direct correlation between the release of periprosthetic metal ions and osteolysis, also this study highlights that modularity is related to a higher metal ion release and osteolysis events.

Research conclusions

Our study reveals that there is a correlation between metal ions levels and presence and severity of osteolysis and that this is more evident in modular THA, due to higher corrosion.

Research perspectives

Obviously there is a need for more studies to obtain a good level of evidence and confirm these findings.

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ORIGINAL ARTICLE

Clinical Trials Study

Short-term effectiveness of high- and low-intensity percutaneous electrolysis in patients with patellofemoral pain syndrome: A pilot study

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Author contributions: Valera-Calero JA conceived and designed the study; Valera-Calero JA, Varol U, and Sánchez-Mayoral-Martín A contributed to data acquisition; Valera-Calero JA analyzed and interpreted the data; Valera-Calero JA drafted and critically revised the manuscript; Valera-Calero JA contributed to the statistical analysis and supervised the study.

Institutional review board statement: This manuscript was revised and approved by the Institutional Ethics Committee of Clinical Research of Alfonso X el Sabio University (UAX 26-02-2020).

Clinical trial registration statement: The study protocol is prospectively registered and available at ClinicalTrials.gov (NCT04390438).

Informed consent statement: All participants read and signed a written consent prior to their participation in the study.

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Abstract

BACKGROUND

Unilateral patellofemoral pain syndrome (PFPS) is the most frequently diagnosed knee condition in populations aged < 50 years old. Although the treatment of myofascial trigger points (MTrPs) is a common and effective tool for reducing pain, previous studies showed no additional benefits compared with placebo in populations with PFPS. Percutaneous electrolysis is a minimally invasive approach frequently used in musculotendinous pathologies which consists of the application of a galvanic current through dry needling (DN).

AIM

To evaluate changes in sensitivity, knee pain perception and perceived pain during the application of these three invasive techniques.

METHODS

A triple-blinded, pilot randomized controlled trial was conducted on fifteen patients with unilateral PFPS who were randomized to the high-intensity percutaneous electrolysis (HIPE) experimental group, low-intensity percutaneous electrolysis (LIPE) experimental group or DN active control group. All interventions were conducted in the most active MTrP, in the rectus femoris muscle. The HIPE group received a 660 mA galvanic current for 10 s, the LIPE group 220 mA × 30 s and the DN group received no galvanic current. The MTrP and patellar tendon pain pressure thresholds (PPTs) and subjective anterior knee pain perception (SAKPP) were assessed before, after and 7 d after the single intervention. In addition, perceived pain during the intervention was also assessed.

conflicts of interest.

Data sharing statement: The data that support the findings of this study are available from the corresponding author (JA Valera-Calero), upon reasonable request.

CONSORT 2010 statement: This clinical trial followed the CONSORT for pragmatic clinical trials.

Manuscript source: Invited manuscript

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RESULTS

Both groups were comparable at baseline as no significant differences were found for age, height, weight, body mass index, PPTs or SAKPP. No adverse events were reported during or after the interventions. A significant decrease in SAKPP (both HIPE and LIPE, $P < 0.01$) and increased patellar tendon PPT (all, $P < 0.001$) were found, with no differences between the groups (VAS: $F = 0.30$; $\eta^2 = 0.05$; $P > 0.05$; tendon PPT immediate effects: $F = 0.15$; $\eta^2 = 0.02$; $P > 0.05$ and tendon PPT 7-d effects: $F = 0.67$; $\eta^2 = 0.10$; $P > 0.05$). A significant PPT increase in rectus femoris MTrP was found at follow-up in both the HIPE and LIPE groups (both, $P < 0.001$) with no differences between the groups (immediate effects: $F = 1.55$; $\eta^2 = 0.20$; $P > 0.05$ and 7-d effects: $F = 0.71$; $\eta^2 = 0.10$; $P > 0.05$). Both HIPE and LIPE interventions were considered less painful compared with DN ($F = 8.52$; $\eta^2 = 0.587$; $P < 0.01$).

CONCLUSION

HIPE and LIPE induce PPT changes in MTrPs and patellar tendon and improvements in SAKPP, and seem to produce less pain during the intervention compared with DN.

Key Words: Patellofemoral pain syndrome; Electrolysis; Myofascial pain syndromes; Dry needling; Clinical trial

Core Tip: Percutaneous electrolysis is a minimally invasive approach frequently used in lower limb musculotendinous pathologies which consists of the application of a galvanic current through a dry needling (DN) or acupuncture needle which acts as a negative electrode, increasing the pH and cellular necrosis by a local electrochemical reaction. However, the current evidence regarding its application in myofascial trigger points (MTrPs) is limited. Therefore, the aim of this study was to assess the efficacy of percutaneous electrolysis compared with DN in patients with unilateral patellofemoral pain syndrome to improve rectus femoris MTrP and patellar tendon pain pressure thresholds, subjective anterior knee pain perception and induced pain during interventions.

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INTRODUCTION

In patients with knee complaints younger than 50 years, patellofemoral pain syndrome (PFPS) is the most frequently diagnosed condition[1] and is characterized by the high rates of recurrence and chronicity (up to the 90%)[2]. The current evidence suggests a multifactorial etiology[3]. Although the incidence is still unknown and sociodemographic features [*e.g.*, height, weight, body mass index (BMI), and age] are not clearly identified as risk factors, women are more likely to develop PFPS (Odds ratio: 2.23)[4]. In addition, psychological conditions, physical conditioning, larger medial tibial intercondylar distance, vertical ground reaction force, plantar pressure features, onset timing of vastus medialis and lateralis, muscle flexibility (*e.g.*, hamstring, quadriceps and gastrocnemius) and general joint laxity are clinical risk factors for developing PFPS[1].

With regard to PFPS management, although a systematic review and meta-analysis considered that trigger point dry needling (DN) is a common and (in general) effective technique in clinical practice[5] for reducing pain, the evidence shows no additional improvements compared with placebo in patients with PFPS[6]. DN consists of inserting a solid and thin needle into a myofascial trigger point (MTrP) to reduce the muscle stiffness, relieve pain and improve muscle function[7]. MTrPs are located in

taut bands of skeletal muscles and course with pain and motor and neurovegetative dysfunctions[8]. At least one part of the MTrP nociceptive input is derived from blood capillary compression by these taut bands, inducing ischemia and hypoxia in the MTrP area[9]. Reduced levels of oxygen result in decreased pH (to 4.5), activation of acid-sensing ion channels, inhibition of acetylcholinesterase, and liberation of ATP, bradykinins, tumor necrosis factor-alpha, interleukins, serotonin, noradrenaline, substance P and calcitonin gene-related peptide[10-13].

Percutaneous electrolysis is a minimally invasive approach frequently used in lower limb musculotendinous pathologies[14] as preliminary evidence has suggested that it is more effectiveness when compared with DN[15], which consists of the application of a galvanic current through a DN or acupuncture needle which acts as a negative electrode, increasing the pH and cellular necrosis by a local electrochemical reaction [16]. Although the application of this procedure in a MTrP is limited, a previous clinical trial demonstrated greater improvements in pain and function compared with DN in patients with temporomandibular disorders[17].

As a previous study proposed that treatment of MTrP may be an effective way to diminish the pain associated with PFPS[6,18], the aim of this study was to assess the efficacy of percutaneous electrolysis compared with DN in patients with unilateral PFPS for improving rectus femoris MTrP and patellar tendon pain pressure thresholds (PPTs), subjective anterior knee pain perception (SAKPP) and perceived pain during interventions.

MATERIALS AND METHODS

Study design

A parallel-group, controlled, triple-blinded, randomized pilot clinical trial comparing the effects of a single session of high-intensity percutaneous electrolysis (HIPE), low-intensity percutaneous electrolysis (LIPE) and DN applied to the rectus femoris most active MTrP in patients with unilateral PFPS was conducted. This clinical trial followed the Consolidated Standards of Reporting Trials for pragmatic clinical trials [19]. This study was conducted according to the Declaration of Helsinki and approved by the Institutional Ethics Committee of Clinical Research of Alfonso X el Sabio University (UAX 26-02-2020). All participants signed a written informed consent prior to their participation in this study.

Participants

A consecutive sample of patients with unilateral PFPS was screened for eligibility criteria from September 2020 to December 2020 from a private university located in Spain (Camilo José Cela University). To be eligible, participants had to report anterior knee pain of at least 6 mo duration, unilateral pain location, aged 18 to 50 years, with at least one active MTrP present in the rectus femoris muscle. Exclusion criteria included being under pharmacological (*e.g.*, analgesics) or physiotherapy treatment 7 d prior to their participation or during the study, needle fear, prior lower extremity or spine surgery, absence of pain, any musculoskeletal or neuropathic conditions (*e.g.*, peripheral compressive neuropathy, radiculopathy, sarcopenia, fiber ruptures…), traumatic injuries (*e.g.*, fractures or fissures), or any medical condition or contraindication for needling treatment (*e.g.*, anticoagulants).

Randomization and masking

Participants were randomly assigned to the HIPE experimental group, the LIPE experimental group or the DN active control group. Concealed allocation was conducted using a random-number generator (Research Randomizer Vr.4.0). Individual and sequentially numbered cards with the random assignment were folded in sealed opaque envelopes. One external researcher selected the envelope and proceeded with appropriate allocation. Then, the participants' allocation was revealed after baseline data collection. Participants, examiner and rater were blinded to the allocation group.

Interventions

All interventions were performed by an experienced assessor (more than 10 years of experience) in invasive physiotherapy procedures and MTrP management.

As MTrP diagnosis is most commonly conducted by manual palpation, active MTrPs were located following the instructions provided by Fernández-de-las-Peñas

and Dommerholt[20]. Palpation evaluation can be used for the clinical diagnosis of MTrPs in this specific location as it shows acceptable reliability if experienced examiners are involved[21]. All participants were placed in the supine position with their knee passively flexed at 30º. The single intervention was conducted on the most painful active MTrP of the rectus femoris ipsilateral to the affected area. This MTrP was marked with a grid of 2 perpendicular lines and considered to be the one that elicited the highest recognized pain sensation under the same palpation pressure[22] (Figure 1A).

The same procedure was conducted for all groups as follows: After cleaning the skin with chlorhexidine (Lainco® 2%), a DN 0.30 × 40 needle (Agupunt, Barcelona, Spain) was inserted using an in-plane approach with a 70-80º angle to the skin surface until it produced the first local twitch response following a multiple rapid insertion technique, pain response and recognized MTrP referred pain pattern. The needle was statically placed in this location for 30 s in all groups. After placement, the needle was connected to a modified electrosurgical scalpel from an EPTE device (Ionclinics, Valencia, Spain) which acted as a cathode while a surface anode was placed 10 cm proximal to the location of the MTrP (Figure 1B).

