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REVIEW

Ankle arthrodesis: A systematic approach and review of the literature

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Abstract

Ankle arthrodesis is a common treatment used for patients with end-stage ankle arthritis (ESAA). The surgical goal of ankle arthrodesis is to obtain bony union between the tibia and talus with adequate alignment [slight valgus (0°-5°)], neutral dorsiflexion, and slight external rotation positions) in order to provide a pain-free plantigrade foot for weightbearing activities. There are many variations in operative technique including deferring approaches (open or arthroscopic) and differing fixation methods (internal or external fixation). Each technique has its advantage and disadvantages. Success of ankle arthrodesis can be dependent on several factors, including patient selection, surgeons' skills, patient comorbidities, operative care, *etc*. However, from our experience, the majority of ESAA patients obtain successful clinical outcomes. This review aims to outline the indications and goals of arthrodesis for treatment of ESAA and discuss both open and arthroscopic ankle arthrodesis. A systematic step by step operative technique guide is presented for both the arthroscopic and open approaches including a postoperative protocol. We review the current evidence supporting each approach. The review finishes with a report of the most recent evidence of outcomes after both approaches and concerns regarding the development of hindfoot arthritis.

Key words: Ankle; Osteoarthritis; Arthrodesis; Review; Ankle fusion

Core tip: Ankle arthrodesis is an effective treatment option for end stage arthritis. There is no current consensus on the most optimal approach and fixation method. It is thus important for the surgeon to understand both the open and arthroscopic approach and when each approach is indicated. Joint alignment must be slightly valgus (0°-5°), neutrally dorsiflexed and slightly in an externally rotated

position. Limb length discrepancies should also be minimal (less than 2.5 cm or 1.0 inch). Failure to address these biomechanical aspects may result in pain and an altered gait pattern. The importance of adequate preoperative forefoot balance cannot be understated to allow for successful postoperative mobility. When performed according to these principles ankle arthrodesis leads to functional improvement and adequate joint fusion in patients with end stage arthritis.

Yasui Y, Hannon CP, Seow D, Kennedy JG. Ankle arthrodesis: A systematic approach and review of the literature. *World J Orthop* 2016; 7(11): 700-708 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i11/700.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i11.700

INTRODUCTION

Ankle arthrodesis and ankle arthroplasty are the two common operative treatments used in end stage ankle arthritis (ESAA)[1,2]. Recent clinical evidence suggests that ankle arthroplasty leads to superior functional outcomes over ankle arthrodesis[3-7]. However, ankle arthroplasty is associated with higher rates of postoperative complications and revision surgeries[3-8]. Despite the increasing popularity of ankle arthroplasty, a large database has indicated that ankle arthrodesis still remains the most common surgical treatment for ESAA[9,10].

There are several operative techniques for ankle arthrodesis including open or arthroscopic approaches[11-15]. Although successful clinical outcome can be achieved following both approaches[11-15], reported outcomes have varied and are conflicted[16]. The differences in techniques, surgeon skill, patient selection and populations, and outcome measurements utilized all contribute to the variability in outcome after arthrodesis. Ankle arthrodesis should be performed judiciously in young patients, highly active patients, and patients with advanced foot and ankle deformity.

The purpose of this manuscript is to provide: (1) to provide an evidence-based review of ankle arthrodesis for ESAA; and (2) to describe a standardized approach to both open and arthroscopic ankle arthrodesis.

INDICATIONS AND GOALS OF ARTHRODESIS

Ankle arthrodesis is indicated for patients with ESAA that failed a minimum of 3 mo of conservative treatment. The goal of ankle arthrodesis is to provide a pain-free plantigrade foot during weightbearing activities[17]. Alignment following ankle arthrodesis must be slight valgus (0°-5°), neutral dorsiflexion, and slightly externally rotation. Equinus position of the ankle joint can accompany genu recurvatum and a varus position of hindfoot can develop painful callosities to the lateral forefoot[18], which may cause hindfoot pain[19,20]. Additionally, the surgeon should attempt to minimize limb length discrepancies (less than 2.5 cm or 1.0 inch)[21-23]. Limb length discrepancies can result in a symptomatic malalignment with altered gait pattern[24].

Arthroscopic ankle arthrodesis is typically reserved for patients with little to no joint deformity (less than 15° of varus or valgus in the coronal plane). Open arthrodesis is best utilized for patients with moderate to severe deformity as this allows for better visualization for malalignment correction. Additionally, as fusion of the ankle joint will inevitably lead to a lack of motion, preoperative balance of the forefoot is essential. Therefore, careful examination of forefoot balance without excessive pronation or supination is needed[25]. Arthroscopic or open debridement with subsequent external fixation would be preferred by the authors in patients with significant malalignment, comprised skin, limbs discrepancies, and active/previous infection.

TYPES OF ANKLE ARTHRODESIS

Numerous surgical techniques for ankle arthrodesis have been described[11-15]. The technique should be selected based on patient characteristics, function and goal of treatment, as well as the preference of the surgeon.

Approach

The approach to ankle arthrodesis is broadly divided into open and arthroscopic techniques. The open approach is further subdivided into the anterior approach, posterior approach, lateral approach, medial approach, and combined medial and lateral approach. Compared with the arthroscopic approach, the main benefit of an open approach includes less difficulty in correcting malalignment, and ease in applying plates and bone grafts. However, open arthrodesis is associated with higher rates of wound complications due to the extensive amount of soft tissue dissection required[3-7]. This can subsequently lead to longer hospitalization and recovery. Therefore, open approaches are generally reserved for patients with moderate to severe ankle deformities with healthy skin.

Arthroscopic ankle arthrodesis is as a less invasive procedure enabling shorter operative time with comparable union rates[26-28]. This procedure is most commonly performed using anterior ankle arthroscopy, however recent studies have suggested that posterior ankle arthroscopic arthrodesis may provide better fusion rates[29]. Arthroscopic ankle arthrodesis is indicated for patients with minimal ankle joint deformity (less than 15° of varus or valgus in coronal plane) or patients who are at higher risk of wound complications (*e.g.,* immunosuppressed, diabetics, rheumatoid arthritis patients). Although arthroscopic arthrodesis is increasingly becoming popular, open ankle arthrodesis remains the mainstay procedure

Table 1 Open ankle arthrodesis

Investigator	Year	Method	No. of patients	Union rate	Outcome(s)
Charnley *et al*[51]	1951	Charnley compression	19	79%	N/A
Boobbyer[52]	1981	Internal and external fixation	37	84%	N/A
Kenzora *et al*[53]	1986	External fixation	26	69%	N/A
Sowa *et al*[54]	1989	Compression blade plate	17	94%	10 excellent; 2 good; 2 fair (out of 14; Mazur)
Helm *et al*[55]	1990	Charnley compression	47	85%	N/A
Mann *et al*[11]	1991	Screws from talus to tibia	18	94%	N/A
Kitaoka *et al*[56]	1992	External fixation and bone graft	26	77%	N/A
Wang *et al*[57]	1993	T plate on lateral side	11	91%	N/A
Chen *et al*[58]	1996	Cross screws	40	95%	N/A
Patterson *et al*[59]	1997	Anterior sliding graft with screws	27	93%	N/A
Levine *et al*[44]	1997	Internal fixation and bone graft	22	92%	N/A
Mann *et al*[12]	1998	Internal fixation and fibular graft	81	88%	74 (AOFAS)
Dereymaeker *et al*[60]	1998	Internal and external fixation	14	64%	N/A
Ben-Amor *et al*[61]	1999	80% internal fixation, 20% external fixation	36	97%	56.2 (Duquennoy)
Takakura *et al*[62]	1999	Anterior sliding graft with screws	43	93%	77.9 (Takakura)
Coester *et al*[20]	2001	Internal or external fixation	23	N/A	27 limiation, 38 pain, 47 disability (Foot Function Index)
Bertrand *et al*[63]	2001	84% internal fixation, 16% external fixation	23	87%	69.7 (Duquennoy)
Anderson *et al*[64]	2002	Internal and external fixation	29	89%	N/A
Fuchs *et al*[65]	2003	22% internal fixation, 78% external fixation	18	95%	59.4 (Olerud and Molander)
Buchner *et al*[66]	2003	38% internal fixation, 62% external fixation	45	92%	73.6 (AOFAS)
Kopp *et al*[67]	2004	Internal fixation with staples and screws	41	93%	72.8 (Mazur)
Kennedy *et al*[16]	2006	Internal fixation with screws	41	95%	80.6 (AOFAS)
Thomas *et al*[39]	2006	Internal fixation with transfibular approach	26	100	74 (AOFAS)
Trichard *et al*[68]	2006	60% internal fixation, 40% external fixation	25	N/A	64.7 (Duquennoy)
Smith *et al*[69]	2007	Internal fixation	25	96%	43.7 (AOFAS)
Colman *et al*[70]	2007	Transfibular approach with grafting	48	96%	69 (AOFAS)

for ESAA in the United States of America[9,10].

Fixation methods

Both internal and external fixation may be used in ankle arthrodesis. Each has its unique advantages; successful outcomes having been demonstrated with both fixation methods[11-15].

Various methods of internal fixation have been described, including screws, plates, and retrograde intramedullary nails. Many surgeons prefer to use screw fixation as the primary means of internal fixation, because screws are easy to use, have low morbidity (they only require small percutaneous incisions) and are cheaper compared to most other methods. However, higher nonunion rates of the ankle joint have been reported with screw fixation especially in osteoporotic bone[30,31]. Plates are advantageous for ankle arthrodesis because there are many options when using plates. The surgeon has choices with regard the type of plate needed (*e.g.,* conventional or locking), how many plates and where to place the plates. While some surgeons prefer plates because they are stiffer constructs than screws that may achieve better union rates, the extensive dissection needed to place the plate can lead to a higher risk of infection and morbidity[32-34]. A combination of plates and screws may also be used. A recent bio-mechanical study found that a combination of plate and screw fixation provided significantly greater stiffness than plates or screws alone. In this study there were no significant difference between 3 compression screws, anterior plate and lateral plate fixation[34]. Retrograde intramedullary arthrodesis is typically reserved for arthrodesis of both the ankle and subtalar joints[35-38]. Patients with ESAA typically have concomitant subtalar arthritis. In these patients, it is difficult to delineate whether the pain is coming solely from the tibiotalar joint, the subtalar joint or a combination of both. The surgeon must determine this preoperatively because it is best to avoid arthrodesis of the subtalar joint whenever possible especially when the ankle will be fused. In the setting of a tibiotalar arthrodesis the subtalar joint is critical for gait stability[20,39,40]. The subtalar joint allows for inversion and eversion of the ankle joint and therefore, this can compensate for a more stable gait when joint motion is permanently reduced post-arthrodesis.

External fixation is typically indicated for complex patients with significant bone defects, limb length discrepancies discrepancies, poor bone quality, and active or previous infection[31]. Overall, union rates and outcomes measures of external fixation are inferior to internal fixation (Table 1).

OPERATIVE TREATMENT

Two standardized methods of ankle arthrodesis for ESAA is described here: Open and arthroscopic. For both methods, the joint is fixed with two or more screws. Patients are placed in a short leg cast and immobilized for 6 wk. Patients have achieved successful outcomes following either approach in our experience[16].

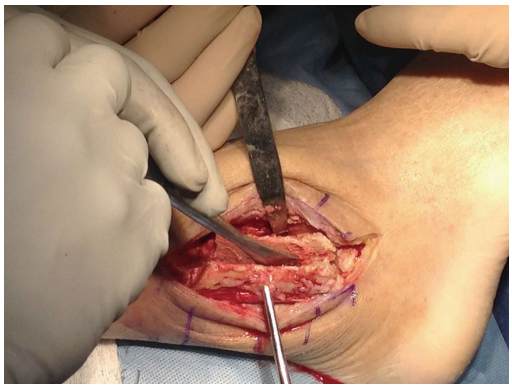

Figure 1 Lateral transfibular approach.

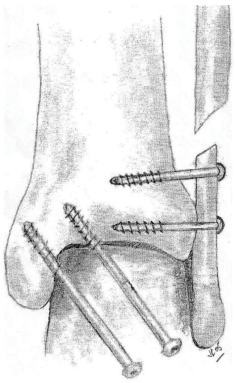

Figure 2 Anteroposterior scheme shows the placement of screws.