For both HIPE and LIPE groups, a Q = 0.0066 coulombs (C) current was set. From the total 30 s intervention time in all groups: (1) The HIPE group received a galvanic current of 660 mA × 10 s and 20 s with no current; (2) The LIPE group received 220 mA × 30 s; and (3) The DN group, although the needle was connected to the device, received no current during the 30 s. Finally, hemostasis using a cotton swab was performed for 1 min in order to avoid post-needling soreness[20].

To ensure participants, examiner and rater blindness, one external assessor set the device settings according with the group allocation (660 mA × 10 s; 220 mA× 30 s; or none) and the same sounds were emitted for all groups at the start of the intervention and after 30 s.

Outcomes

Outcomes were evaluated before, immediately after and 7 d after the single intervention by an assessor blinded to the subject allocation group.

The primary outcome measure was the PPT of the most active MTrP. In addition, patellar tendon PPT, SAKPP and perceived pain during the intervention were the secondary outcomes.

As patients with PFPS showed lower PPTs compared with controls, PPTs were considered a pain sensitivity indicator[24]. First, PPTs were assessed using the analogic algometer Fischer FPN100. Two locations were unilaterally examined by the same rater: (1) MTrP; and (2) Patellar tendon (at the midpoint between the lower edge of the patella and tibial tuberosity)[25]. We performed three evaluations at each point with a 30 s rest, increasing the pressure at a rate of 1 kg/s and the average (kg/cm^2) was recorded for analysis. Prior to the evaluation, the patients received standardized instructions to signal the first change from pressure to pain[26].

Second, SAKPP was assessed as an indicator of subjective pain perception using a Visual Analogue Scale (VAS). Patients were asked to identify their level of pain in a 100 mm VAS, where 0 was "no pain" and 100 was the worst imaginable pain[27]. The mean of 3 scores was calculated: The maximum pain perceived during the last 7 d, the minimum pain perceived during the last 7 d, and the current pain[28].

Finally, to assess the tolerability of all the techniques, the pain perceived during intervention was assessed using a VAS. Participants were asked to identify their mean level of pain during the 30 s interventions in a 100 mm VAS.

Treatment side effects

Participants were asked to report any adverse events experienced during or after the interventions (up to the 1-mo duration of this study). Adverse events were defined as sequelae of short-medium term symptoms perceived as unacceptable to the patient and required further treatment using a self-reported document provided to the participants and informed to an external clinician during the study[29].

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics Version 22 (IBM Corporation, Armonk, NY, United States), with a significance level of $P < 0.05$. After verifying the normal distribution of the data, descriptive statistics were used to summarize the sociodemographic and clinical variables. Normal-distributed data were described by means, SD, and 95%CI.

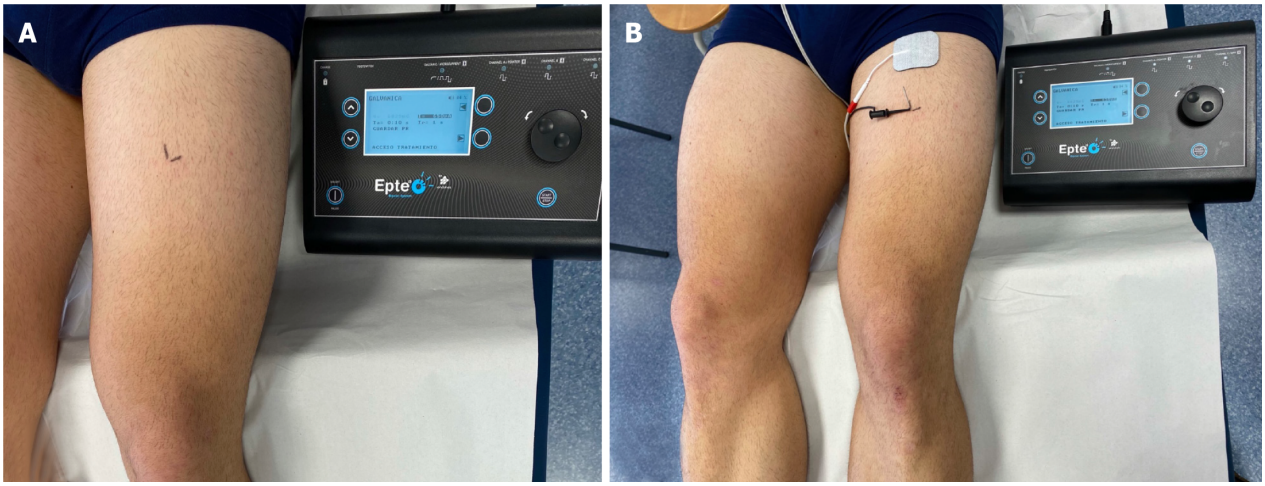

Figure 1 Rectus femoris myofascial trigger point location and needle insertion for all three procedures. A: Rectus femoris myofascial trigger point location; B: Needle insertion for all three procedures.

Comparability of groups at baseline was assessed using a one-way analysis of variance (ANOVA) test (Bonferroni *post-hoc* correction). To assess the effects of the three types of treatment on the primary and secondary outcomes, between-group differences in response to the interventions (HIPE, LIPE or DN) were analyzed using AN(C)OVA repeated measurement (groups *vs* time). For SAKPP, within-groups differences were assessed with the Student *t*-test. The effect size was estimated using η2 when significant. An effect size of 0.01 was considered small, 0.06 medium and 0.14 large. *P* values were assumed to be significant only at < 0.017 (Bonferroni correction: 0.05/3) level[30].

RESULTS

Twenty-one patients with PFPS were initially recruited in September 2020. Six participants were excluded for the following reasons: Fear of needles (n = 2), bilateral PFPS (n = 3), and refused to participate for personal reasons (n = 1). Fifteen patients with unilateral PFPS were finally included and randomized into one of three groups: HIPE (n = 5), LIPE (n = 5) or DN (n = 5). None of the participants in these groups were lost at 7 d follow-up (Figure 2). None of the participants reported adverse effects during the study. Both groups were comparable at baseline as no significant differences in the variables assessed were observed (Table 1).

The mixed-model ANCOVA revealed no significant group * time interactions for the outcomes assessed in this study (all, P > 0.05). Post hoc analyses revealed significant improvements in both MTrP (HIPE and LIPE, P < 0.001) and patellar tendon (all groups, P < 0.001) PPTs and SAKPP (HIPE and LIPE, P < 0.05) at follow-up with no significant within-group immediate changes (P > 0.05) (Tables 2 and 3).

Finally, participants who received the HIPE and LIPE interventions experienced less pain during the intervention compared with the DN group (HIPE *vs* DN and LIPE *vs* DN, P < 0.01) (Table 4).

DISCUSSION

Findings

The aim of this study was to assess the efficacy of two different protocols of percutaneous electrolysis at different intensities and time periods (applying the same electric charge in both groups) compared with DN to improve subjective pain and PPTs at the 7 d follow-up after a single intervention. In addition, perceived pain during the intervention was also assessed. Local twitch responses were found in all the participants during the interventions.

Several findings in this pilot clinical trial were observed. First, the results showed similar improvements in patellar tendon PPTs in all the groups at the 7 d follow up. Second, significant changes in the active rectus femoris MTrP after both electrolysis

Table 1 Sociodemographic features of the total sample and by group

	Subjects, *n* (%)	Age (yr)	Height (m)	Weight (kg)	BMI (kg/m^2)
Sample	15 (100)	25.6 ± 1.9	1.73 ± 0.05	73.5 ± 6.7	24.4 ± 1.6
Intervention group					
HIPE	5 (33.3)	25.4 ± 2.3	1.71 ± 0.05	72.0 ± 7.7	24.5 ± 2.1
LIPE	5 (33.3)	26.8 ± 1.4	1.75 ± 0.04	75.9 ± 6.1	24.6 ± 1.4
DN	5 (33.3)	24.8 ± 1.8	1.73 ± 0.05	72.8 ± 6.9	24.1 ± 1.6

HIPE: High-intensity percutaneous electrolysis; LIPE: Low-intensity percutaneous electrolysis; DN: Dry needling; BMI: Body mass index.

Table 2 Pain pressure thresholds

Variable	Time of measurement	HIPE	LIPE	DN	Mean difference	ANOVA interaction effect	Bonferroni *post-hoc* analysis	
MTrP (kg/cm^2)	Pre	4.20 ± 0.57	4.10 ± 0.54	3.80 ± 0.67	0.10 (-0.95-1.15)[1]; 0.40 (-0.65-1.45)[2]; 0.30 (-0.75-1.35)[1]	$F = 0.65$; $P = 0.562$; $\eta^2 = 0.09$	Group	NA
	Post	3.50 ± 0.61	3.60 ± 0.41	4.00 ± 0.35	0.10 (-0.73-0.93)[1]; 0.50 (-0.33-1.33)[2]; 0.40 (-0.43-1.23)[3]	$F = 1.55$; $P = 0.251$; $\eta^2 = 0.20$	Time	
	7 d follow-up	5.00 ± 1.00	5.00 ± 0.50	4.50 ± 0.70	0.00 (-1.34-1.34)[1]; 0.50 (-0.84-1.84)[2]; 0.50 (-0.84-1.84)[3]	$F = 0.71$; $P = 0.509$; $\eta^2 = 0.10$		Follow up > post, $P < 0.001$[4,5]
Patellar tendon (kg/cm^2)	Pre	5.20 ± 0.83	5.30 ± 0.27	5.20 ± 0.83	0.10 (-1.13-1.33)[1]; 0.00 (-1.23-1.23)[2]; 0.10 (-1.13-1.33)[3]	$F = 0.03$; $P = 0.967$; $\eta^2 = 0.00$	Group	NA
	Post	4.90 ± 1.19	4.70 ± 0.44	5.00 ± 0.79	0.20 (-1.32-1.72)[1]; 0.10 (-1.42-1.62)[2]; 0.30 (-1.22-1.82)[3]	$F = 0.15$; $P = 0.858$; $\eta^2 = 0.02$	Time	Follow-up > pre, $P < 0.001$[4,5,6]
	7 d follow-up	9.10 ± 0.82	9.50 ± 0.35	9.00 ± 0.86	0.40 (-1.66-0.86)[1]; 0.10 (-1.16-1.36)[2]; 0.50 (-0.76-1.76)[3]	$F = 0.67$; $P = 0.526$; $\eta^2 = 0.10$		Follow-up > post, $P < 0.001$[4,5,6]

[1]High-intensity percutaneous electrolysis (HIPE) *vs* low-intensity percutaneous electrolysis (LIPE).
[2]HIPE *vs* dry needling (DN).
[3]LIPE *vs* DN.
[4]Simple within-group effects in the HIPE group.
[5]Simple within-group effects in the LIPE group.
[6]Simple within-group effects in the DN group.
MTrP: Myofascial trigger point; HIPE: High-intensity percutaneous electrolysis; LIPE: Low-intensity percutaneous electrolysis; DN: Dry needling; ANOVA: One-way analysis of variance.

procedures were observed at the 7 d follow-up, but no changes were found after DN. Third, both electrolysis procedures showed lower SAKPP compared with DN. Fourth, surprisingly, both percutaneous electrolysis procedures were perceived as "less painful" when compared with DN. Finally, several statistical estimates for sample size calculation are reported to develop further research with proper statistical power.

Current evidence recommends a multidisciplinary therapeutic approach, including MTrP management to reduce exacerbated mechano-sensitivity and SAKPP and improve knee function[6,18]. Although several invasive procedures have been compared (*e.g.*, DN with MTrP infiltration (with no significant differences between the methods)[31], and superficial *vs* deep DN)[32], the available evidence comparing DN with percutaneous electrolysis applied to MTrPs is limited. To our knowledge, only one clinical trial has compared percutaneous electrolysis and DN in patients with temporomandibular disorders[17]. Although this study reported greater improvements in pain reduction and function recovery, these results cannot be extrapolated (as just one pathology was assessed). In addition, as only one electrolysis procedure was assessed, studies evaluating the same electric charges with different application intensity and time or different electric charges are needed.

Available evidence on the efficacy of DN in pain and disability management of patients with PFPS is also limited with controversial findings[33,34]. The use of DN on quadriceps active MTrPs showed no additional pain or function improvements compared with placebo in a single session[6]. However, although VAS and PFPS disability questionnaires were assessed, it should be noted that PPTs were not

Table 3 Subjective anterior knee pain perception

Variable	Time of measurement	HIPE	LIPE	DN	Mean difference	ANOVA interaction effect	Group: Bonferroni *post-hoc* analysis; time: Student *t*-test	
VAS (0-10)	Pre	4.2 ± 0.5	4.5 ± 1.0	4.6 ± 1.3	0.3 (-1.6-2.1)[1]; 0.3 (-1.5-2.2)[2]; 0.1 (-1.8-1.9)[3]	F = 0.14; *P* = 0.868; η^2 = 0.02	Group	NA
	7 d follow-up	2.9 ± 0.9	2.8 ± 0.7	3.2 ± 0.9	0.1 (-1.5-1.6)[1]; 0.3 (-1.2-1.9)[2]; 0.4 (-1.1-1.9)[3]	F = 0.30; *P* = 0.741; η^2 = 0.05	Time	Follow up < pre, *P* < 0.05[4,5]

[1]High-intensity percutaneous electrolysis (HIPE) *vs* low-intensity percutaneous electrolysis (LIPE).
[2]HIPE *vs* dry needling (DN).
[3]LIPE *vs* DN.
[4]Simple within-group effects in the HIPE group.
[5]Simple within-group effects in the LIPE group.
VAS: Visual Analogue Scale; HIPE: High-intensity percutaneous electrolysis; LIPE: Low-intensity percutaneous electrolysis; DN: Dry needling; ANOVA: One-way analysis of variance.

Table 4 Pain induced during the interventions

Variable	HIPE (*n* = 5)	LIPE (*n* = 5)	DN (*n* = 5)	Mean difference (95%CI)	ANOVA interaction effect	Bonferroni *post-hoc* analysis	
VAS (0-10)	3.2 ± 0.8	3.2 ± 0.8	5.0 ± 1.1	0.0 (-1.4-1.4)[1]1.80 ± (-3.2--0.4)[2]1.80 (-3.2--0.4)[3]	F = 8.52; *P* = 0.005; η^2 = 0.587	Group	*P* < 0.01[4,5]

[1]High-intensity percutaneous electrolysis (HIPE) *vs* low-intensity percutaneous electrolysis (LIPE).
[2]HIPE *vs* dry needling (DN).
[3]LIPE *vs* DN.
[4]Simple between-group effects between HIPE and DN.
[5]Simple between-group effects between LIPE and DN.
VAS: Visual Analogue Scale; HIPE: High-intensity percutaneous electrolysis; LIPE: Low-intensity percutaneous electrolysis; DN: Dry needling; ANOVA: One-way analysis of variance.

included and samples sizes are not representative.

One possible explanation for our results regarding better PPT improvements in the active MTrP following HIPE or LIPE compared with DN could be the combined effect of both mechanic (twitch response) and electric stimuli (electrolysis)[14-16]. Further research is needed to analyze the association between clinical improvements and pH-induced changes.

Limitations

This study had several limitations. First, this was a pilot study. Therefore, our results should be carefully interpreted as the sample size was small and type II errors should be considered. This pilot study was designed to calculate the effect size and provide the sample size needed to obtain appropriate power. Considering the PPT as our primary outcome and setting the effect size f to 0.314 (since eta-squared = 0.09); a = 0.05; 3 groups; and 3 measurements and correlation among repeated measures = 0.3 in the G*Power software V.3.1 for Mac OS, a sample size of 39 subjects is needed to obtain > 0.90 of power. Second, we applied a single session with a limited follow-up. Further research with a larger sample size, number of interventions and longer follow-up is needed to confirm the clinical significance of these study findings.

CONCLUSION

This triple-blinded, randomized clinical pilot study suggests that a single session of high- or low-intensity percutaneous electrolysis, if the same electric charge is applied, induced similar SAKPP and PPTs improvements in patients with unilateral PFPS. Furthermore, both HIPE and LIPE interventions seemed to be better tolerated compared with DN. However, no differences between-groups were found for SAKPP or PPTs. Further research including larger sample sizes, number of sessions and longer follow-up are needed to confirm these findings.

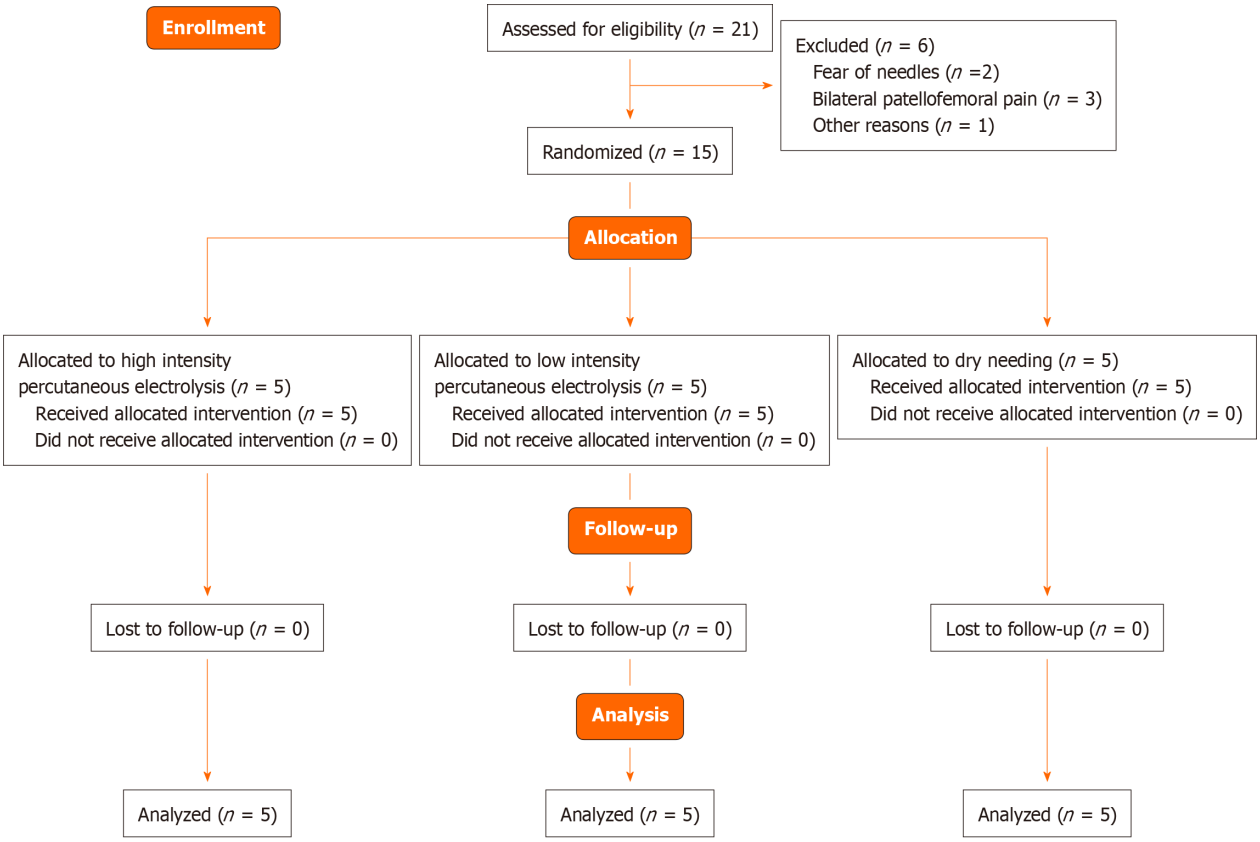

Figure 2 Participants Consolidated Standards of Reporting Trials 2010 flow diagram.

ARTICLE HIGHLIGHTS

Research background

Dry needling (DN) has shown no additional improvements compared with placebo in patients with patellofemoral pain syndrome (PFPS).

Research motivation

Previous evidence suggested that percutaneous electrolysis could be more effective than DN for managing musculoskeletal pain. However, evidence is limited regarding its efficacy in different conditions and locations.

Research objectives

The efficacy of percutaneous electrolysis compared with DN in patients with unilateral PFPS for improving pain pressure thresholds, subjective anterior knee pain perception and perceived pain during interventions were assessed.

Research methods

A parallel-group, controlled, triple-blinded, randomized pilot clinical trial was conducted to compare high-intensity percutaneous electrolysis, low-intensity percutaneous electrolysis and DN applied to the most active myofascial trigger points located in the rectus femoris.

Research results

Both percutaneous electrolysis modalities induced similar short-term effects on pain perception and sensitivity in patients with unilateral patellofemoral pain syndrome. However, percutaneous electrolysis was better tolerated compared with DN.

Research conclusions

Percutaneous electrolysis could be a potential less-painful alternative to DN for reducing pain in patients with unilateral PFPS.

Research perspectives

Further research including larger sample sizes, number of sessions and longer follow-up is needed.

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SYSTEMATIC REVIEWS

Alignment of the hindfoot following total knee arthroplasty: A systematic review

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Abstract

BACKGROUND

There appears to be a close relationship between deformities at the knee joint and at the hindfoot in patients with knee osteoarthritis (OA). Despite this intrinsic link, there is a dearth of studies investigating alterations in hindfoot alignment following total knee arthroplasty (TKA) in patients with knee OA.

AIM

To evaluate changes in alignment of the hindfoot following TKA, foot and ankle clinical outcomes in terms of subjective clinical scoring tools following surgical intervention, and to analyse the level of evidence (LOE) and quality of evidence (QOE) of the included studies.

METHODS

MEDLINE, EMBASE and Cochrane Library databases were systematically reviewed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Studies reporting changes in the postoperative alignment of the hindfoot following TKA were included. The level and QOE were recorded and assessed.