Open arthrodesis with screw fixation

Patient positioning and equipment: The patient is placed in the supine position with the feet at the edge of the bed. A tourniquet is typically used at the level of the thigh and applied before the start of the case. All equipment should be confirmed prior to the onset of the case. Osteotomes, a bone saw, and curettes are needed for the osteotomy and debridement of the joint surface. A large fragment cannulated drill set and screws (4.0/6.5/7.3 mm) are required to fuse the ankle joint. Fluoroscopy should be used to confirm ankle alignment and screw positions.

Steps of the procedure: (1) Marking anatomical landmarks: Anatomical landmarks are marked using a sterile surgical marker. In this procedure, the lateral malleolus (LM), medial malleolus (MM), ankle joint line, fourth metatarsal, fifth metatarsal, superficial peroneal nerve, and sural nerve are all identified and marked. Then, a hockey-stick-shaped incision is outlined over the lateral aspect of the LM, starting approximately 7.0 cm above the tip of the LM and extending distally to the base of the fourth metatarsal. Additionally, a longitudinal medial skin incision line is marked over medial gutter of ankle joint; (2) Skin incision and osteotomy of distal fibula: The first skin incision is made over the fibula along the previously described outline. Once distal tibiofibular joint is identified, soft tissues including the anterior inferior talofibular ligament, interosseous ligament, and interosseous membrane are resected. An osteotomy of the distal fibula is then made in a beveled fashion approximately 2.5 cm proximal to the ankle joint using a sagittal oscillating saw. The resected bone block (medial side of fibula) should be kept for local autologous bone grafting later on in the case (Figure 1). After the osteotomy is complete, the lateral aspect of the fibula is retracted posteriorly. It is important to preserve the fibula as best as possible to minimize the risk of non-union; (3) Debridement of joint surface cartilage: After the fibular osteotomy, the ankle joint is distracted using a lamina spreader. Any inflammation or scar tissue within the ankle joint is debrided and/or removed carefully to fully expose the joint surface. Careful attention during exposure of the joint surface is essential to avoid injury to the neurovascular bundle located anterior of the ankle joint capsule. If the full joint surface cannot be visualized at this point, a medial incision with arthrotomy may be needed to reduce the future potential of saphenous nerve damage. After fully exposing the joint surface, cartilage is removed from both the tibia and talus to expose the subchondral bone. The authors prefer to use an osteotome and curette rather than a bone saw or burrs to minimize the risk of thermal necrosis of the subchondral bone. The debridement should also be minimalized to maintain joint congruency; (4) Fusion of tibiotalar joint: The tibiotalar joint is fixed typically using two to three 7.3 mm cannulated screws after adequate alignment is obtained. The alignment of tibiotalar joint should be slightly valgus (0°-5°), neutrally dorsiflexed, and slightly external rotated. The talus should be reduced in a posterior position to obtain the largest possible contact area of joint surfaces. This is to reduce the lever arm of the foot on the mechanical construct. The alignment is evaluated using fluoroscopy in two planes. Two to three guide wires are then inserted in the inferolateral aspect of the base of the talar neck. This technique is similar to what was previously described by Mann *et al*[12]. The positions of the guide wires should be confirmed using fluoroscopy. Three 7.3 mm cannulated screws are then inserted through the guide wires starting at the talus through the ankle joint and into the tibia. The authors believe that two to three screws are optimal to fuse the joint, as too few screws results in the inadequate compression of the bony surfaces and too many screws reduces the availability of bony surface for osseous integration[16]; (5) Fusion of lateral malleolus to tibia (Figure 2): Two 4.0 mm screws are used to fix the lateral malleolus and distal tibia into place. Guide wires may be placed before insertion of the screws to ensure adequate alignment. The position of the screws/guide wires should be confirmed with fluoroscopy. Bone graft may be placed around the fusion site to facilitate union. This is especially recommended when there might be factors that could complicate the union such as osteonecrosis of the talus, previous non-union or bony defects[41-45]. Bone graft can be prepared through the morselization of bone acquired

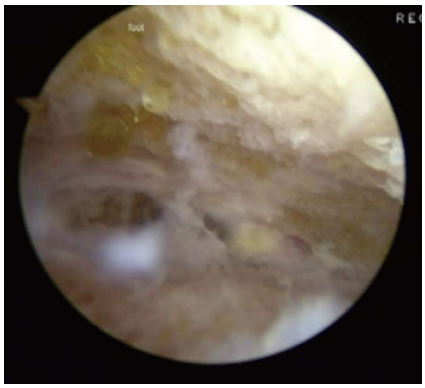

Figure 3 Any remaining cartilage on the tibia, the talus or in the medial or lateral gutters is debrided.

during the distal fibula osteotomy and placed around the site of fusion.

Arthroscopic arthrodesis with screw fixation

Patient positioning and equipment: General arthroscopy equipment is required for an arthroscopic arthrodesis. A 2.7/4.0 mm, 30°/70° arthroscope is typically used. Shavers are required for debridement of soft tissue and for bony resection. A non-invasive distractor and irrigation system are both helpful to obtain good visualization. The fluid pressure is usually set at 50 to 60 mmHg with the fluid flow rate at 0.5 L/min. The ankle joint is fixed using equipment from the large fragment cannulated drill and screw set (6.5 mm). For this procedure, fluoroscopy is necessary.

The patient is placed in the supine position with the ipsilateral hip flexed and supported by a well-padded leg holder. The position of the holder should be proximal to popliteal fossa to avoid constriction of the neurovascular bundle. The ankle and hindfoot is held with a sterile distraction strap.

Steps of the procedure: (1) Marking anatomical landmarks and establishing portals: The careful identification of anatomical landmarks is critical for any arthroscopic procedure of the ankle. The most commonly injured nerve following anterior ankle arthroscopy is the superficial peroneal nerve (up to 2.9%)[46]. Anterior ankle arthrodesis is performed using anteromedial (AM), anterolateral (AL) and occasionally posterolateral (PL) portals. The lateral malleolus (LM), medial malleolus (MM), peroneus tertius, tibialis anterior tendon (TAT), superficial peroneal nerve, and sural nerve are all identified and marked. At the level of ankle joint, the AM portal is established just medial to the medial border of the TAT and the AL portal is placed lateral to peroneus tertius. The PL portal is marked 1.0 mm anterior to the lateral borders of Achilles tendon with also bring at horizontal level with the inferior pole of the MM and the tip of LM. Arthroscopic portals are created using "nic and spread" technique to decrease the risk of iatrogenic nerve damage. After the skin incision, subcutaneous blunt dissection is performed using a mosquito clamp. A 2.7 mm arthroscope sleeve with a trocar is then carefully advanced. Once the anterior aspect of tibia can be palpated with the trocar, it is switched out for a 2.7 mm arthroscope. The authors prefer the insertion of portals in the following order: AM portal, AL portal and PL portals; (2) Debridement and exposure: Debridement of the synovium and scar tissue is typically required to improve visualization of the ankle joint surface. Any remaining cartilage on the tibia, the talus or in the medial or lateral gutters is then debrided using a shaver, burr, or curette (Figure 3). To fully visualize the posterior aspect of the joint, the PL portal may need to be utilized. In several previous studies, investigators have suggested that poor debridement of the posterior portion of the ankle joint may compromise ankle fusion rates[47,48]. Adequate debridement can be assessed by the visualization of blood arising from the subchondral bone of the talus and tibia when inflow pressure is decreased; and (3) Tibiotalar fixation: The tibiotalar joint is fixed typically using two to three large cannulated screws. A Kirschner wire is first inserted 10° to 20° starting at the anterolateral tibia approximately 3 to 4 cm above the joint line and towards the posterior aspect of the horizontal axis of the tibia. A second Kirschner wire is then inserted from the anteromedial aspect of the tibia in a similar orientation aiming toward the central talar dome. These Kirschner wires should be altogether inserted at the tibial joint surface. The location of the Kirschner wires should be confirmed by both arthroscopy (Figure 4A) and fluoroscopy. Following the confirmation of adequate talocrural joint alignment, the wires are then advanced into talus (Figure 4B). Screws are then inserted over these Kirschner wires (Figure 4C). A countersink may be required to reduce the prominence of the screw heads.

BIOLOGICS

Biologics may be used to aid in fusion of the ankle in both the open and arthroscopic techniques. Two types of biologics are currently available: Osteoconductive and osteoinductive agents. Osteoconductive agents, *e.g.,* bone allografts, demineralized bone matrix and various apatitic pastes, are agents that serve as a scaffold at the site of fusion. This scaffold acts as a tissue network to facilitate autologous cell interaction for osteogenesis. Osteoinductive agents, *e.g.,* bone morphogenetic proteins, platelet-rich plasma or concentrated bone marrow aspirate, are agents that directly facilitate osteogenesis. This may be in the form of containing growth factors (platelet-rich plasma) or stem cells (concentrated bone marrow aspirate) to stimulate the formation of osteoblasts. Biologics should be placed into the fusion site before and after the final seating of screws.

POSTOPERATIVE REHABILITATION

The ankle joint is immobilized in a non-weightbearing leg cast for 6 wk. The cast is then removed and

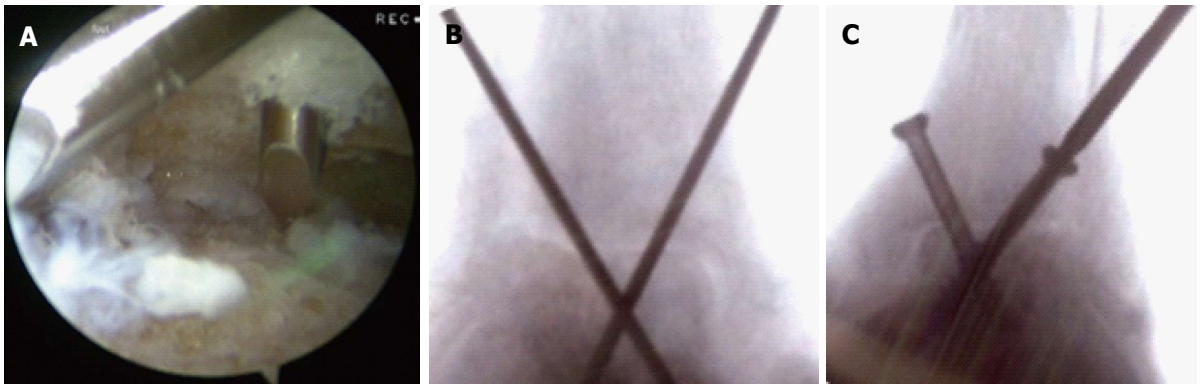

Figure 4 Kirschner wires should be altogether inserted at the tibial joint surface. A: Arthroscopic view shows the location of the Kirschner wires; B: Fluoroscopic view shows location of Kirschner wires; C: Screw fixation.

Table 2 Arthroscopic ankle arthrodesis

Investigator	Year	Method	No. of patients	Union rate	Outcome(s)
Ogilvie-Harris *et al*[71]	1993	Tibiotalar and fibulotalar screws	19	89%	N/A
Dent *et al*[72]	1993	Crossed tibiotalar, charnley clamp	8	100%	N/A
De Vriese *et al*[73]	1994	Arthroscopic arthrodesis	10	70%	N/A
Turan *et al*[74]	1995	Arthroscopic arthrodesis	8 (10 ankles)	100%	N/A
Corso *et al*[75]	1995	Tibiotalar and fibulotalar screws	16	100%	N/A
Crosby *et al*[76]	1996	Arthroscopic arthrodesis	42	93%	N/A
Glick *et al*[77]	1996	Cannulated screws	34	97%	N/A
Jerosch *et al*[78]	1996	Tibiotalar and fibulotalar screws	26	85%	N/A
Cameron *et al*[13]	2000	Arthroscopic arthrodesis	15	100%	N/A
Zvijac *et al*[79]	2002	Arthroscopic arthrodesis	21	95%	N/A
Cannon *et al*[80]	2004	Arthroscopic arthrodesis	36	100%	N/A
Saragas[81]	2004	Arthroscopic arthrodesis	26	96%	63.9 (modified AOFAS out of 78 points)
Winson *et al*[25]	2005	Arhroscopic arthrodesis	116 (118 ankles)	92%	N/A
Ferkel *et al*[82]	2005	Arthroscopic arthrodesis	35	97%	73.9 (Mazur)
Gougoulias *et al*[83]	2007	Arthroscopic arthrodesis	74 (78 ankles)	97%	N/A
Dannawi *et al*[84]	2011	Arthroscopic arthrodesis	55	91%	81.5 (Mazur)

the patient is transferred over to a Controlled Ankle Movement Walker Boot. Radiographs should be taken at intervals of 6 wk, 3 mo, 6 mo and 1 year to assess the position of fusion and adequacy of union. A gradual 10% increase every two weeks in weightbearing is advised. However, as soon as complete union is evident on radiographs, patients may be allowed to fully weightbear.