RESULTS

Eleven studies with a total of 1142 patients (1358 knees) met the inclusion/exclusion criteria. Six studies were of LOE II and 5 studies were of LOE III. Patients with preoperative varus knee deformity and valgus hindfoot deformity demonstrated improvement in hindfoot alignment post TKA. Patients with preoperative varus knee deformity and varus hindfoot deformity demonstrated no improvement in hindfoot alignment following TKA. Twelve different radiographic parameters were used to measure the alignment of the hindfoot across the included studies, with the tibio-calcaneal angle most frequently utilised

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(27.3%).

CONCLUSION

This systematic review demonstrated that the hindfoot may display compensatory changes in alignment following TKA in patients with knee OA. However, the marked heterogeneity between the included studies and poor QOE limits any meaningful cross sectional comparisons between studies. Further, well designed studies are necessary to determine the changes and outcomes of hindfoot alignment following TKA.

Key Words: Total knee arthroplasty; Hindfoot alignment; Hindfoot; Knee osteoarthritis; Varus knee deformity; Valgus hindfoot deformity

Core Tip: This current systematic review has found that correction of deformities at the knee joint following total knee arthroplasty typically resulted in improved changes in the alignment of the hindfoot. However, the poor quality of evidence together with the marked heterogeneity between the included studies, underscores the need for further higher quality studies.

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INTRODUCTION

Osteoarthritis (OA) of the knee is one of the leading causes of pain in the older population, affecting 30% of adults over the age of 60 years old[1]. Although the etiology and pathogenesis of knee OA remains unclear, knee malalignment is a significant risk factor for knee OA. Even minor changes in knee alignment can lead to abnormal load distribution across the articular surface of the knee joint, leading to degeneration of the joint capsule and further progression of OA[2,3]. Replacement procedures, such as total knee arthroplasty (TKA), aim to restore neutral mechanical alignment of the lower extremity.

The alignment of the lower extremity is frequently evaluated by extrapolating the femoral-tibial angle (FTA) and the mechanical axis from standing, full-length, plain radiographs[4,5]. However, the FTA and mechanical axis provide an incomplete picture of the alignment of the lower limb as they exclude assessment of the hindfoot axis. There are a variety of reports demonstrating a relationship between varus or valgus deformities at the knee joint and hindfoot malalignment in patients with knee OA[6-16]. In fact, hindfoot malalignment has been shown to improve following TKA in patients with knee OA[6-10,12-16]. This suggests that knee OA leads to compensatory changes in the hindfoot or, hindfoot deformities may predispose the knee to osteoarthritic change. As a result, pre and post-operative radiological imaging of the hindfoot, *via* Cobey views or otherwise, is crucial in the management of knee OA[17].

Despite the intrinsic link between deformities at the knee joint and the hindfoot in knee OA, there appears to be scant literature extensively investigating the relationship between these 2 pathologies. There also seems to be no consensus regarding the optimal imaging method for hindfoot alignment. The purpose of this systematic review was to evaluate changes in hindfoot alignment and foot and ankle clinical outcomes in terms of subjective clinical scoring tools following TKA.

MATERIALS AND METHODS

Search strategy

During October 2019, a systematic review of the MEDLINE, EMBASE and Cochrane Library databases was performed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Figure 1) guidelines. The following search terms were used: [(Hindfoot OR foot OR ankle) AND (alignment OR malalignment OR misalignment OR position OR kinematics OR axis OR anatomy) AND (knee replacement OR TKR OR knee arthroplasty OR TKA)]. The inclusion and exclusion criteria are shown in Table 1. Following retrieval of the data, the titles, abstracts and full text articles were screened by two independent reviewers of all searched studies by applying the aforementioned criteria. A senior author was consulted to arbitrate any disagreements that arose.

Assessment of level of evidence and methodological quality

The level of evidence (LOE) was assessed using the criteria published by the Journal of Bone & Joint Surgery. The methodological quality of evidence (QOE) was assessed using the Modified Coleman Methodology Score (MCMS)[18]. Two independent reviewers determined the MCMS for each study. If any discrepancy existed, the senior author evaluated the available data and a consensus was reached. Excellent studies had a score between 85 to 100 points, good studies scored between 70 to 84 points, fair studies had a score between 55 to 69 points and poor studies scored less than 55 points.

Data extraction and evaluation

Two independent reviewers independently extracted and assessed the data from each study. Patient demographic data and postoperative follow up times were gathered. Radiographic parameters used to evaluate the alignment of the hindfoot, lower extremity and ankle joint were also collected. Data on postoperative clinical outcomes in terms of subjective clinical scoring tools were evaluated.

Statistical analysis

All other statistical analyses were performed using SAS software version 9.3 (SAS Institute, Inc., Cary, NC, United States). Descriptive statistics were calculated for all continuous and categorical variables. Continuous variables were reported as weighted mean and estimated standard deviation, whereas categorical variables were reported as frequencies with percentages. A value of $P < 0.05$ was considered statistically significant.

RESULTS

The search generated 2606 studies. Of these, 11 met the inclusion and exclusion criteria of this systematic review (Table 1). The studies were published between 2004 and 2019.

Patient demographics

From the 11 studies, 1142 patients (1358 knees) with a weighted mean age of 69.1 ± 3.6 years (range, 63.4-74.7), had radiographic imaging of the hindfoot following TKA. The weighted mean postoperative follow-up time was 10.9 ± 9.4 mo (range, 0.75–31.3) (Table 2).

LOE and QOE

Six studies were LOE II and 5 studies were LOE III. The mean MCMS of all included studies was 53.5 ± 8.5 of 100 points. No studies were classified as excellent quality using the MCMS. There was 1 study of good quality, 3 studies of fair quality and 7 studies of poor quality. 8 studies had a large patient cohort ($n > 60$).

Radiologic assessment

The radiologic assessment data are listed in Table 3. Twelve different radiographic parameters were used to evaluate the alignment of the hindfoot. The most commonly utilised radiographic tool was the tibio-calcaneal angle (TCA) in 3 studies (27.3%)[6,7,13]. Other radiographic parameters utilised included the varus-valgus angle (VVA) in 2 studies (18.2%)[8,16], hindfoot alignment view angle (HAVA) in 1 study[10], calcaneal pitch and naviculocuboid overlap in 1 study (9.1%)[14], tibia-hindfoot angle

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Clinical studies related to changes in the hindfoot following TKA	Less than 10 patients
Published in a peer review journal	Case reports
Written in English	Cadaveric studies
Full text version available	Animal studies
	Review articles
	In vivo studies

TKA: Total knee arthroplasty.

Table 2 Study characteristics and patient demographics

Ref.	LOE	Patients, *n* (%)	Knees, *n* (%)	Age (yr)	Sex (M/F)	Follow-up (mo)	MCMS
Chandler and Moskal[6], 2004	2	86	86	N/R	N/R	3	48
Cho *et al*[7], 2017	2	117	195	69.1	8/187	24	66
Hara *et al*[8], 2015	3	100	100	74.3	14/86	0.75	48
Jeong *et al*[9], 2018	2	331	375	68.3	23/308	6	60
Kim *et al*[10], 2018	3	55	65	69.3	N/R	31.3	71
Levinger *et al*[11], 2012	2	19	26	67.5	13/6	12	46
Mansur *et al*[12], 2019	2	72	72	N/R	23/49	3	44
Mullaji and Shetty[13], 2011	2	125	165	66.1	24/101	12	51
Okamoto *et al*[14], 2017	3	75	80	72.5	8/67	24	48
Palanisami *et al*[15], 2020	3	91	121	63.4	29/62	12	58
Takenaka *et al*[16], 2016	3	71	73	74.7	17/56	12	48

LOE: Level of evidence; M/F: Male/female; MCMS: Modified Coleman methodological score.

and varus-valgus index (VVI) in 1 study (9.1%)[15], foot posture index in 1 study (9.1%)[11], the hindfoot alignment angle (HA), hindfoot alignment ratio (HR) and hindfoot alignment distance (HD) in 1 study (9.1%)[9], and the intersection of the load axis of the leg and the calcaneus axis in 1 study (9.1%)[12].

Six radiographic parameters were used to measure the alignment of the lower extremity, the most common of which was the FTA in 4 studies (36.4%)[6,8,11,12]. Other radiographic tools used included mechanical axis in 2 studies (18.2%)[9,14], mechanical axis deviation angle in 1 study (9.1%)[10], mechanical alignment angle in 1 study (9.1%)[7], conventional mechanical axis deviation in 1 study (9.1%)[13], femorotibial mechanical angle in 1 study (9.1%)[15].

Only 3 studies (27.3%) recorded the alignment of the ankle joint, with the talar tilt (TT) utilised in 3 studies (27.3%)[9,10,14], the tibial anterior surface angle (TAS) used in 2 studies (18.2%)[9,10], the ground talar dome angle of foot (GD) and lateral surface angle of distal tibia used in 1 study each (9.1%)[9], the TAS, distal medial clear space (DMCS), and medial tibiotalar joint space (MTTJS) and frontal tibial ground angle (FTGA) were utilised in 1 study each (9.1%)[10].

Changes in hindfoot alignment following TKA

Ten studies evaluated changes in hindfoot alignment following TKA for patients with varus deformity of the knee joint[7-16]. Nine of these studies demonstrated improvement of hindfoot valgus alignment following TKA[7-10,12-16]. Chandler and Moskal[6], Cho *et al*[7] and Mullaji and Shetty[13] showed a mean postoperative improvement in TCA of 3.1°, 3.1° and 2.0° respectively. Hara *et al*[8] and Takenaka *et al*[16] highlighted a mean postoperative improvement in VVA of 3.1° and 3.4° respectively. Jeong *et al*[9] demonstrated a mean postoperative improvement in HA,

Table 3 Summary of outcomes

Ref.	Patients, *n* (%)	Knees, *n* (%)	Knee deformity	Radiographic Assessment			AOFAS		Postoperative outcomes
				Hindfoot	Ankle	Lower limb alignment	Pre-op	Post-op	
Chandler and Moskal [6], 2004	86	86	Both valgus and varus	TCA: Pre-op = 0.4°; Post-op = -0.1°		FTA: Pre-op = 3.6°; Post-op = 6.6°			Both valgus and varus hindfoot alignment improved post TKA Valgus hindfoot alignment remained in valgus alignment post TKA Varus hindfoot alignment remained in varus alignment post TKA
Cho *et al* [7], 2017	117	195	Varus only	TCA: Pre-op = 5.2° valgus; Post-op = 2.1° valgus		Mechanical alignment angle: Pre-op = 10.8° varus; Post-op = 1.8° varus			Valgus hindfoot alignment improved post TKA Severe varus knee deformities had best improvement in hindfoot alignment post TKA
Hara *et al* [8], 2015	100	100	Varus only	VVA: Pre-op = 78.8°; Post-op = 76.7°		FTA: Pre-op = 186.7°; Post-op = 174.4°			Varus hindfoot alignment with varus knee deformity remained in varus alignment post TKA Valgus hindfoot alignment with varus knee deformity improved post TKA
Jeong *et al* [9], 2018	331	375	Varus only	HA: Pre-op = 13.5°; Post-op = 5.8°. HR: Pre-op = 0.2°; Post-op = 0.3°. HD: Pre-op = 11.0°; Post-op = 5.2°	TT: Pre-op = 0.4°; Post-op = 0.1°. GD: Pre-op = 6.5°; Post-op = 0.2°. TAS: Pre-op = 92.0°; Post-op = 92.0°. TLS: Pre-op = 81.8°; Post-op = 81.3°	Mechanical axis: Pre-op = 11.1° varus; Post-op = 0.3° varus			Valgus hindfoot alignment improved post TKA Subtalar joint became more varus post TKA
Kim *et al* [10], 2018	55	65	Varus only	HAVA: Pre-op = 6.1°; Post-op = 5.7°	TT: Pre-op = 1.9°; Post-op = 1.7°. TAS: Pre-op = 85.9°; Post-op = 84.9°. MCS: Pre-op = 2.4 mm; Post-op = 2.6 mm. MTTJS: Pre-op = 2.8°; Post-op = 2.3°. FTGA: Pre-op = 85.6°; Post-op = 86.5°	Mechanical axis deviation angle: Pre-op = 10.0°; Post-op = 1.9°	95.2	91.5	Valgus hindfoot alignment slightly improved post TKA Newly developed ankle pain post TKA was associated with larger degrees of residual varus knee deformity
Levinger *et al*[11], 2012	19	26	Varus only	FPI: Pre-op = 2.9°; Post-op = 2.7°		FTA: Pre-op = -1.2°; Post-op = 4.9°			Increased range of motion of the rearfoot in the frontal plane post TKA No change in static foot pressure post TKA
Mansur *et al* [12], 2019	72	72	Both varus and valgus	Intersection of the load axis of the leg and the calcaneus axis: Pre-op = -3.8°; Post-op = -4.4°		FTA: Pre-op = ?	74.3	89.4	Varus hindfoot alignment with varus knee deformity remained in varus alignment post TKA Varus hindfoot alignment with valgus knee deformity, valgus hindfoot alignment with valgus knee deformity and valgus hindfoot alignment with varus knee deformity all improved post TKA
Mullaji and Shetty[13],	125	165	Both varus and valgus	TCA: Pre-op = 188°; Post-op = 185.5°		CMAD: Pre-op = 34.3 mm;			Valgus hindfoot alignment with varus knee deformity

2011						Post-op = 0.0 mm. GMAD: Pre-op = 31.0 mm; Post-op = -6.0 mm			improved post TKA 87% of patients had persistent valgus hindfoot alignment post TKA
Okamoto *et al*[14], 2017	75	80	Varus only	Calcaneal pitch: Pre-op = 14.9°. Naviculocuboid overlap: Pre-op = 84.7°; Post-op = 65.7°	TT: Pre-op = 13.1°; Post-op = 4.4°. TI: Pre-op = 9.9°; Post-op = 0.8°	Mechanical axis: Pre-op = 5.0°; Post-op = 0.7°	46.6	60.2	Valgus hindfoot alignment with severe varus knee deformity did not improve post TKA Valgus hindfoot alignment with moderate varus knee deformity improved post TKA
Palanisami *et al*[15], 2020	91	121	Varus only	TH: Pre-op = 9.9°; Post-op = 4.7°. VVI: Pre-op = -0.29; Post-op = -0.04		FTMA: Pre-op = 162.0°; Post-op = 178.8°	59.2	88.7	Valgus hindfoot alignment with varus knee deformity improved post TKA TKA restores foot loading pattern medially
Takenaka *et al*[16], 2016	71	73	Varus only	VVA: Preop = 78.2; Post-op = 76.0		FTA: Pre-op = 184.8; Post-op = 173.9			Valgus hindfoot alignment with varus knee deformity improved post TKA Varus hindfoot alignment with varus knee deformity did not improve post TKA

TKA: Total knee arthroplasty; FTA: Femoral-tibial angle; VVA: Varus valgus angle; TH: Tibial hindfoot; VVI: Varus-valgus index; FTMA: Femorotibial mechanical angle; AOFAS: American Orthopaedic Foot and Ankle Society; TCA: Tibio-calcaneal angle; FPI: Foot posture index; MTTJS: Medial tibiotalar joint space; FTGA: Frontal tibial ground angle; HA: Hindfoot alignment; CMAD: Conventional mechanical axis deviation.

HR and HD of 7.7°, 0.1° and 5.8° respectively. Kim *et al*[10] illustrated a mean postoperative improvement in HAVA of 1.4°. Mansur *et al*[12] demonstrated a mean postoperative improvement of hindfoot alignment of 3.6. Okamoto *et al*[14] illustrated a mean postoperative improvement in naviculocuboid overlap of 19.0°. Palanisami *et al*[15] highlighted a mean postoperative improvement in VVI of 0.25.

Okamoto *et al*[14] noted that a cohort of patients with severe varus knee deformity did not show correction of hindfoot malalignment following TKA[14]. Conversely, Cho *et al*[7] showed that patients with severe varus knee deformity had the greatest overall improvement in hindfoot alignment. Patients with a severe varus knee deformity displayed a mean change in HA of 4.0° ± 3.0° in contrast to patients with a less severe varus knee deformity who displayed a mean change in HA of 1.8° ± 2.5°[7].

Three studies highlighted that patients with preoperative hindfoot varus malalignment with varus deformity at the knee joint retained varus hindfoot alignment post TKA[8,12,16].

Two studies investigated alterations in hindfoot alignment following TKA in patients with valgus deformity at the knee joint[12,13]. Both studies recorded improvements in postoperative hindfoot varus alignment. Mansur *et al*[12] reported an increase in mean hindfoot alignment axis of 7.5, while Mullaji and Shetty[13] recorded a mean decrease in TCA of 1.5°. Also, Mullaji and Shetty[13] reported an improvement in postoperative hindfoot valgus alignment, as evident by a decrease in mean hindfoot alignment axis of 3.3.

Changes in ankle joint alignment following TKA

Three studies reported changes in ankle joint alignment following TKA for knee OA[9,10,14]. There was a decrease in the TT postoperatively in 2 studies, indicating a varus shift in the TT[9,14], with no significant change reported in 1 study[14]. The GD shifted towards a valgus alignment in 1 study[9]. The TLS changed significantly in 1 study[9]. The TAS, DMCS, MTTJS and FTGA showed no statistically significant change following TKA.

Subjective clinical outcomes

Clinical outcomes were evaluated using the American Orthopaedic Foot and Ankle Society (AOFAS) score in 4 studies[10,12,14,15]. The weighted mean preoperative AOFAS score improved from 66.1 ± 18.1 to 82.0 ± 12.9 postoperatively at a mean of 17.6 mo of follow-up. One study reported that patients with newly developed ankle

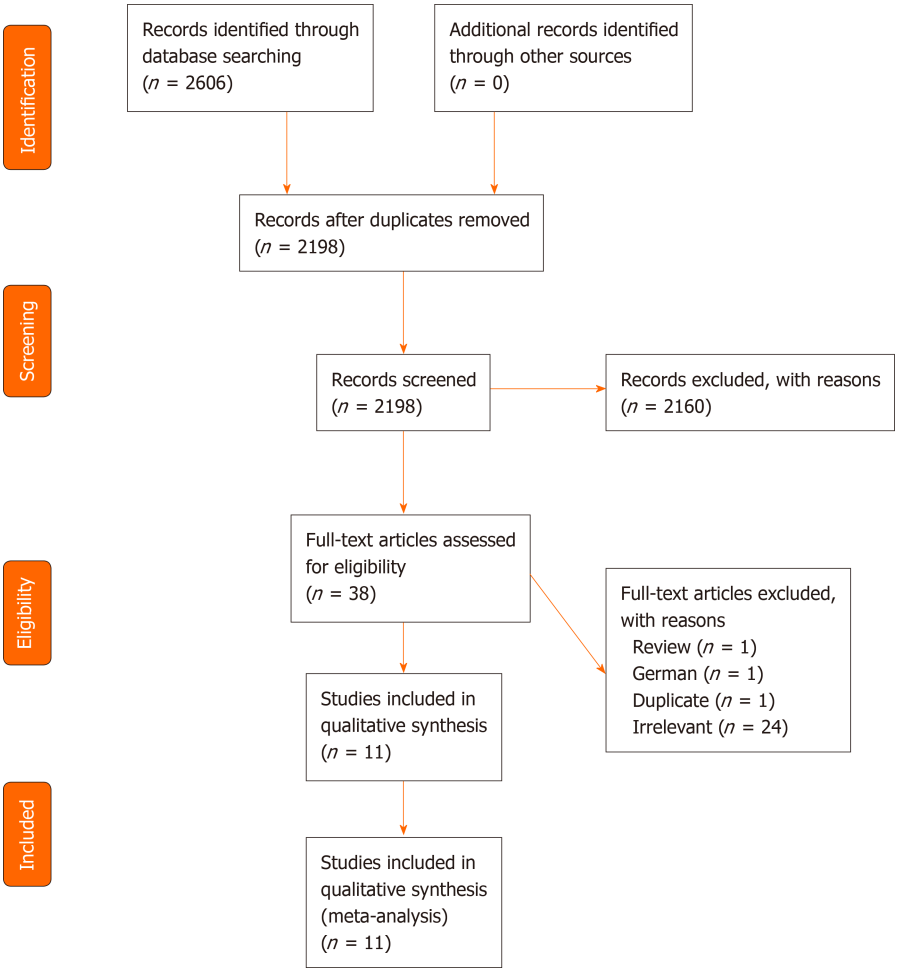

Figure 1 A systematic review of the MEDLINE, EMBASE and Cochrane Library databases was performed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.

pain or who experienced an aggravation of existing pain after TKA had significantly larger degrees of residual varus knee than patients without ankle pain before and after TKA or those with ankle pain before surgery that did not change during the follow-up period[10]. One study demonstrated that patients with severe preoperative varus deformity at the knee had no statistically significant improvement in AOFAS score following TKA

DISCUSSION

This current systematic review has found that correction of deformities at the knee joint following TKA typically resulted in improved changes in the alignment of the hindfoot. However, the poor QOE together with the marked heterogeneity between the included studies, underscores the need for further higher quality studies.

All studies reported that preoperative varus or valgus knee deformity was associated with malalignment of the hindfoot. Typically varus knee OA was accompanied by a valgus hindfoot deformity. Furthermore, the findings of this current review highlights that patients who undergo TKA for a varus osteoarthritic knee with pre-existing valgus hindfoot deformity may display improvements in hindfoot alignment postoperatively. This suggests that these patients may have a residual capacity to compensate for the corrected lower limb malalignment. Interestingly, Cho *et al*[7] reported improvement in hindfoot alignment at 6 wk post TKA but little to no improvement at 2 years postoperatively, suggesting that compensatory changes in hindfoot alignment predominantly occur during the early postoperative period. This lack of improvement in hindfoot alignment at the 2 year follow up point may indicate that following the early postoperative period, there may be no further hindfoot alignment compensation as the knee joint alignment has now been corrected following

TKA. However, Takenaka *et al*[16] recorded improvement in hindfoot alignment at 3 wk post TKA with further improvement noted 1 year post TKA. The discrepancy between these 2 studies highlights that further research is warranted to understand the complex lower limb biomechanical alterations that occur in sequential postoperative time points following TKA.