OUTOCOMES AFTER ANKLE ARTHRODESIS: A SYSTEMATIC REVIEW

Clinical studies on ankle arthrodesis were searched for on the MEDLINE and EMBASE databases using the terms: (open OR arthroscopic) AND (ankle) AND (arthrodesis OR fusion). The search revealed 463 papers from MEDLINE and 695 papers from EMBASE. The inclusion criteria were: (1) the studies' intervention included the use of arthrodesis; (2) clinical studies; and (3) published in a peer-review journal. Exclusion criteria were: (1) review studies; (2) cadaver studies; and (3) animal studies. This resulted in the inclusion of 26 studies on open ankle arthrodesis and 16 studies on arthroscopic ankle arthrodesis (Table 2).

Union rate has been shown to be a popular outcome measure following arthrodesis, as indicated by its prevalent use in the current literature. Other popular measures included the AOFAS, Duquennoy, Mazur, Takakura, Foot Function Index and Olerud and Molander scoring systems.

The average union rate following open arthrodesis was 89% (range: 64%-100%) and following arthroscopic arthrodesis was 94% (range: 70%-100%). In the cohort of patients in the four comparative studies, the average union rate in the open group was 89% and in the arthroscopic group was 91%. However, in the only comparative study reporting clinical outcomes, Townshend *et al*[26] demonstrated that clinical outcomes only mildly improved following the use of the arthroscopic technique.

In regards to the effects of ankle arthrodesis on the automobile breaking. Jeng *et al*[49] demonstrated that ankle arthrodesis can significantly decreased the total break reaction time. However, this delay does not exceed the safe reaction brake timing criteria by the United States Federal Highway. Schwienbacher *et al*[50]

Table 3 Open *vs* arthroscopic ankle arthrodesis

Investigator		Year	Method	No. of patients	Union rate	Outcome(s)
Myerson *et al*[28]	Open	1991	Screws from tibia to talus	16	100%	N/A
	Arthroscopic		Cannulated screws	17	94%	
O'Brien *et al*[27]	Open	1999	Open technique	17	82%	N/A
	Arthroscopic		Arthroscopic technique	19	84%	
Nielsen *et al*[85]	Open	2008	Open technique	49	84%	N/A
	Arthroscopic		Arthroscopic technique	58	95%	
Townshend *et al*[26]	Open	2013	Open technique	30	N/A	AOS = 29.2 ± 17.2; SF-36 physical = 38.2 ± 11.8; SF-36 mental = 52.2 ± 12.0
	Arthroscopic		Arthroscopic technique	30		AOS = 17.2 ± 17.9; SF-36 physical = 45.0 ± 9.3; SF-36 mental = 55.1 ± 8.1

performed comparative case series in a driving simulator and found that patients receiving ankle arthrodesis had less of an ability to brake under emergency circumstances compared to healthy volunteers.

Relationship between ankle arthrodesis and adjacent-joint arthritis in the hindfoot

The development of adjacent hindfoot arthritis following tibiotalar arthrodesis remains a concern. A recent systematic review by Ling *et al*[86] investigated the relationship between ankle arthrodesis and adjacent-joint arthritis and demonstrated that there was insufficient evidence to support either that ankle arthrodesis caused adjacent-joint arthritis or that pre-existing joint arthritis could have already existed in those cohort of patients. As the current postulation include that there may be inherent pre-existing adjacent joint arthritis in the majority of patients requiring fusion, no clear consensus can be made on whether ankle arthrodesis can cause or predispose to hindfoot arthritis.

Recently, Yasui *et al*[9] published a large retrospective cohort study that investigated the postoperative adjacent-joint hindfoot arthritis following ankle arthrodesis. The authors found there was significant higher rate of subsequent adjacent-joint arthrodesis in the open cohort than the arthroscopic cohort (7322 open procedures *vs* 1152 arthroscopic procedure, reoperation rate: 5.6% *vs* 2.6%, odds ratio: 2.17, 95% confidence level: 1.49-3.16). Regardless of whether adjacent hindfoot arthritis is present before or develops after arthroedesis the authors believe that these patients more commonly have open procedures. The authors hypothesized that open ankle arthrodesis leads to degenerative OA of the adjacent joints more frequently than does the arthroscopic procedure; or, patients undergoing open ankle arthrodesis develop concurrent degenerative arthritis in the adjacent joints more frequently than does the arthroscopic group. To address this subject, further investigation is necessary (Table 3).

CONCLUSION

Ankle arthrodesis is an effective treatment for ESAA that may be achieved through either the open or arthroscopic approach. Several fixation options exist, however the authors prefer two to three screws. It is difficult to generate a clear consensus on whether open or arthroscopic arthrodesis should the mainstay of treatment for ESAA because conflicting evidence currently exists. As the current success of arthrodesis continues to depend on a variety of factors, the current review aims to summarize an up-to-date knowledge for optimizing the outcomes of ankle arthrodesis.

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REVIEW

Depression and psychiatric disease associated with outcomes after anterior cruciate ligament reconstruction

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Abstract

While most patients with an anterior cruciate ligament (ACL) injury indicate satisfaction with surgical intervention, a significant proportion still do not return to pre-injury level of function or sport. Psychiatric comorbidities, such as depression, have recently been associated with poor clinical outcomes after ACL reconstruction (ACLR). To date, no article has yet examined how depression affects ACLR outcomes and how potential screening and intervention for psychological distress may affect postoperative activity level. The purpose of this review is to delineate potential relationships between depression and ACLR outcome, discuss clinical implications and identify future directions for research.

Key words: Depression; Preoperative evaluation; Anxiety; Anterior cruciate ligament reconstruction; Patient reported outcome; Orthopedic surgery

Core tip: A difference exists between patients suffering

from psychiatric disease, such as depression, and those with psychological constructs, such as pain catastrophization, that hinder sport performance. The former may require clinical evaluation by a mental health professional. The latter may be dealt with through counseling and physical therapy. When assessing a patient with anterior cruciate ligament injury, it may be useful to screen for symptoms of hopelessness and anhedonia that have persisted for at least two weeks, two inquiries found on the Patient Health Questionnaire 2 (PHQ-2). Patients who respond positively to the PHQ-2 should be referred for further evaluation and counseled accordingly.

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INTRODUCTION

The anterior cruciate ligament (ACL) is the most commonly injured ligament of the knee[1]. Although treatment with ACL reconstruction (ACLR) can restore stability and knee kinematics[2], a significant proportion of ACLR patients still do not return to pre-injury level of activity or sport[1,3-6]. In recreational and professional athletes, Ardern *et al*[1] found that as much as 40% do not return to pre-injury level of sport two years postoperatively. Investigating this discouraging result, recent literature has recognized an association between psychological factors and ACLR outcome[2,7-25].

In the continuum of psychological factors, clinical depression has recently been suggested as one of the most debilitating[26-29]. Garcia *et al*[26] found that preoperative depressive symptomatology is associated with significantly worse self-reported functional outcome at one year postoperatively for patients undergoing ACLR[26]. In addition, as many as two out of every five ACLR candidates may exhibit significant depressive symptomatology preoperatively[16,26], a fourfold higher rate than the national average[30].

To date, no review article has examined the impact of psychiatric disease, such as depression, on ACLR outcome and clinical practice. Instead, most of the focus has been on other psychological factors, such as fear of reinjury, athletic identity, self-efficacy, and locus of control, which are not true clinical diagnoses[2,10,14,15,20,22,25,28]. Although psychological impediments may interfere with ACLR rehabilitation, they rarely have implications outside of sport[2,16,18]. In contrast, depression is associated with significant general comorbidities and is the major risk factor for suicide in ACLR patient age groups[31-36]. While past ACLR literature has called for patients reporting depressive symptoms to seek care from a sports psychologist[2], recent studies have advocated for depression screening tools and referral to mental health professionals, where therapy and pharmacologic treatment may be necessary[15,26].

The purpose of this review is to delineate potential associations between depression and ACLR outcome, discuss clinical implications and identify future directions for research.

DEPRESSION SYMPTOMATOLOGY AND ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

In the United States, the second-most likely cause of death for patients in the 15-34 age group is suicide[31]. According to the American Psychiatric Association, major depressive disorder (MDD) is the most salient risk factor for suicide[32,37] and is estimated to affect up to 10% of the adult United States population[30]. Individuals can meet diagnostic criteria for MDD when they exhibit at least five out of nine depression symptoms, such as anhedonia or hopelessness, for a duration of at least two weeks without the influence of substances (Table 1). Depression accounts for $43 billion in medical costs annually and by 2020 could be the second largest cause of disability[38]. Given the prevalence and impact of depression, many primary care specialties recommend guidelines for screening, treatment and referral[38].

Although the Academy of American Orthopaedic Surgeons (AAOS) and American Orthopaedic Society for Sports Medicine (AOSSM) do not have guidelines in place for when to screen orthopaedic patients for symptoms of depression, recent literature suggests that depression can significantly affect orthopaedic patients and outcomes[15]. For instance, the incidence for depression can be as high as 45% in orthopaedic trauma patients[39], 42% in ACLR patients[26], and above national average level for patients undergoing joint replacement[40] and rotator cuff repair[41]. In addition, depression has been found to be a risk factor for poor functional outcome for orthopaedic procedures with lengthy rehabilitation periods, such as joint replacement and vertebral disc replacement[40,42]. Common symptoms of depression, such as fatigue, psychomotor agitation, and inability to concentrate, may interfere with rehabilitation[32], particularly if recovery takes at least one year[2].

Given the patient demographic and length of rehabilitation, ACLR and its association with depression has drawn recent interest. It is known that 15-25 year-olds have the highest incidence of ACL injury, which make patients of this age group common ACLR candidates[12]. However, this is the same age-group vulnerable to the sequelae of depression, as suicide remains the second most common cause of death[37]. In addition, rehabilitation after ACLR has long been recognized as an important aspect to recovery and return to sport[6]. Compliance with rehab, however, can be especially difficult for those afflicted with depression due to the

Table 1 Diagnostic criteria of major depressive disorder[1]

DSM-V	Diagnostic Criteria
Major depressive disorder	Patient reports at least five of nine of the following depressive symptoms most of the day or almost every day for at least two weeks: (1) Depressed mood that may be characterized by sadness, emptiness or hopelessness; (2) Markedly diminished interest or pleasure in all or almost all activities; (3) Significant unexpected weight loss; (4) Inability to sleep or oversleeping; (5) Psychomotor agitation or retardation; (6) Fatigue or loss of energy; (7) Feelings of worthlessness or inappropriate guilt; (8) Diminished ability to think, concentrate or make decisions; (9) Recurrent thoughts of death, suicidal ideation without a specific plan or a specific suicide attempt or specific plan for committing suicide Symptoms cause clinically significant distress or impairment in social, occupational or other important areas of functioning The episode is not due to the effects of substance or to a medical condition The occurrence is not better explained by schizoaffective disorder, schizophrenia, schizophreniform disorder, delusional disorder, or other specified and unspecified schizophrenia spectrum and other psychotic disorders There has never been a manic episode or a hypomanic episode

[1]Adapted from the DSM-V guidelines.

length and intensity of exercise[6].

RECOVERY FROM ACLR: A LENGTHY REHAB PROCESS

A number of postoperative rehabilitation protocols exist for ACL reconstruction patients, and many are physically demanding; however, there is minimal consensus as to which programs are most effective[43]. In general, programs can incorporate early weight bearing and motion, closed kinetic chain exercises, cryotherapy and exercises to enhance balance, proprioception, and core strength[44-48]. These are implemented at various stages in a tiered fashion beginning with controlling inflammation and restoring gait which later progresses to normalizing range of motion, strength, and activity[46,49]. Other components of a physical therapy regimen such as neuromuscular electrical stimulation (electrotherapy), gait training, hydrotherapy, stair climber, and slide board programs have also been found to be safe and beneficial to some[45-48]. In contrast, there is little evidence to support the use of a knee brace, continuous passive motion, or creatine supplements to enhance recovery[47,48].

While most protocols are similar in the activities that are prescribed, they vary greatly on the time frame in which increasing levels of activity are permitted. Traditional rehabilitation programs tend to be more conservative in the level of activity permitted at each phase of treatment and typically require approximately one year to complete[50]. Recently, aggressive protocols have become popular and have reduced the length down to 6 mo before return to full active function[48,50-52]. These more progressive regimes typically allow full range of motion at 10 wk and return to sports if strength is greater than 80% as early as 16 wk[43,46-48,50,52]. The number of physical therapy sessions in these accelerated programs varies greatly but generally averages around 20 sessions, most of which occur in the first three month[49,53]. Home based programs, which average around 4 sessions within the same timeframe, have been found to be equally effective for motivated patients[47,53-57].

Regardless of the exact regimen followed, the road to recovery requires myriad hours of physical therapy to return to pre-injury level of activity. In addition, return to full, pre-injury state function does not always occur. For instance, Schenck *et al*[54] found that patients returned to good function on average at 21.6 mo (range: 12-48). In a meta-analysis conducted by Ardern *et al*[6], only 63% of patients were able to return to their pre-injury sport; 44% returned to competition. The average time between surgery and the resumption of any type or level of sports was 7.3 (range 2-24) mo, and those that returned to competition required on average 36.7 mo postoperatively[3].

The psychosocial impact of such a long recovery process can be particularly devastating. A lack of mobility may result in social isolation and lowered self-efficacy or a loss of self-worth as a result of not being able to perform pre-injury state functions[15]. The latter is particularly applicable for collegiate or professional athletes who gain a strong sense of self-worth from their physical performance capabilities[58]. For instance, collegiate athletes who sustained ACL injuries demonstrated seven times more depression relative to baseline and exhibited mood disturbances, anger, depression, and lowered self-esteem[10,17,27,59]. Those who suffered career ending injuries reported much lower life satisfaction scores compared to their non-injured counterparts[27]. Those that require knee stability as part of their occupation, such as military personnel and manual laborers, are also severely affected by the long recovery process. A study conducted by the Australian Army found that only 71% of personnel who underwent ACLR returned to active duty after 3 years[60,61]. Particular emphasis must be placed on these patient populations to minimize psychosocial health deterioration during the rehabilitation process[62].

THE MECHANISM OF DEPRESSION AND IMPLICATIONS FOR RECOVERY

Although it has been shown that depressed patients undergoing ACLR report lower self-reported outcome

Table 2 Systemic effects of clinical depression on immune system and hypothalamic-pituitary-adrenal axis

Target system	Effect
Immunologic system	Increased interleukin-1
	Increased interleukin-6
	Increased tumor necrosis factor-α
Musculoskeletal system	Decreased bone formation
	Increased bone resorption (likely 2/2 increased interleukin-1 and subsequent osteoclast activity)
Hypothalamic-pituitary-adrenal axis	Increased cortisol

scores, it is unclear why. Since no randomized controlled studies have been conducted, causation has yet to be determined. ACL injury alone may lead to depressed mood and depressed mood may lead to poor self-reported functional outcome. Adherence to rehabilitation protocol after ACL reconstruction has been shown to strongly correlate with surgical outcome[18]. Thus, one possible explanation for compromised subjective outcomes in depressed patients is that those who experience greater symptoms of depression are less likely to adhere to the necessary rigorous ACL rehabilitation, leading to poorer clinical outcomes. Other literature propose fear of reinjury, pain catastrophizing and a lower internal Health Locus of Control - defined as the perception of one's ability to control life events - as other possible mechanisms[63]. It is plausible that ACL patients who are depressed are more likely to have these aforementioned psychosocial impediments that can disrupt the recovery process. Indeed, successful recovery from surgical intervention has been suggested to require a dynamic biopsychosocial cycle consisting of a patient's affect, cognition and behavior[22]. Thus, it is also possible that clinical depression is just one in a continuum of psychosocial and musculoskeletal factors that contribute to surgical outcome[18,22,63].

In addition, it has been suggested that depression is a systemic disorder with increased inflammatory markers that contribute to worse medical outcome[33,64,65] (Table 2). In addition to decreased serotonin levels, depressed patients have been found to have elevated levels of interleukin (IL)-1, IL-6 and tumor necrosis factor (TNF)-α, decreased cell-mediated immunity and increased cytokine response compared to non-depressed HIV and cardiovascular disease patients[33,64,65]. These cytokines are particularly significant to musculoskeletal injury since IL-1 activates osteoclasts, thereby decreasing bone formation and density, while IL-6 and TNF-α are acute phase reactants that are implicated in fever and inflammation[33]. While depression may certainly exacerbate psychological impediments to recovery, there may be an immunologic basis as well, a concept that warrants future investigation.

OTHER PSYCHIATRIC DISEASE AND ACLR

Other common psychiatric diseases, such as anxiety and psychotic disorders, have not been studied with respect to recovery after ACLR, but have been implicated in orthopaedic disease. For instance, many studies have noted an elevated incidence of preoperative anxiety disorders in orthopaedic patients such as those with osteonecrosis of the femoral head[66-68], which have led to worse patient reported outcomes for joint replacement patients[69-72]. Others have noted that anxiety disorders, such as posttraumatic stress disorder have led to worse clinical outcome following lower extremity orthopedic surgery for patients[73-76].

In addition, psychotic disorders such as schizophrenia and delirium have been implicated in worse postoperative outcome and leaving the hospital against medical advice[77-80]. In orthopaedic patients, it has been suggested that patients with psychiatric disease may have increased hypothalamic-pituitary-adrenal (HPA) responses to the stress of surgery[34]. As Kudoh *et al*[34] suggests, elevated cortisol may accelerate injury to vascular endothelial cells and promote the development of atherosclerosis or hypertension.

However, no studies have yet to look at anxiety and psychotic disorders and their association with ACLR outcome.

RECOMMENDATIONS FOR CLINICAL PRACTICE: EVALUATION OF ACLR CANDIDATE

Evaluation of ACL reconstruction candidates requires obtaining a pertinent history, performing a thorough physical exam, and utilizing diagnostic imaging. Classically, patients with ACL tears will complain of a "popping" sensation followed by acute swelling and a feeling that their knee is unstable. Other aspects of a clinical history to elicit include time and mechanism of injury, location of pain, and functional ability. On the physical exam, general evaluation for knee pain should be conducted which include inspection, palpation, and testing for mobility, strength, and stability. Specialized tests for ACL integrity include the Lachman, Pivot Shift, and Anterior Drawer[81-83]. While all three should be performed, the Lachman has been shown to be the most useful[83]. Sensitivity and specificity of the Lachman for ACL tears have been reported at 84% and 94%, respectively[83]. Comparison with the contralateral knee is also important as many patients have increased laxity that may not be

Table 3 Patient Health Questionnaire 2[1]

Over the past 2 wk, how often have you been bothered by any of the following problems?	Not at all	Several days	More than half the days	Nearly every day
Litter interest or pleasure in doing things	0[2]	1[2]	2[2]	3[2]
Feeling down, depressed, or hopeless	0[2]	1[2]	2[2]	3[2]

[1]Adapted from Arroll *et al*[86]; [2]Sum points from both questions (range 0-6). A score of 3 or higher is considered positive and should be further evaluated by Patient Health Questionnaire-9.

Table 4 Diagnostic criteria for major depressive disorder utilizing SIGECAPS mnemonic[1]

Sleep	Insomnia or hypersomnia nearly every day
Interest	Markedly diminished interest or pleasure in nearly all activities most of the time
Guilt	Excessive or inappropriate feelings of guilt or worthlessness most of the time
Energy	Loss of energy or fatigue most of the time
Concentration	Diminished ability to think or concentrate; indecisiveness most of the time
Appetite	Increase or decrease in appetite
Psychomotor	Observed psychomotor agitation/retardation
Suicide	Recurrent thoughts of death/suicidal ideation

[1]Adapted from the Diagnostic and Statistical Manual of Mental Disorder, 4th ed.

pathologic. Lastly, MRI imaging may be used to assist with diagnosis[83]. Together, the constellation of signs and symptoms can be used to determine whether the patient is a candidate for ACLR.

Recommendations for managing an ACLR patient with depression center on three domains: Stratifying risk, screening for early signs of mental health deterioration, and implementing effective interventions. Risk stratification involves identifying patients who may have poor postoperative rehabilitation outcomes as a result of their mental health state. This can be performed both preoperatively and postoperatively. While depression is not an absolute contraindication for surgery, if it is identified at the preoperatively, consideration can be made to delay surgery so that the patient can seek mental health services[15]. Postoperatively, those who are considered high-risk should be monitored more closely. Emphasis should be placed on demographic groups that have been shown to be the most affected by ACL injury and the lengthy recovery process including athletes, military personnel, and manual laborers[59-62,84]. Those who exhibit high levels of psychological stress or low levels of self-efficacy should also be placed in the high-risk category given literature suggesting a connection between these two factors and poor recovery from injury or surgery[15,85].

Most importantly, many questionnaires exist for screening depression, including the Patient Health Questionnaire (PHQ), Center for Epidemiologic Studies Depression Scale (CESDS), and Geriatric Depression Scale (GDS)[15,38,86]. Among the validated tests, perhaps the one that is most applicable to the ACLR population is the PHQ which, due to a concise format that can be applied rapidly in an orthopedic setting[86] (Table 3). It involves a short, two question survey (PHQ-2) to screen for depressed mood and anhedonia over the past 2 wk. Those that screen positive are then evaluated by the longer PHQ-9, a nine-question survey. The PHQ-2 may rule out, but not definitively diagnose, depression, but is as effective as longer screening instruments, such as the Beck Depression Inventory. The PHQ-2, for instance, has been found to be up to 97% sensitive in adults. In addition to the PHQ-2, SIGECAPS is also a popular mnemonic that can be easily used by orthopedic surgeons or physical therapists to quickly screen for different manifestations of depression[33] (Table 4).

A number of interventions have been recommended for ACLR patients with depression, although it is important to note that none have been studied with respect to ACLR outcomes. Most suggest referral to a primary care or mental health provider with the application of pharmacotherapy if indicated[2,15]. Existing psychiatric literature suggests that pharmacologic intervention can improve medical outcome, such as decreasing mortality in HIV and cardiovascular patients[33,65]. In the orthopaedic literature, referral to a sports psychologist, pain desensitization therapy, cognitive behavioral pain management, goal setting, and positive self-talk courses, books, or audiotapes[15,48]. Specific interventions include attending preoperative education classes or developing a peer support network with previous patients or athletes who have recovered from injury. Given the link between physical therapy adherence and outcomes, it may also be beneficial to increase the number of in-office sessions for ACLR patients with depressed symptomatology especially in the later stages of treatment where more home sessions are typically prescribed. Indeed, patients with or without MDD who adhere to the same in-office schedule report similar outcomes in the early phase of treatment[26]. Conversely, home based programs with

minimal supervision have only been shown to be effective in motivated individuals with high self-efficacy[47,53], which would not be recommended to potentially depressed ACLR patients. Establishing a treatment pathway for preoperatively depressed ACLR patients could help improve rehabilitation adherence and potentially functional outcomes.

RECOMMENDATIONS FOR FUTURE RESEARCH

Review of the literature leads to three recommendations for future research regarding ACLR patients and their association with psychiatric disease. First, it is clear while recent literature suggests an association exists between depression and ACLR outcome, more work is needed to elicit the significance of the chronology of the mood disturbance and its effects. For instance, do only patients with preoperative depression symptomatology perform worse or do the symptoms primarily manifest in the recovery phase? In addition, up to how long postoperatively do patients classified as having MDD report worse outcomes than non-MDD counterparts? Currently, there is no literature on outcomes past one-year follow-up; second, research examining the importance of intervention for ACLR patients with depression symptomatology is needed. While many studies encourage providers to be aware of depression symptomology, there has yet to be evidence that intervention, whether through referral, behavioral therapy, or pharmacotherapy, can improve outcomes; lastly, future studies should also examine other common psychiatric disorders, such as general anxiety disorder and PTSD, since these have been implicated in poor outcome for patients undergoing other orthopaedic procedures.

CONCLUSION

Existing literature suggests that patients who sustain ACL injury may report higher rates the national average of depression symptomology and that these symptoms may be associated with worse postoperative outcome. Providers should therefore consider screening ACLR candidates for depression, perhaps with the PHQ-2. Future research should strive to delineate the timing of depression in ACLR patients, the effect of interventions and whether other psychiatric diseases are associated with ACLR outcomes.