This current study demonstrated that patients with co-existing varus knee deformities and varus hindfoot malalignment showed no improvement in hindfoot alignment post TKA[8,12,16]. There are several reasons that could explain this resistance to change in varus hindfoot deformity. Firstly, varus feet cause nonparallel alignment of the midtarsal axes, which in turn leads to the foot displaying rigid stability so as to support the body's weight[8]. This may reduce the ability of the preoperative varus hindfoot to change alignment following TKA of a varus osteoarthritic knee. Varus hindfoot is often associated with a rigid or non-correctible hindfoot alignment, either from increase calcaneal pitch or mechanical changes from neuromuscular changes that are not reversible. Charcot Marie Tooth is commonly associated with a varus hindfoot but this is typically not compensated for by knee realignment. In contrast, many valgus hindfoot alignments are correctible and flexible adapting to better alignment in the femoral tibia joint by re-establishing improved hindfoot alignment.

The ability to achieve a neutral alignment is essential if knee re-alignment is to have any measurable impact on hindfoot alignment. Tarsal coalition in valgus hindfeet and CMT and other neurological conditions associated with varus hindfeet will prevent re-establishing normal hindfoot alignment. In addition, advanced post-traumatic osteoarthritis (PTOA) of the ankle or subtalar joint will also prevent neutral alignment of the hindfoot[9]. The ability to change alignment of the hindfoot is critical in survivorship of the knee implant as persistent varus hindfoot deformity post TKA may lead to asymmetric wear, osteolysis and failure of the implant[19].

There were conflicting reports regarding the severity of knee joint deformity and postoperative outcomes. Okamoto *et al*[14] demonstrated that patients with severe varus knee deformity presented with postoperative hindfoot pain and valgus alignment[14]. This may in part be explained by the advanced stage of PTOA in the hindfoot and the advanced stage of knee varus malalignment from delayed operative intervention. Restriction in motion preventing restoration of neutral hindfoot alignment would be expected in the advanced stages of PTOA where peri articular osteophytes and soft tissue cicatrization would prevent choparts and ankle joint motion. In contrast, Cho *et al*[7] showed that patients who underwent surgical intervention for severe varus knee deformity had the best postoperative outcomes but his cohort was younger and had less advanced ankle arthritic change[7]. Further studies are required to determine the correlation between severity of knee deformity and post TKA outcomes, but it does seem that earlier intervention in knee OA is helpful in addressing knee pain but also has downstream effects on hindfoot biomechanical alignment and consequent health of the ankle joint.

This current systematic review has demonstrated that there is marked heterogeneity in the assessment of the alignment of the hindfoot. Twelve different radiographic parameters were utilised across the 11 studies, with the TCA being the most commonly utilised metric in 3 studies[6,7,13]. The lack of consensus regarding what radiographic parameter to utilise to evaluate the alignment of the hindfoot underpins the need for a standardised imaging protocol of the limb following knee arthroplasty. In addition, only 2 studies reported radiographic data at 2 or more sequential operative time points[7,16]. Assessing the alignment of the hindfoot at regular intervals postoperatively may be necessary to determine the time at which correction of hindfoot malalignment occurs and could possibly predict the time at which a surgical realignment of the hindfoot is required to protect the longevity of the knee implant (Table 4).

This current systematic review found that only 4 studies reported pre and postoperative clinical scoring systems, with the AOFAS score utilised in all 4 studies [10,12,14,15]. AOFAS scores tended to increase post TKA, suggesting that correction of lower limb malalignment resulted in improved functional and pain outcomes in the foot and ankle. Interestingly, 1 study demonstrated that patients presenting with new or aggravated pre-existing foot and ankle pain following TKA had a residual varus deformity at the knee joint[10]. Furthermore, Okamoto *et al*[14] reported that patients with severe varus deformity at the knee joint had no statistically significant improvement in AOFAS score, possibly due to loss of residual capacity for compensation in the hindfoot[14]. However, these outcomes should be assessed with caution due to a lack of a validated scoring tool for the foot and ankle following TKA.

Table 4 Hindfoot radiographic parameters

Hindfoot radiographic parameters	Studies, *n* (%)
TCA	3 (27.3)
VVA	2 (18.2)
HAVA	1 (9.1)
Intersection of the load axis of the leg and the calcaneus axis	1 (9.1)
TH	1 (9.1)
Calcaneal pitch	1 (9.1)
Naviculocuboid overlap	1 (9.1)
FPI	1 (9.1)
HA	1 (9.1)
HR	1 (9.1)
HD	1 (9.1)

TCA: Tibiocalcaneal angle; VVA: Varus valgus angle; HAVA: Hindfoot alignment view angle; TH: Tibial hindfoot angle; FPI: Foot posture index; HA: Hindfoot alignment angle; HR: Hindfoot alignment ratio; HD: Hindfoot alignment diameter.

This systematic review has several inherent limitations and/or potential biases. The criterion was limited to MEDLINE, EMBASE and Cochrane Library Database articles published exclusively in English. A further limitation was the marked heterogeneity between studies, in terms of both patient selection and pre and post-operative radiographic assessment. As a result, cross-sectional comparison amongst studies could not be analysed. Another limitation with this review is the poor QOE of the included studies. Lastly, the data was not extracted blindly, but was extracted by two independent reviewers and later confirmed by the lead author.

CONCLUSION

In conclusion, this systematic review demonstrated that the hindfoot typically displays compensatory changes in alignment following TKA in patients with knee osteoarthritis. However, the marked heterogeneity between the included studies and poor QOE limits any meaningful cross sectional comparisons between studies. Further, well designed studies, are necessary to determine the changes and outcomes of hindfoot alignment following TKA.

ARTICLE HIGHLIGHTS

Research background

There are a variety of reports demonstrating a relationship between deformities at the knee joint and hindfoot malalignment in patients with knee osteoarthritis (OA).

Research motivation

The relationship between knee joint deformities and alterations in hindfoot alignment following total knee arthroplasty (TKA) has not been fully investigated to date.

Research objectives

To evaluate changes in alignment of the hindfoot following TKA and foot and ankle clinical outcomes in terms of subjective clinical scoring tools following surgical intervention.

Research methods

MEDLINE, EMBASE and Cochrane Library databases were systematically reviewed. Studies reporting changes in the postoperative alignment of the hindfoot following

TKA were included.

Research results

Eleven studies with a total of 1142 patients (1358 knees) were included. Patients with preoperative varus knee deformity and valgus hindfoot deformity demonstrated improvement in hindfoot alignment post TKA. Patients with preoperative varus knee deformity and varus hindfoot deformity demonstrated no improvement in hindfoot alignment following TKA. Twelve different radiographic parameters were used to measure the alignment of the hindfoot, with the tibio-calcaneal angle most frequently utilised (27.3%).

Research conclusions

The hindfoot may display compensatory changes in alignment following TKA in patients with knee OA. However, the marked heterogeneity between the included studies and poor quality of evidence confounds the generation of robust conclusions from this review.

Research perspectives

Further, higher quality studies are required to determine the changes and outcomes of hindfoot alignment following TKA.

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CASE REPORT

Simultaneous repair of bilateral pectoralis major tendons: A case report

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Author contributions: Okoroha KR, Shah S, Buckley P, and Abbas MJ were members of the patients care team and reviewed the literature and contributed to manuscript writing; Okoroha KR and Shah S were the orthopaedic surgeons who managed the patient operatively; Buckley P and Abbas MJ recorded the operative technique and captured images of the patients in the perioperative setting; all authors contributed to revisions of the manuscript and issued approval on the draft submitted.

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Abstract

BACKGROUND

Injuries to the pectoralis major are infrequent, with only a few hundred cases currently recorded in the literature.

CASE SUMMARY

We report a case of a patient who sustained bilateral pectoralis major tendon ruptures. While other cases of bilateral pectoralis major tears have been reported in the literature, the operative management in this report differs. Due to delayed presentation of the patient right and left pectoralis major repairs were performed simultaneously.

CONCLUSION

Patients with delayed presentation of bilateral pectoralis major tendon ruptures can undergo simultaneous repair of both tendon with a good postoperative outcome and high patient satisfaction.

Key Words: Bilateral repair; Pectoralis major; Tendon rupture; Simultaneous repair; Case report

Core Tip: Patients with delayed presentation of bilateral pectoralis major tendon ruptures can undergo simultaneous repair of both tendon with a good postoperative outcome and high patient satisfaction.

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INTRODUCTION

Injuries to the pectoralis major are infrequent, with only a few hundred cases currently recorded in the literature[1,2]. Yet, pectoralis major tears are occurring at an increasing rate over the past few decades, including over half all reported cases occurring in the past decade[1,3-6]. Over 80% of pectoralis major injuries result from indirect trauma and up to half occur during weight training, especially during the eccentric part of a bench press[1-3,7,8]. We report a case of a patient who sustained bilateral pectoralis major tendon ruptures. While other cases of bilateral pectoralis major tears have been reported in the literature, the operative management in this report differs by providing clinical outcomes for simultaneous repair of both tendons[9-12].

CASE PRESENTATION

Chief complaints

A thirty-nine-year-old man presented to our ambulatory sports medicine clinic with complaints of painful range motion in the upper extremities, as well as localized swelling and ecchymosis over bilateral pectoralis major and arms.

History of present illness

Four weeks ago, the patient was performing a flat bench pressing with 405 Lbs. On the sixth repetition of his second set, the patient described feeling a tearing sensation and hearing loud pop emanating from both axillae before re-racking the weight (Video 1). Patient reports the immediate onset of a dull and aching pain and swelling following the incident, as well as reduced strength in internal rotation and adduction of the bilateral upper extremities. In the subsequent morning the patient described significant ecchymosis and swelling in the axillae and anterior surface of the arms bilaterally. Upon assessment of medications, patient denied the use of anabolic steroids and fluoroquinolones. Due to issues with insurance, the patient delayed seeking care. The patient provided informed consent for all imaging, reports, and publications regarding his injury.

History of past illness

The patient has no known surgical history and a past medical history of a transient ischemic attack, myalgia and Wilson's disease.

Physical examination

During a focused physical exam, our patient presented with a loss of the anterior axillary contour bilaterally (Figure 1), as well as retraction of the pectoralis major muscles medially when performing an isometric contraction in the prayer position (Figure 2). On clinical strength testing, the patient's internal rotation was 4- of 5 bilaterally and adduction was of 4- of 5 bilaterally.