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Management of syndesmotic injuries: What is the evidence?

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Abstract

Ankle fractures are accompanied by a syndesmotic injury in about 10% of operatively treated ankle fractures. Usually, the total rupture of the syndesmotic ligaments with an external rotation force is associated with a Weber type B or C fracture or a Maisonneuve fracture. The clinical assessment should consist of a comprehensive history including mechanism of injury followed by a specific physical examination. Radiographs, and if in doubt magnetic resonance imaging, are needed to ascertain the syndesmotic injury. In the case of operative treatment the method of fixation, the height and number of screws and the need for hardware removal are still under discussion. Furthermore, intraoperative assessment of the accuracy of reduction of the fibula in the incisura using fluoroscopy is difficult. A possible solution might be the assessment with intraoperative three-dimensional imaging. The aim of this article is to provide a current concepts review of the clinical presentation, diagnosis and treatment of syndesmotic injuries.

Key words: Ankle sprain; Syndesmotic injury; Syndesmotic screw; Ankle; TightRope; Three-dimensional

Core tip: The aim of this article is to provide a current concepts review of the clinical presentation, diagnosis and management of syndesmotic lesions. Even if syndesmotic injuries are common, the appropriate management is still under discussion. Current treatment options are discussed and future directions are provided.

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INTRODUCTION

Ankle fractures are accompanied by a syndesmotic injury in about 10% of operatively treated ankle fractures[1-3]. Numerous mechanisms can lead to disruption of the syndesmosis complex, and the most accepted mechanism of injury is external rotation, hyperdorsiflexion and talar eversion[4-6]. This leads to sequentially tearing the anterior inferior tibiofibular ligament and the deltoid complex or causing a malleolar fracture, the interosseous ligament and finally the posterior inferior tibiofibular ligament[7-9]. In most cases, a total lesion of the syndesmotic ligaments is associated with a distal fibular fracture type Weber B or C or a proximal fibular fracture (Maisonneuve injury)[10,11].

CLINICAL AND RADIOLOGICAL EVALUATION

Local swelling and tenderness are suspicious for a syndesmotic injury[12]. There are several tests available such as the external rotation test, heel thump test, dorsiflexion compression test or the squeeze test to evaluate the integrity of the syndesmosis[6]. However, in the presence of pain or swelling these tests are of limited use[13]. Clinical tests for syndesmotic lesions have a low predictive value to verify a syndesmotic injury. Several authors could show that the external rotation test might be the most sensitive test with the lowest false-positive rate[6,14].

Intraoperatively, the integrity of the syndesmosis can be checked by the external rotation test or the bone hook test, which is supposed to be more reliable (Figure 1). However, these tests are also limited by a poor inter-observer reliability, which further highlights the importance of both clinical examination and imaging to diagnose an injury of the syndesmosis[13-15].

RADIOGRAPHS

Standard radiographic examination of the ankle should consist of at least two views: Lateral view and mortise view (Figures 2 and 3). The anterior-posterior (AP) view of the ankle can be obtained as a third view, but it does not provide any additional information regarding the reduction of the mortise. In case of suspicion of a proximal fibular fracture or an injury of the syndesmosis in the clinical examination or on plain radiographs of the ankle, standard radiographs of the whole lower leg should be obtained to exclude proximal fractures/Maisonneuve injury (Figure 4)[6].

If an ankle fracture is present, the fracture pattern is most commonly described using the AO comprehensive classification system[16,17]. The plain radiographs should also be carefully checked for avulsion fractures of the anterior part of the syndesmosis, the so-called Tubercule de Chaput or Wagstaffe le Fort fragment and the posterior malleolus (Volkmann fragment) (Figure 5)[18,19].

If the mechanism of injury and the clinical examination are suspicious for a syndesmotic injury, the

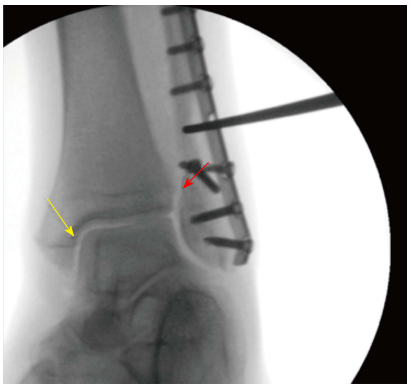

Figure 1 Intra-operative assessment of the syndesmotic integrity in a Weber B fracture with the hook test under fluoroscopy (Mortise view). In this case, the tibiofibular clear space (red arrow) and the medial clear space (yellow arrow) do not open indicating that the syndesmotic ligaments are intact.

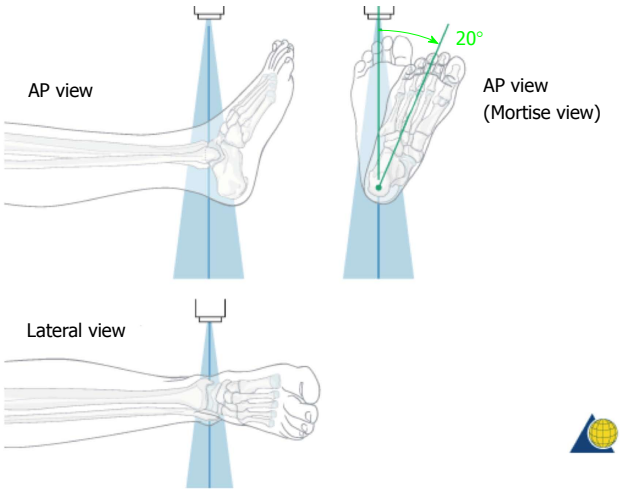

Figure 2 Illustration of the plain radiographs of the ankle (Copyright by AO Foundation, Switzerland). AP: Anterior-posterior.

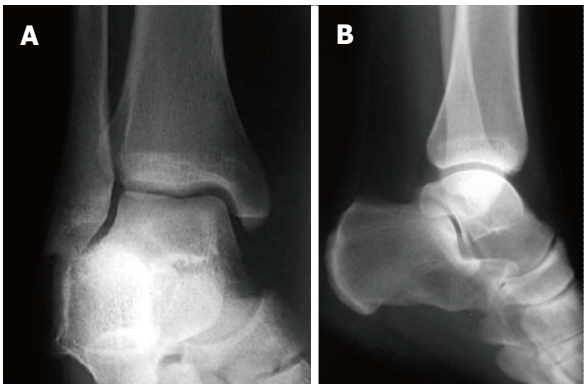

Figure 3 Examples for radiographs of the ankle: Mortise view (A) and lateral view (B).

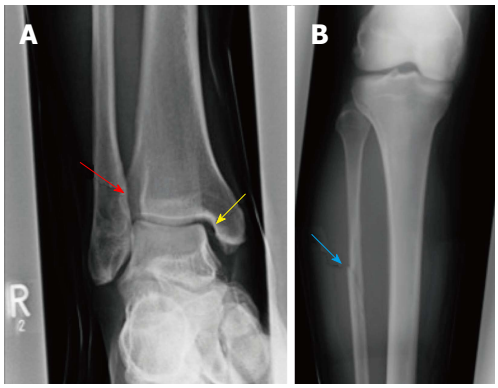

Figure 4 The increased tibiofibular clear space (red arrow) and medial clear space (yellow arrow) are highly suspicious for a syndesmotic lesion (A) and the radiograph of the proximal part of the lower leg is showing a Maisonneuve injury (blue arrow) (B).

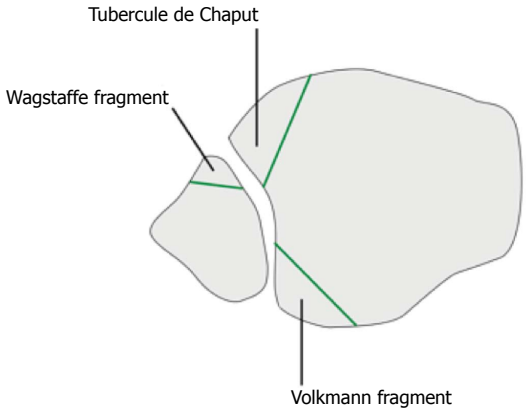

Figure 5 Schematic illustration of the avulsion fractures of the anterior part of the syndesmosis (Tubercule de Chaput, Wagstaffe fragment) and posterior Volkmann fragment (Copyright by AO Foundation, Switzerland).

plain radiography should be examined for: (1) the tibiofibular clear space; (2) the tibiofibular overlap; and (3) the increased medial clear space (Figure 4). These measurements are helpful to detect the presence of syndesmotic injuries[19].

As a limitation, it should be mentioned that the measurements for the assessment of the syndesmosis on radiographs are based on cadaveric studies, and that the measurements are influenced by the quality of the radiographs. Recently, Hermans *et al*[20] investigated a study to compare magnetic resonance imaging (MRI) findings with plain radiographs in syndesmotic injuries. The authors found that the tibiofibular overlap and the tibiofibular clear space did not correlate with a syndesmotic injury seen on MRI. Therefore, further imaging with MRI scan is recommended, if there is any suspicion of a syndesmotic lesion. The sensitivity and specificity of MRI scans for the evaluation of the syndesmotic complex is up to 100%, and the integrity of the syndesmosis can be optimally visualized on MRI axial views (Figure 6)[21,22].

In addition to plain radiographs, manual or the gravity external rotation stress radiographs can be applied to the injured ankle to evaluate the integrity

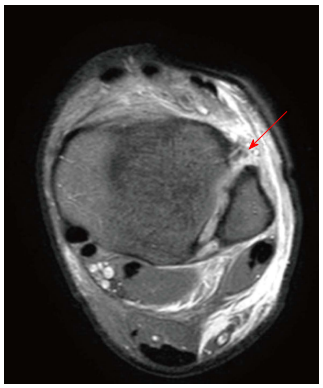

Figure 6 Axial plane of magnetic resonance imaging showing a full thickness tear of the anterior part of the syndesmosis (red arrow).

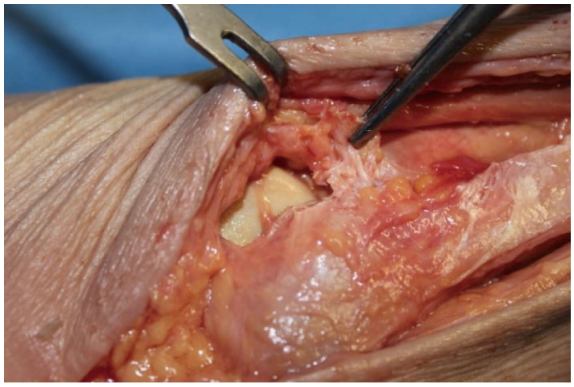

Figure 7 Intraoperative visualization of the anterior part of the syndesmosis; in this patient the anterior part of the syndesmosis is completely disrupted (hold with the pincers).

of the deltoid ligament[23]. The amount of medial clear space widening of > 5 mm is highly suspicious for a rupture of the deep deltoid ligament. As a limitation of the manual stress test it should be mentioned that the amount of applied force necessary when performing an external rotation stress radiograph is not well defined and mainly determined by the patient's pain level[23].

In the presence of fractures, clinical or radiological examination of the syndesmotic integrity is not necessary, as this can be done intraoperatively[6]. Lui *et al*[24] could show that arthroscopy can detect syndesmotic injuries more reliable than intraoperative stress radiographs. However, arthroscopy of the ankle joint is technically demanding and therefore, it is not used routinely. Normally, the integrity of the syndesmosis is checked by the hook test following fixation of ankle fractures (Figure 1). Alternatively, especially in unclear cases with fracture type Weber B, the integrity of the syndesmosis can be verified by intraoperative visualization and by intraoperative testing of the stability (Figure 7).

MANAGEMENT OF ISOLATED SYNDESMOTIC INJURIES

Syndesmotic injuries without an associated fracture

occur much less frequently compared to fracture associated syndesmotic lesions[6,25]. However, if an isolated syndesmotic injury is missed, it is prone to deteriorated clinical outcome with pain and instability. The management of isolated syndesmotic injuries is still under discussion. In simple syndesmotic sprains without diastasis of the syndesmotic region most authors prefer non-operative management with a non-weight bearing cast and report good functional long-term results[26]. In contrast, a displaced and widened mortise needs operative fixation of the syndesmosis[26,27].