Imaging examinations

Magnetic resonance imaging (MRI) confirmed the diagnosis of bilateral pectoralis major tendon ruptures and demonstrated tears with approximately 7 cm of retraction on the right and 5cm of retraction on the left (Figure 3).

FINAL DIAGNOSIS

The final diagnosis of was bilateral pectoralis major tendon ruptures.

Figure 1 Photographs of patient four weeks since initial injury, demonstrating loss of axillary fold on the right side and on the left side. A: Right side; B: Left side.

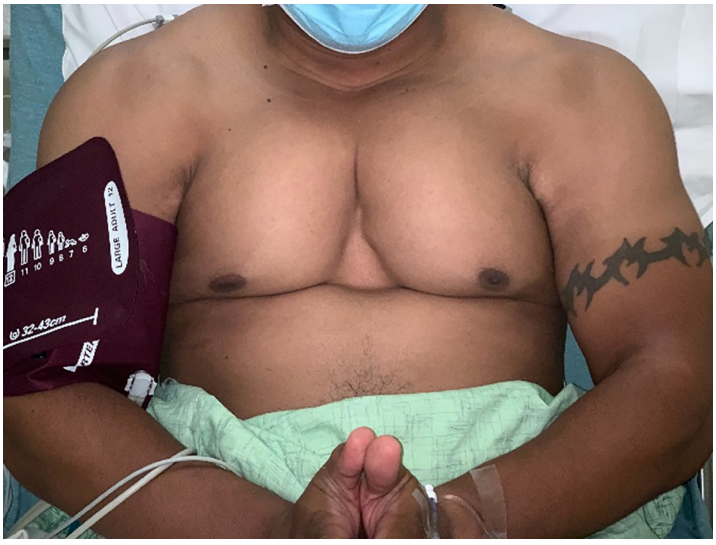

Figure 2 Photograph of patient four weeks since initial injury, demonstrating medial retraction of pectoralis major muscle while isometrically contracting in the prayer position.

TREATMENT

Due to delayed presentation of the patient and his desire to return to maximal strength, right and left pectoralis major repairs were performed simultaneously using all suture anchors. The patient was placed in beach chair position and both upper extremities were draped simultaneously (Figure 4). The bed was placed in a slight Trendelenburg and a deltopectoral approach was used (Figure 5). Fascia distal to the clavicular head of the pectoralis major was opened and hematoma was evacuated before identifying the retracted ruptured pectoralis major tendon. A tag stitch was then placed through the tendon to facilitate mobilization (Figure 6). The pectoralis major insertion site was then identified lateral to the long head of the biceps tendon and a burr was used to create a bleeding bony bed (Figure 7). Following the preparation of the insertion site three 2.8 Q fix all suture anchors (Smith & Nephew, Waterford, England, UK) were place with one proximally, one in the middle, and one distally (Figure 8). One set of sutures from each anchor pair was passed through the tendon in a horizontal mattress fashion and the second suture set was passed medially to act as a rip stop (Figure 9). All sutures were sequentially tied from proximal to distal. Range of motion was then examined, and wound was closed and dressed in standard fashion. Postoperatively both shoulders were immobilized for 6 wks. in adduction and internal rotation with a Shoulder Immobilizer.

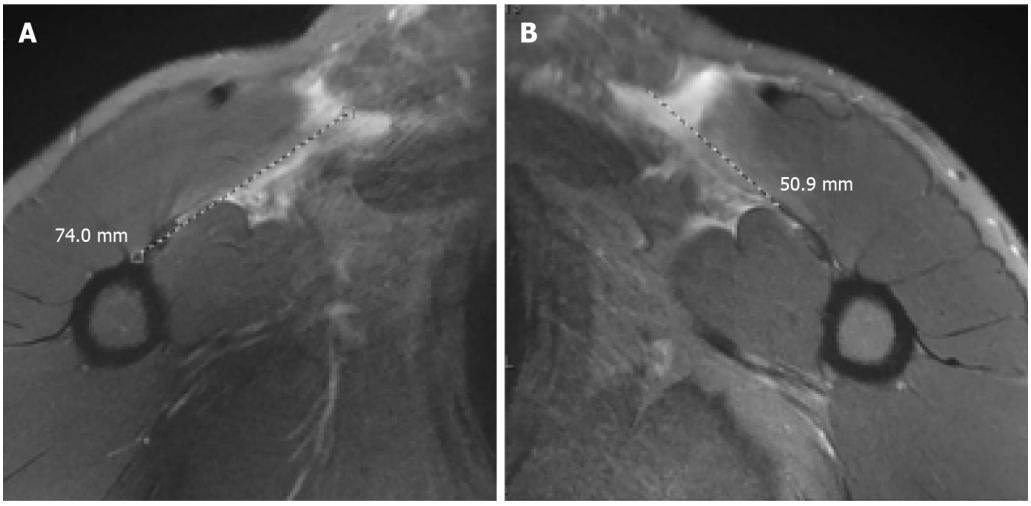

Figure 3 Magnetic resonance imaging of pectoralis major tear. A: 7 cm of retraction on the right pectoralis major tendon; B: 5 cm of retraction on the left pectoralis major tendon.

Figure 4 Photograph demonstrating patient in the beach chair position with both upper extremities draped.

OUTCOME AND FOLLOW-UP

During the first post-operative visit at 10 d following surgery the patient reported PROMIS interference scores for upper extremity, physical function, pain, and depression of 21.2, 26.1, 68.1, and 34.2 respectively. Patient visual analog pain score (VAS) was 7. Rehabilitation started at 2 wks. post-operatively with Cuff isometrics and passive shoulder ROM. After 6 wks. postoperatively the sling was discontinued, and the patient began active shoulder motion, rotator cuff and scapular stabilizer strengthening, and restoration of full passive shoulder range of motion (ROM).

At three-months postoperatively the patient presented with strength of 5- of 5 on clinical evaluation of internal rotation and adduction of the arms bilaterally. The patient had full ROM in forward flexion, abduction, internal rotation and external rotation bilaterally. PROMIS interference scores for upper extremity, physical function, pain, and depression were recorded as 54.2, 56.1, 58.1, and 54.2 respectively. VAS score was reported as 2. In physical therapy the patient continued to progress with strengthening and was permitted to start performing a light bench press. The patient has reported no discomfort with resistance training.

During the patients most recent follow-up, six-months postoperatively, the patient reported PROMIS interference scores for upper extremity, physical function, pain, and depression of 51.4, 56.1, 38.7, and 34.2 respectively. The patient reported a VAS score of 1 and demonstrated full range of motion in forward flexion, abduction, internal

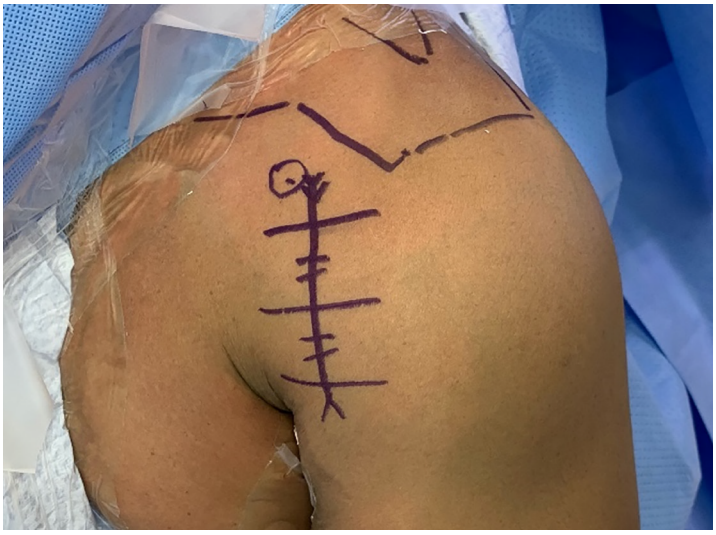

Figure 5 Photograph of anatomical landmarks used to perform a deltopectoral approach

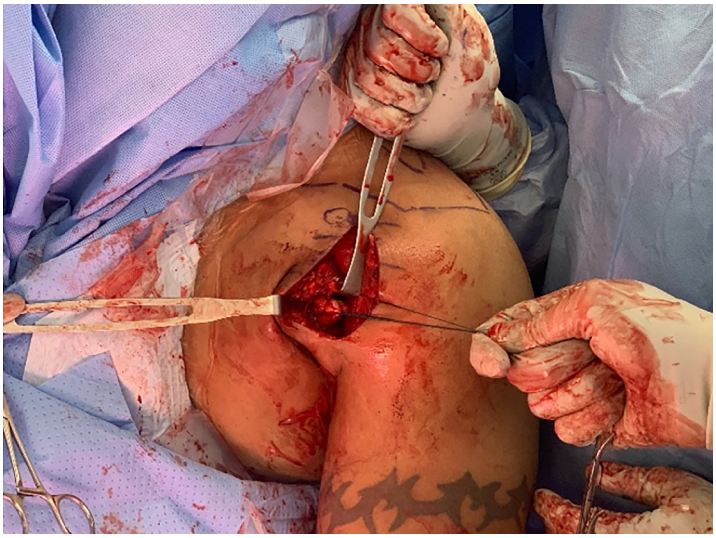

Figure 6 Photograph of a tag stitch that was place through the pectoralis major tendon.

rotation and external rotation bilaterally (Figure 10). Patient has completed physical therapy and was cleared to resume full strengthening activities.

DISCUSSION

Complete tear of the pectoralis major is increasing in frequency over the past few decades. Between the first case recorded in 1822[13] and 1990, fewer than 90 cases were documented in the literature. As of 2010 there have been 365 recorded cases in the literature[1]. According to a recent meta-analysis performed by Bodendorfer *et al* [3], there are currently 693 cases reported in the literature. The authors described that 63.2% of pectoralis major tears occur due to weight training, including 39.5% of all documented tears resulting from a bench press. Eighty-seven percent (n = 603) of all tears underwent surgical management either acutely or chronically. Bodendorfer *et al* [3]'s results were consistent with previous studies which concluded operative treatment is superior to non-operative treatment in both the acute and chronic setting [1,14,15]. When compared to patients managed non-operatively, surgical intervention yielded greater functional improvement according to Bak criteria[2] (scored 1-4; P = 0.027), increased likelihood to regain full isometric strength (P < 0.001), better iso-kinetic strength as measured against the contralateral side (P < 0.001), decreased chance of a resting deformity (P = 0.037), and increased cosmetic satisfaction (P <

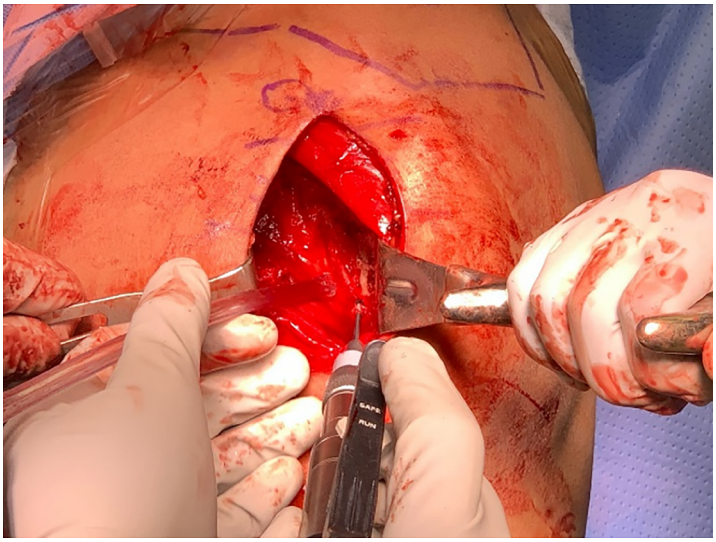

Figure 7 Photograph of the pectoralis major insertion was site with the burr that was used to debride the site and create a bleeding bony bed.