Non-surgical management

Non-surgical management includes plaster immobilization for 2-6 wk with a non weight-bearing cast[26]. There are only few literature data available reporting on clinical results after conservative treatment of isolated syndesmotic injuries. Recently, a comprehensive review with isolated syndesmotic injuries has been published[25]. The period of plaster immobilization varies between 2 and 6 wk indicating that there is no consensus. From our experience, plaster immobilization should be performed for at least 6 wk to prevent chronic instability and recurrent injuries.

The reported complication rates after non-surgical management of isolated syndesmotic injuries were high (up to 68%)[28-30]. The most common complications recorded in the studies were stiffness, pain with activity, heterotopic ossification and residual painful instability.

Surgical management

Reports about operatively treated isolated syndesmotic injuries are rare. Taylor *et al*[31] published the results of six patients with isolated syndesmotic injuries that were treated operatively with a 4.5-mm stainless steel cortical screw. The mean time from injury to treatment was 3 d and all the patients were treated within 7 d. Average time to return to sports was 40.7 d (32-48 d) in all patients. The assessment of the clinical outcome showed good to excellent results in all patients.

MANAGEMENT OF ANKLE FRACTURES WITH SYNDESMOTIC INJURIES

In the treatment of ankle fractures with an associated syndesmotic lesion the primary goal is to restore ankle stability and to maintain correct alignment of tibia and fibula to allow sufficient healing of the syndesmotic ligaments[32]. In the case of surgical stabilization, the method of fixation is still under discussion[6]. Beside the use of syndesmotic screws, which is the most widespread method, suturing of the syndesmosis, syndesmosis hooks, bioabsorbable screws, Endo Buttons (Smith and Nephew Endoscopy, Andover, Massachusetts), and the TightRope device (Arthrex, Naples, Florida), which in particular became popular in the last decade, are also used for syndesmotic fixation[6].

Stabilization of the ankle mortise is generally recommended, when the fracture pattern, intraoperative assessment with a hook or the direct visualization demonstrates a syndesmotic diastasis. A consensus for the appropriate size of the syndesmosis screw has not been reached yet. Most authors prefer either 3.5 or 4.5 mm cortical screws. In Europe most surgeons use one single 3.5-mm tricortical diastasis screw for stabilization of the syndesmosis in Weber B or C fractures. The preferred height is at 2.1 to 4 cm above the ankle joint line. Two syndesmotic screws are commonly used in Maisonneuve fractures[33]. In biomechanical studies, 3.5 and 4.5 mm cortical screws showed comparable biomechanical characteristics[34]. In cadaveric studies the influence of the numbers of syndesmotic screws has been investigated[35]. There is evidence that two screws provide a better construct biomechanically compared to one diastasis screw alone.

The placement height of the syndesmotic screw and the number of cortices engaged with the diastasis screws are also the topic of an ongoing discussion. Beumer *et al*[35] could show that there is no difference in clinical outcome comparing the engagement of three *vs* four cortices. Most authors agree that diastasis screws should be placed 2 to 3 cm proximal to the tibial plafond. Interestingly, the placement of diastasis screws at 2, 3 and 5 cm proximal to the ankle joint seems to have no influence on functional outcome[36].

Despite the invention of novel devices such as the Tightrope or bioabsorbable screws for restoration and maintenance of the congruent syndesmosis following syndesmotic injury, the metallic syndesmotic screw is still considered to be the gold standard[37]. A possible disadvantage of the syndesmotic screw is the need for implant removal. In general, the syndesmosis takes 8 to 12 wk to heal, and afterwards removal of the hardware is recommended by most authors[38]. However, the hardware removal is accompanied by high complication rates such as wound infection, re-occurrence of screw breakage and diastasis during removal[39]. Alternatively, the syndesmotic screw can be left *in situ*. Schepers published a review with 472 patients included with retained syndesmotic screws. Eighty patients had loose diastasis or broken screws[40]. Despite this, there were no significant differences in clinical outcome between retained or removed screws.

Another alternative fixation device are bioabsorbable screws. Bioabsorbable screws can be used instead of syndesmotic screws for stabilization of the syndesmosis but have the advantage that screw removal is unnecessary. A recently published review compared the results of bioabsorbable and metallic syndesmotic screws[38]. Bioabsorbable syndesmotic screws and metallic syndesmotic screws were comparable with respect to the incidence of complications and range of motion. However, the absolute number of complications was greater with bioabsorbable screws (23.4% *vs* 5.7%). Most frequent complications of bioabsorbable screws were wound-related complications in 19.7% of the patients.

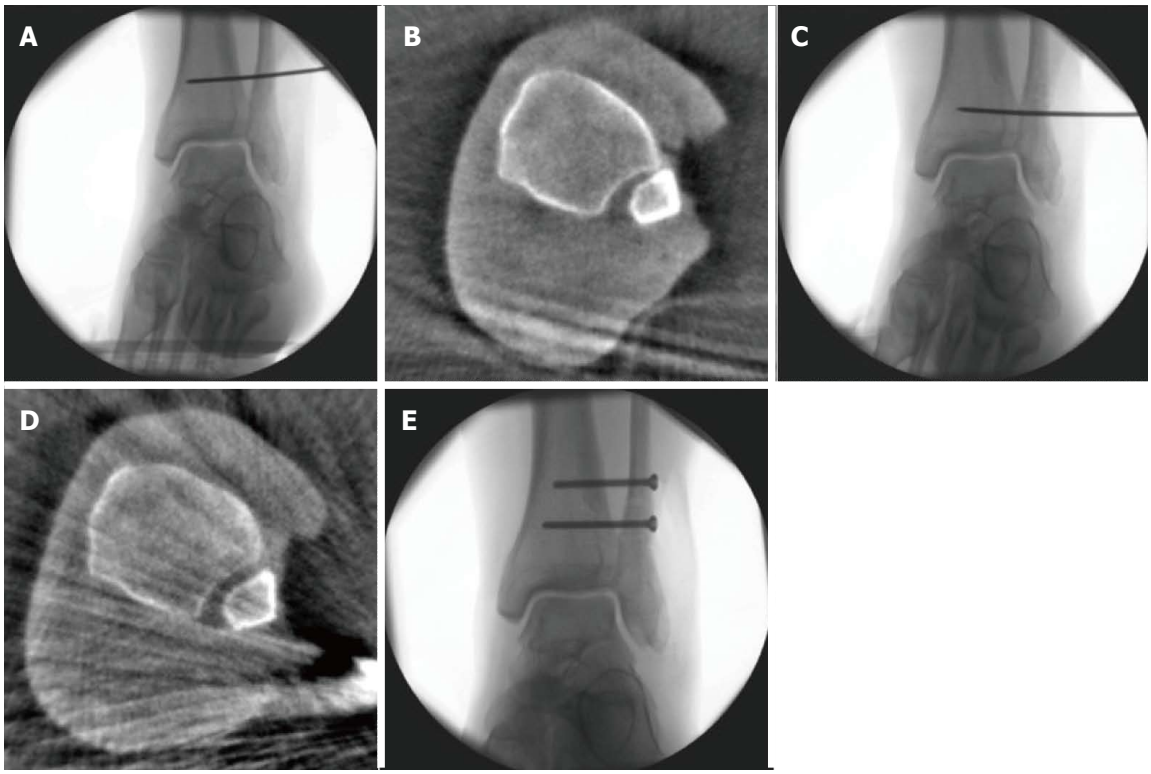

Figure 8 A 25-year-old patient with a Maisonneuve injury. Assessment of reduction with intra-operative three-dimensional scan (A-E): After closed reduction and temporary fixation with a k-wire (A) the three-dimensional scan shows malreduction of the distal fibula in the incisura (B). Immediate intraoperative revision was performed (C) with repeated intraoperative three-dimensional scan showing correct reduction of the distal fibula. With k-wire in place, two syndesmotic screws have been placed to stabilize the ankle diastase (E).

Currently, debate exists over rigid screw fixation *vs* suture button techniques as the ideal fixation method. The theoretical advantages of a suture-button device over metallic syndesmotic screws are that it allows physiologic motion at the syndesmosis while maintaining the reduction, less risk of hardware pain and subsequent implant removal, and it may permit earlier return to motion as there is no risk of screw breakage and subsequent recurrent syndesmotic diastasis[41]. In a cadaveric study, Teramoto *et al*[42] sequentially assessed native syndesmosis ligament stability, suture button, and screw fixation for diastasis in six anatomic specimens. With anatomically directed fixation, there was no significant difference in diastasis for any fixation technique compared with the intact native ligaments. However, screw fixation provided the most rigid fixation and greatest stability against external rotation force.

In the last two decades, many authors have sought to compare suture button techniques *vs* rigid fixation with cortical screws[26]. To date, for isolated unstable syndesmosis injuries, no study has shown suture button techniques to be inferior to rigid fixation with regard to joint stability and patient satisfaction.

The use of the Tightrope as fixation method of the ankle diastases has been developed recently. Naqvi *et al*[43] reported on their experience with 49 patients who were stabilized with the Tightrope device, and found satisfactory clinical results after 2 years of follow-up. One major advantage of this method compared to screws is that there is no need to remove the knot routinely. A potential limitation of this technique might be the higher costs compared to the screws and, some authors have reported soft tissue irritation from the knot with the need for revision surgery[44]. According to current literature, the functional outcome is comparable using either Tightrope or syndesmotic screws as fixation device. Detailed analysis of both groups revealed that the Tightrope device was superior to syndesmotic screws regarding the time to return to work. In addition, fewer patients needed implant removal after Tightrope fixation of the syndesmotic diastasis. Recently, a prospective randomized controlled study was published to compare syndesmosis screw and TightRope fixation in terms of accuracy and maintenance of syndesmosis reduction using intraoperative 3D imaging and postoperative bilateral computed tomography (CT)[45]. No difference was found regarding reduction of the syndesmosis. At two-year follow-up the incidence of ankle joint osteoarthritis and functional outcome showed no difference between the fixation methods.

Intraoperative assessment of reduction of syndesmosis

Several cadaveric studies have demonstrated that standard radiographic measurements used to evaluate the integrity of the syndesmosis are inaccurate and unreliable[46-48]. Multiple articles have described mal-reduction after operative treatment in up to 50% of the cases[46,49]. Even under direct visualization of the

syndesmotic region malreduction has been reported in about 15% because of missing anatomical landmarks[50-52]. A CT scan allows better visualization of the transverse relationship between the fibula and incisura fibularis[53-55].

Accuracy of reduction has been shown to correlate with poorer outcome and the development of post-traumatic arthritis[56-58]. Therefore, some authors advocate the use of a CT scan routinely after operative stabilization of syndesmotic diastasis[59]. Gardner *et al*[46] reported on 25 patients who underwent open reduction of a syndesmotic diastasis, and postoperative CT scans showed that 52% of the patients had a malreduced fibula within the incisura.

One possible solution to overcome these problems might be the routine use of intraoperative three-dimensional imaging, as this will allow anatomical fixation of the syndesmosis and immediate intraoperative revision in the case of malreduction. Franke *et al*[3] investigated a study with the routine use of the intraoperative three-dimensional scan for the assessment of accuracy of syndesmosis reduction in 251 patients. After closed reduction and fixation of the syndesmosis with a 3.5 mm syndesmosis screw, a conventional check of the ankle joint by fluoroscopy in the three standard views was performed. Only if the findings on fluoroscopy showed an adequate reduction by the surgeon's impression an intraoperative three-dimensional scan was performed. In 82 patients (32.7%), malreduction of the syndesmosis was found on the three-dimensional scan despite the fact that the fracture appeared to be adequately reduced on fluoroscopy. After immediate intraoperative revision(s), a repeated intraoperative three-dimensional scan showed anatomical reduction of the syndesmosis.

Examples of intraoperative assessment of syndesmotic reduction with an intraoperative three-dimensional scan are shown in Figure 8.

CONCLUSION

Syndesmotic injuries are common lesions after ankle sprain and require careful examination and management. A displaced and widened mortise requires operative fixation of the syndesmosis. Variable fixation techniques have been reported with comparable results. Furthermore, accuracy of reduction of the syndesmosis is of great concern, as it has been shown to correlate with poorer outcome and the development of post-traumatic osteoarthritis. In view of the high percentage of patients with malreduction of the syndesmosis, intraoperative three-dimensional imaging may be a solution for overcoming this problem. Alternatively, a postoperative CT scan should be performed to assess appropriate reduction.