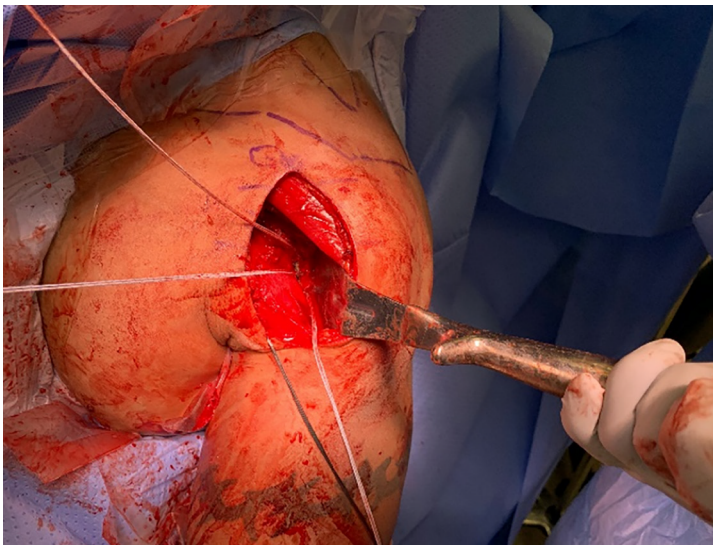

Figure 8 Photograph of the three 2.8 Q fix all suture anchors that were place with one proximally, one in the middle, and one distally.

0.001).

Our patient's bilateral tears occurred during a bench press, the most common mechanism by which pectoralis major tears occur[1-3,7,8]. Additionally, as a thirty-nine year old male, our patient matches the demographic most often affected by pectoralis major tears: males in their third or fourth decade[1-3,5]. MRI was performed (Figure 3) to confirm the diagnosis, determine the severity and location of the tear, and better create a preoperative plan as described by Kadu *et al*[16].

Our patient presented to our clinic 29 d out from injury; if the patient had appeared closer to the date of injury, staggering the surgeries between sides would have been contemplated. This would have allowed for use of the contralateral arm while the surgical arm was placed in a sling. It has been demonstrated that patients who underwent surgery within 6 wks. of injury have better outcomes compared to those who delay surgery beyond 6 wks.[14,15]. Furthermore, the findings from Ritsch's[17] prospective study of 25 patients with chronic pectoralis major tears demonstrated even when post-operative clinical outcomes are adequate, as defined by the Bak criteria, there is a higher risk of complications (24%). Considering all factors along with confirmation from our patient there was someone to help with activities of daily living when both arms would be in a sling post-operatively, we decided to proceed with simultaneous, bilateral pectoralis major repairs. Extra considerations must be made

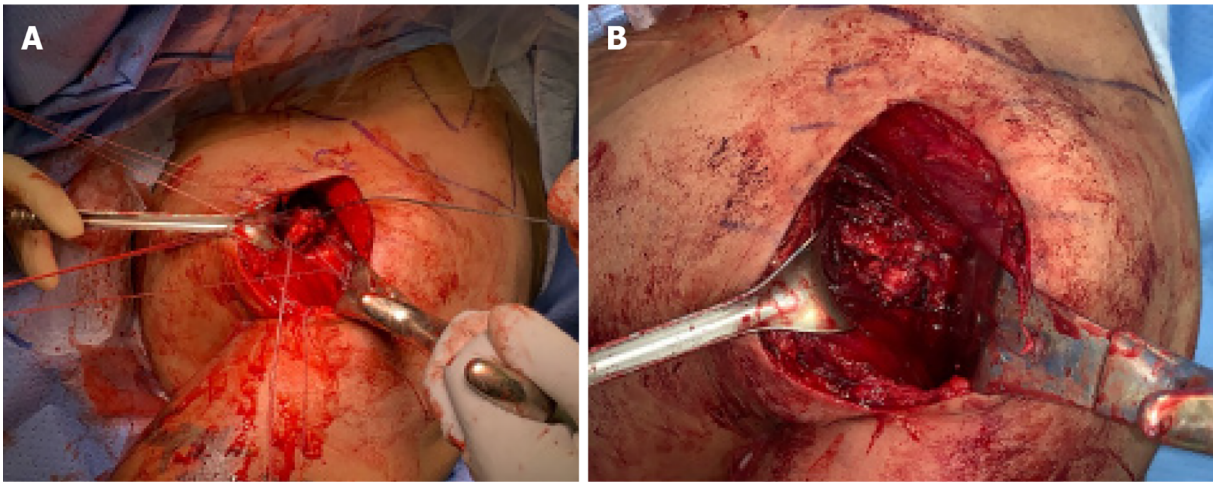

Figure 9 Photograph of sutures being passed through the tendon and all sutures being tied from proximal to distal. A: Sutures being passed through the tendon; B: All sutures being tied from proximal to distal.

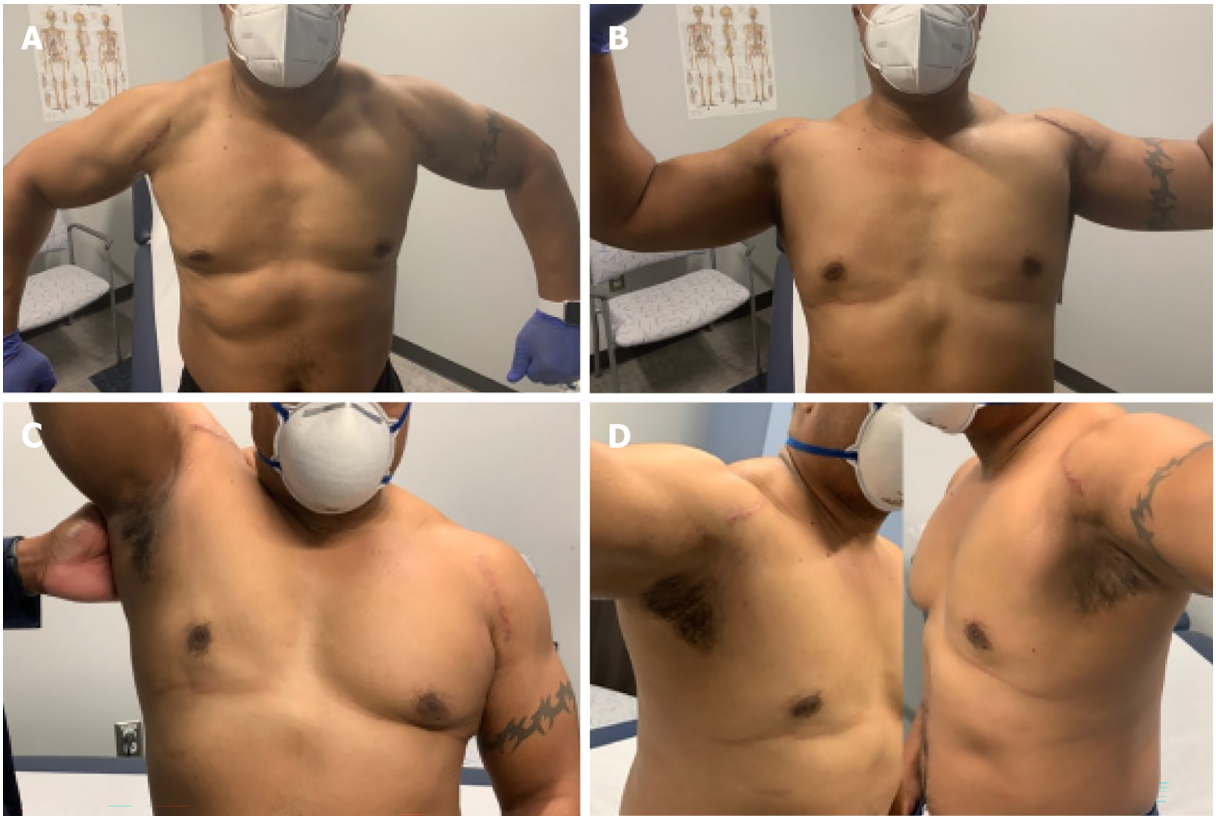

Figure 10 Photograph of patient at 6 months post-operatively in abduction internal rotation of shoulder, abduction external rotation of the shoulder, forward flexion of the shoulder, and abduction of the shoulder. A: Abduction internal rotation of shoulder; B: Abduction external rotation of the shoulder; C: Forward flexion of the shoulder; D: Abduction of the shoulder.

when opting to perform simultaneous bilateral surgical repairs. Patient selection is critical particularly in patients with significant comorbidities as there could be potential for increased perioperative complications. Additionally, it is essential that patients understand their limited function in the immediate postoperative period and have a dependable support system to aid in the recovery process. Operative time is also a consideration as performing bilateral simultaneous repairs will lead to increased anesthesia, higher risk for clotting, and increased blood loss than a one sided procedure.

According to the systematic review performed by Gupton *et al*[18], there are currently three main surgical techniques used to repair a pectoralis major tear:

Transosseus suture *via* drill holes, suture anchor, and unicortical or bicortical button. Compared to the button technique, both the transosseus suture (OR = 6.28, 95%CI: 1.37-28.75; P = 0.02) and suture anchor (OR = 3.40; 95%CI: 1.06-10.85; P = 0.04) techniques demonstrated better clinical outcomes according to the Bak criteria. There was no significant difference between the suture anchor and transosseus techniques (OR = 1.85; 95%CI: 0.33-10.45; P = 0.49). The benefits to the suture anchor technique include decreased operative time, less operative insult to the cortical humerus, excellent approximation of the tendon to its anatomic insertion, and reliable fixation [14,18-21]. All-suture anchors confer the benefit of decreased bone loss and smaller anchor footprint has been demonstrated compared to traditional anchors[22-24]. Only a handful of cases regarding bilateral rupture of the pectoralis major tendon have been recorded in the literature demonstrating staggered repair of each tendon[9-12]; however, this case represents a simultaneous repair for bilateral rupture of the pectoralis major tendons.

CONCLUSION

Patients with delayed presentation of bilateral pectoralis major tendon ruptures can undergo simultaneous repair of both tendon with a good postoperative outcome and high patient satisfaction.

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