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Vitamin D and spine surgery

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Abstract

Vitamin D is crucial for musculoskeletal health, maintenance, and function. Vitamin D insufficiency is common among patients undergoing spine surgery and the ideal vitamin D level for spine surgery has yet to be investigated. There is a high prevalence of hypovitaminosis D in patients with musculoskeletal pain regardless of surgical intervention. With the frequency and costs of spine surgery increasing, it is imperative that efforts are continued to reduce the impact on patients and healthcare services. Studies into vitamin D and its associations with orthopaedic surgery have yielded alarming findings with regards to the prevalence of vitamin D deficiency. Importantly, altered vitamin D status also contributes to a wide range of disease conditions. Therefore, future investigations are still essential for better understanding the relationship between vitamin D and spine surgery outcomes. Whilst further research is required to fully elucidate the extent of the effects of hypovitaminosis D has on surgical outcomes, it is strongly advisable to reduce the impacts by appropriate vitamin D supplementation of deficient and at-risk patients.

Key words: Hypovitaminosis D; Outcome; Prevalence; Spine surgery; Vitamin D

Core tip: A growing body of evidence suggests that vitamin D plays an essential role in skeletal development,

bone remodeling, fracture repair, and muscle strength. Vitamin D deficiency is highly prevalent in the elderly and underestimated by spine surgeons. Studies into vitamin D and its associations with orthopaedic surgery have yielded alarming findings with regards to the prevalence of vitamin D deficiency. Importantly, altered vitamin D status also contributes to a wide range of disease conditions and surgical outcome. Therefore, further investigations are still essential for better understanding paradoxical relationship between vitamin D status and spine surgery outcome.

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INTRODUCTION

A growing body of evidence suggests that vitamin D plays an essential role in skeletal development, bone remodeling, fracture repair, and muscle strength. Vitamin D deficiency is highly prevalent in the elderly and underestimated by spine surgeons. With the frequency and costs of spine surgery increasing, it is imperative that efforts are continued to reduce the impact on patients and healthcare services. Studies into vitamin D and its associations with orthopaedic surgery have yielded alarming results with regards to the prevalence of vitamin D deficiency. Generally speaking, serum 25-hydroxyvitamin D [25(OH)D] concentrations of less than 20 ng/mL are considered insufficient and below 10 ng/mL are deficient. However, there is still no standardised definition of where hypovitaminosis D starts, in part because of the conflicting data. What is largely agreed on though is that alarming numbers of the global population have insufficient vitamin D levels.

Vitamin D acts *via* the vitamin D receptor (VDR) on a range of tissues where it has multiple effects (reviewed in detail by Hossein-nezhad *et al*[1]). Perhaps most well-known is the way in which activated vitamin D acts on the kidneys and intestines to regulate calcium and phosphorus concentrations in the blood. In addition to this vital function, vitamin D is well known for its involvement in bone metabolism[2]. The induction of both bone formation and remodelling seems at first glance to be somewhat paradoxical. However, there exists strong links between bone mineral density (BMD) and vitamin D levels.

As we explore below, surgical outcomes are hindered by low vitamin D levels. Complications including recurrent fractures, insufficient tissue repair, and loosening of surgical hardware often require further surgeries and therapeutic intervention to ameliorate. Using simple and reasonable measures through the administration of vitamin D supplementation to reduce these effects would be a logical step in the continued effort to improve patient care and minimise financial expenditures.

VITAMIN D IN SPINE SURGERY

Despite the frequency of spinal surgery, particularly in elderly patients, there is a scarcity of research on vitamin D levels and surgical outcomes. However, a number of case studies have indicated the importance of healthy vitamin D levels. In two cases of severe hypovitaminosis D unsuccessful outcomes of spinal fusion surgery were observed, but following high vitamin D supplementation patients improved[3]. Likewise, a 76-year-old female with osteoporosis and circulating 25(OH)D levels of 9 ng/mL suffered compression fractures in thoracic and lumbar vertebrae. Following kyphoplasty, the patient reported no improvement in pain and suffered a further lumbar compression fracture, whereafter she received 2200 IU/d of vitamin D supplementation. Impressive clinical improvements were noted in muscle strength and a decrease in back pain[4]. This is supported by a study of 40 patients with acute symptomatic vertebral compression fractures who underwent kyphoplasty surgery[5]. When investigating the recurrence rate of fractures, serum 25(OH)D concentrations were higher in patients with no new fractures post-operatively compared with those who had suffered additional fractures, but lumbar BMD scores showed no significant difference. Schwalfenberg[6] reported 6 cases of improvements in back pain and failed back surgery patients through vitamin D supplementation. Patients respond over a range of time frames from 3 to 6 wk and whilst all patients showed improvements in pain, some responded better to treatment. It is suggested that 4000-5000 IU/d of vitamin D supplements may be required to improve the patients' conditions. An interesting observation was the improvement in mood noted in some cases, whether through direct psychoactive effects of vitamin D or as a result of decreased pain; it is another aspect to consider when evaluating vitamin D.

Moreover, Waikakul[7] investigated the association of serum 25(OH)D levels with pain and low back function in patients with failed back surgery syndrome. Of the nine cases, an initial 20000 IU loading dose of ergocalciferol, followed by daily doses of 600 IU of cholecalciferol showed improvements in all but one patient for pain and Japanese Orthopaedic Association (JOA) back scores. At 6 mo follow-up, patients continued to improve with just 2 experiencing only slight improvements. It suggests that high loading doses followed by prolonged use of maintenance doses can improve the functional scores of patients. Supporting this, a longitudinal study of 360 idiopathic low back pain patients in Saudi Arabia found that, at baseline, only 17% had normal vitamin D levels[8]. Patients were given high doses of vitamin D (5000-10000 IU/d) for 3 mo. At follow up 95% of patients reported the disappearance of low back pain and all patients had gained normal serum 25(OH)D

levels. Finally, in a prospective follow-up study of 31 females undergoing posterior decompression surgery and instrumented posterolateral fusion for lumbar spinal stenosis, post-operative (1 year follow-up) vitamin D levels were positively correlated with surgery outcome scores. The authors also remark the high prevalence of deficient vitamin D levels in lumbar spinal stenosis patients[9]. These reports showcase the risks to surgical outcomes of hypovitaminosis D, but also the possible benefits of vitamin D supplementation. High and maintained vitamin D treatment appears to be effective at both ameliorating surgical procedures, for example bone grafts and hardware fusion, and patients' symptoms including pain, function, and mood, which in turn often alleviates the need for analgesics.

A number of studies have reported alarmingly high prevalences of insufficient or deficient vitamin D levels in orthopaedic spine patients. A retrospective study of 313 adults undergoing spinal fusion by Stoker *et al*[10] found circulating 25(OH)D concentrations in nearly 90% of patients were insufficient or deficient (< 30 ng/mL); 3.5% were classified as severely deficient (< 10 ng/mL). Whilst females are often regarded as being at higher risk of hypovitaminosis D; no difference was observed between male and female patients, though vitamin D deficient patients tended to have higher pain and worse disability scores. Similarly, when Kim *et al*[11] examined vitamin D levels in 350 lumbar spinal stenosis patients with chronic low back pain and leg pain, they found that there was a high prevalence of hypovitaminosis D, only 2.9% of participants being vitamin D sufficient (> 30 ng/mL). Vitamin D deficiency was associated with both low back pain and leg pain in addition to sun light exposure. Furthermore, in Norway, a study of 572 patients complaining of headaches, fatigue, and musculoskeletal pain observed a high prevalence of vitamin D deficiency. The prevalence was affected by ethnicity; 83% of South Asian and African patients, but only 35% of native Norwegian patients were hypovitaminosis D sufferers[12].

In a cross sectional study of 400 individuals, there was a positive association between vitamin D levels and low BMD in both males and females that was independent of age, although vitamin D deficient participants were older than those with normal levels. Of the deficient participants, 100% had lumbar and hip BMD scores in the range of osteopenia or consistent with osteoporosis[13]. Whilst age is a recognised risk factor of vitamin D deficiency, younger patients should not be assumed to have healthy levels as shown by a study of the 70 paediatric orthopaedic patients undergoing long bone osteotomies, hip osteotomies, and spinal fusions studied by Parry *et al*[14], 90% of whom had subnormal vitamin D concentrations with 16% being severely deficient (< 12 ng/mL). Cholecystectomy put spine patients at an increased risk of vitamin D deficiency[15]. When classified into two groups - those who had previously undergone a cholecystectomy and those who had not - 40.8% of previous cholecystectomy patients were vitamin D deficient (< 20 ng/mL) compared to 25% of non-cholecystectomy patients. The aforementioned studies suggest the need to identify at-risk patients, particularly older patients and those who have histories of low bone density or medical conditions affecting bone metabolism.

Lumbar spine BMD has been shown to be decreased in low vitamin D patients as shown by the lumbar BMD scores of physically active and normal adolescent females in Israel which showed all participants were vitamin D insufficient (< 30 ng/mL) with 64% being defined as deficient (< 14 ng/mL). Furthermore, activity is associated with lumbar BMD and BMD scores are most strongly associated with the lowest tertile of 25(OH)D levels[16]. However, in Swiss teenagers with appendicular fractures, there was no difference between healthy individuals and those with fractures in vitamin D levels or lumbar or heel BMD, nor was there a difference between fracture sites. Despite a high prevalence of hypovitaminosis D, there was no association between vitamin D levels and spinal BMD[17]. Low BMD increases the risk of failure in surgical procedures, especially the application of hardware, for instance in spinal fusion. The vitamin D levels of patients, principally the elderly, should be maintained at satisfactory levels prior to and proceeding surgeries. Equally important is the activity of patients. Excessive and unnecessary use of back support braces can lead to weakening of the supportive muscles in the back, which in turn can lead to pain and less successful surgical outcomes. It should also be noted that genetic factors may contribute to the outcome of spine surgery. VDR gene polymorphisms where investigated by in a cross-sectional study of 318 postmenopausal females in Japan indicated that a VDR haplotype was associated with the severity of spondylosis in lumbar spine[18].

A retrospective investigation of orthopaedic patients undergoing cervical, thoracic, and lumbar disk replacements, decompressions, and arthroplasty revealed vitamin D deficiency (< 20 ng/mL) to be associated with cervical disk herniation, in particular, the number of herniations. The likelihood of disc herniation was higher in patients with lower vitamin D levels[19]. Research has been focused on investigating possible relationships between vitamin D status and clinical outcome in patients with spine surgery, as summarized in Table 1.

There is a disturbingly high prevalence of hypovitaminosis D in orthopaedic patients around the world. Low vitamin D levels appear to be the cause of many failed spinal surgeries, but despite the importance, and apparent severity, little research has been performed on the associations with surgical outcomes. With the relative inexpensiveness and safety of vitamin D supplementation, it would be prudent to screen for low circulating 25(OH)D concentrations and treat those found to be insufficient in an attempt to increase the chances of successful procedural outcomes.

Low vitamin D status is associated with a variety

Table 1 Summary of studies of vitamin status in patients with spine surgery

Ref.	Study design	Subjects	Significance
Schwalfenberg[6], 2009	Case series	6 patients with chronic back pain and failed back surgery	Repletion of inadequate vitamin D levels shows significant improvement or complete resolution of chronic low back pain symptoms
Pneumaticos *et al*[4], 2011	Case series	1 patient with osteoporosis with lumbar compression fracture	After kyphoplasty, vitamin D supplementation can improve muscle strength and decrease back pain
Waikakul[7], 2012	Retrospective study	9 patients with failed back surgery syndrome	Vitamin D supplementation can improve the functional scores of patients with failed back surgery syndrome
Zafeiris *et al*[5], 2012	Prospective longitudinal study	40 postmenopausal women with vertebral compression fractures	Patients with recurrent fractures have lower vitamin D levels than patients without recurrent fractures after kyphoplasty
Kim *et al*[9], 2012	Prospective study	31 female patients with lumbar spinal stenosis	Vitamin D deficiency is common in lumbar spinal stenosis patients and postoperative vitamin D is significantly correlated with surgical outcomes
Kim *et al*[11], 2013	Cross-sectional study	350 patients with lumbar spinal stenosis	Vitamin D deficiency is highly prevalent in lumbar spinal stenosis patients and is associated with severe pain
Stoker *et al*[10], 2013	Cross-sectional study	313 patients with degenerative spondylosis	There is a substantially high prevalence of hypovitaminosis D in patients undergoing spinal fusion
Stoker *et al*[19], 2013	Retrospective study	91 patients: 74 herniation, 17 no herniation	Vitamin D deficiency is associated with cervical disk herniation

of adverse outcomes following surgical procedures. In recent years, previous investigation has documented that serum 25(OH)D level at the time of operation is highly predictive of long term surgical outcomes compared to postoperative vitamin D status, and that benefits can be attained by vitamin D supplementation at the time of surgical procedures or thereafter[20].

Vitamin D status is a prognosticator of extraskeletal abnormalities for which predispositions could be detected and deficiencies should be corrected before surgical treatments. Our recommendation for patients with vitamin D deficiency prior to elective spine surgery is as follows. In patients whose 25(OH)D is less than 20 ng/mL, treatment generally includes initial 50000 IU loading dose of vitamin D orally once weekly for two to three months, and then 1000 or more IU of vitamin D daily thereafter. After three months, serum 25(OH)D should be reassessed. In patients whose 25(OH)D is 20-30 ng/mL, treatment includes 1000 IU of vitamin D by mouth daily, commonly for a three-month period. However, some patients may require higher doses. The ideal dose of vitamin D is determined by measuring serum 25(OH)D, and increasing the dose if serum vitamin D level is not within the normal range. Once a normal level is achieved, continued therapy with 800 IU of vitamin D daily is generally suggested. Although various strategies could be used in treating vitamin D deficiency, a common overlooking in management is to discontinue treatment or administer inadequate vitamin D maintenance dosing when the serum 25(OH)D level reaches the optimal range. It is, therefore, reasonable to routinely screen all patients undergoing spine fusion surgery for serum 25(OH)D levels, and those with vitamin D deficiency should be given vitamin D supplements.

CONCLUSION

Heretofore, limited research has been conducted into the associations of vitamin D and spine surgical outcomes. However, the existing evidence shows a need to improve vitamin D levels in patients with unsatisfactory results. There is an alarmingly high prevalence of subnormal vitamin D levels among orthopaedic patients reported in the literature. Considering the detrimental impact of hypovitaminosis D in patients undergoing spine surgery, preoperative vitamin D screening may be needed for those at high risk of deficiency. Whilst further research is required to fully elucidate the extent of the effects of hypovitaminosis D on clinical outcomes, it is strongly advisable to reduce the impacts by appropriate supplementation of deficient and at-risk patients to adequate levels.

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ORIGINAL ARTICLE

Basic Study

Three-dimensional reconstructed magnetic resonance scans: Accuracy in identifying and defining knee meniscal tears

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Abstract

AIM

To determine whether three-dimensional (3D) reconstruction from conventional magnetic resonance imaging (MRI) is able to accurately detect a meniscal tear, and define the configuration.

METHODS

Thirty-three patients' 3T MRI scan data were collected and sagittal uni-planar 3D reconstructions performed from the preoperative MRI. There were 24 meniscal tears in 24 patients, and nine controls. All patients had arthroscopic corroboration of MRI findings. Two independent observers prospectively reported on all 33 reconstructions. Meniscal tear presence or absence was noted, and tear configuration subsequently categorised as either radial, bucket-handle, parrot beak, horizontal or complex.

RESULTS

Identification of control menisci or meniscal tear presence was excellent (Accuracy: observer 1 = 90.9%; observer 2 = 81.8%). Of the tear configurations, bucket handle tears were accurately identified (Accuracy observer 1 and 2 = 80%). The remaining tear configurations were not

accurately discernable.

CONCLUSION

Uni-planar 3D reconstruction from 3T MRI knee scan sequences are useful in identifying normal menisci and menisci with bucket-handle tears. Advances in MRI sequencing and reconstruction software are awaited for accurate identification of the remaining meniscal tear configurations.

Key words: Knee; Meniscus; Arthroscopy; Magnetic resonance imaging; Three-dimensional reconstruction; Materialise Interactive Medical Control System; Tear

Core tip: Three-dimensional reconstruction from magnetic resonance imaging (MRI) is an expanding field with potentially great clinical utility, but must be applied with caution when segmenting knee meniscal tears. Tear presence or absence, and the complex configuration of bucket handle tears were accurately distinguishable. The remaining tear configurations could not be correctly identified. Advances in MRI sequencing and reconstruction software need to be made before the remaining meniscal tear configurations will be identifiable.

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INTRODUCTION

The knee menisci are vital to tibiofemoral contact mechanics[1,2] and joint longevity[3-5]. Tears thereof are common injuries[6], occurring both as traumatic tears in younger patients and degenerate tears in older patients[7,8]. Traumatic tears may adopt several different configurations[9], depending predominantly upon the mechanism and extent of injury. By contrast, degenerate tears occur mainly as cleavage tears along the horizontal plane in which myxoid meniscal degeneration is known to occur[10,11]. This variation in tear configuration and extent affects surgical planning regarding reparability or resection, and thus patient management. Accurate preoperative diagnosis is therefor important. Currently magnetic resonance imaging (MRI) is commonly used to preoperatively diagnose a meniscal tear. This however relies heavily on specialist radiological interpretation for diagnosis and adds further burden to a loaded service. Three-dimensional (3D) reconstruction from the MRI presents the data as a single alternative image for analysis. Interpretation of meniscal pathology in this 3D reconstructed meniscus is potentially simpler, as presentation of image data in three dimensions allows for better spatial relationship appreciation, easier object manipulation to view in any plane, and lessens the inferential burden on the observer.

3D meniscal reconstruction has accurately demonstrated meniscal dynamics relative to the tibial plateau[12] and shown encouraging results in tear delineation, suggesting that 3D reconstruction may be particularly beneficial in showing up radial and horizontal tears not visible on the 2D MRI[13]. Meniscal reconstruction has previously been used to investigate tibiofemoral contact[14-16], and in calculating pre- and post-meniscectomy meniscal volumes[17]. With current advancement in 3D reconstruction technology, this study aimed to determine whether 3D reconstruction of meniscal tears using current MRI protocols could accurately identify meniscal tears, and define their configuration.

MATERIALS AND METHODS

Study design

Cross sectional clinical cohort study.

Sample population

First the five common meniscal tear types were identified and categorised in groups as either radial, bucket handle (longitudinal displaced), parrot beak (oblique), cleavage (horizontal) and complex tears. Following, the operative notes of all arthroscopies undertaken on adult patients (aged over 18 years) by two experienced consultant orthopaedic surgeons at our institution were retrospectively reviewed to gather a minimum of five meniscal tears in each tear category. A further five normal menisci, defined at arthroscopy as having no tear or degeneration, were identified for each surgeon.

Subsequently the scans from these patients with the various tear configurations were retrieved for segmentation. In all cases arthroscopy was performed after preoperative MRI had indicated a potential meniscal tear. All preoperative scans were performed on a 3T MRI scanner (Philips) and reports on each by a subspecialized consultant musculoskeletal (MSK) radiologists were collected. Due to MRI data recording errors and one patient duplication, the final study population consisted of 24 meniscal tears in 24 patients, and nine control menisci.

MRI features

For all cases, imaging at 3T, and using a Philips Sense extremity Knee Coil, Fast Spin Echo (FSE) sequences were used to obtain Proton Density (PD) Fat Saturated images in the sagittal, coronal and axial planes. Following, a Gradient Recall Echo (GRE) sequence was employed to again image in the sagittal plane. The Time to Repetition (TR) varied from approximately 845 ms (for the GRE) to approximately 2500-7400 ms (for the PD). The Time to Echo (TE) varied from approximately 9 ms (for the GRE) to 30 ms (for the PD). The imaging characteristics were a Field of View (FOV) of 16 cm × 16 cm; a slice thickness of 2-3 mm; an

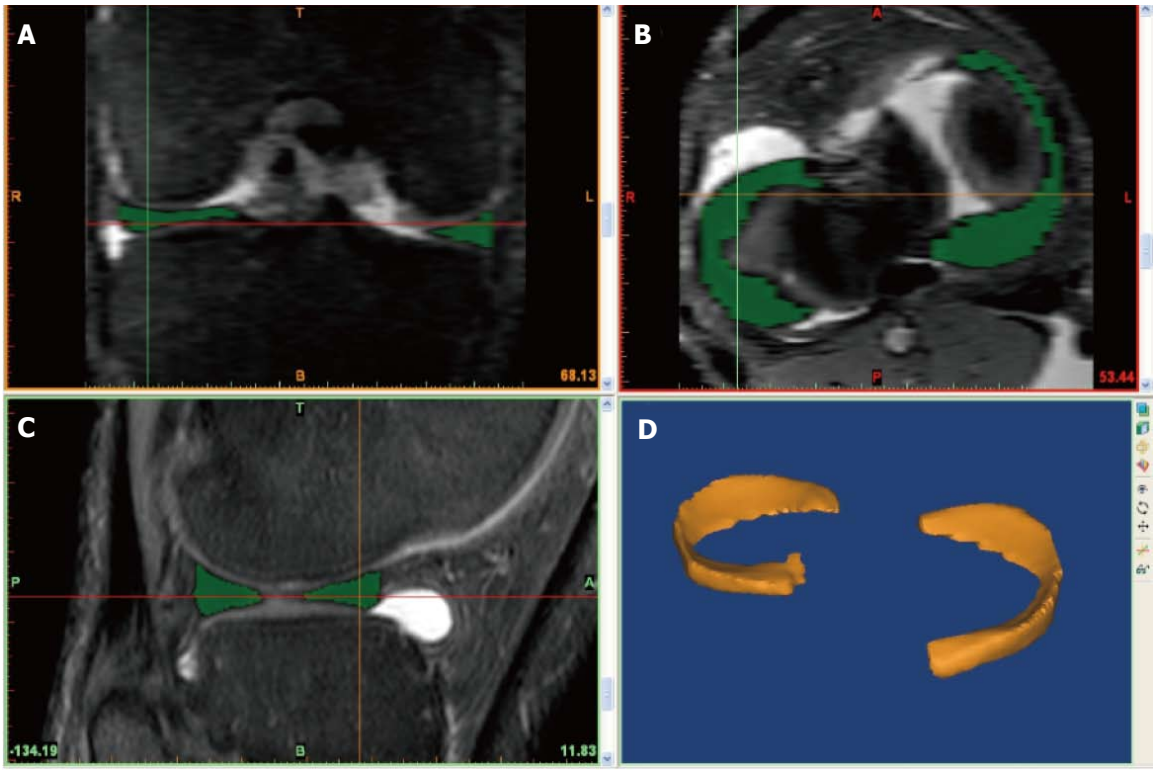

Figure 1 The user interface of the Materialise Interactive Medical Control System segmentation software program depicting the coronal view (A), the axial view (B), the sagittal view (C) and the three-dimentional reconstruction view (D). Note the poorer contrast and pixelated images in coronal and axial windows as compared the sagittal window.

interslice gap of between 2-3.3 mm; a matrix of either 512 × 512 or 1024 × 1024 and an Echo Train Length (ETL) of 14.

3D reconstruction

All patient MRI data for the 3T scans were imported into the Materialise Interactive Medical Control System (MIMICS) 3D reconstruction software program (Materialise, Leuven, Belgium) for subsequent reconstruction. All 33 scans were reconstructed from sagittal plane images by the lead author, segmenting both menisci for each knee scanned. This final image was then "wrapped" and stored as a finite element model for future interpretation. Each reconstruction was time consuming, taking approximately 4 h to generate the final model. In order to minimize the inaccuracies in the segmentation and reconstruction, the lead author undertook a two-day training course by the Materialise staff in using the novel software. Further, each reconstruction was reviewed for error in segmentation by a subspecialised MSK radiologist, and the adjacent uninjured meniscus reconstruction served as an innate control (Figure 1).

3D image analysis

Two orthopaedic trainees, who were both familiar with the different types of meniscal tears, reported on the reconstructions. Prior to reporting, each observer received a separate training session using this new software and were made familiar with user functions and object manipulation, as well as normal and meniscal tear appearances in 3D. Each training session took no longer than ten minutes, as the user functions to zoom or pan and manipulate the image to view it in any desired plane are intuitive and easy to reproduce. There was hence no learning curve associated with this as the execution of each function is binary, and each surgeon was equipped with all the functions prior to undertaking the reporting.

Both trainees were blinded to the preoperative MRI and operative findings, and were blinded as to the number of tears in each configuration category. All 33 meniscal reconstructions were then brought up in random order in the MIMICS software program for independent reporting. Each observer prospectively reported their findings on a standard pro forma. Inter-observer and intra-observer repeatability were determined. Two primary assessments were made. First, tear presence *vs* absence was determined and subsequently the meniscal tear configuration was calculated (Figure 2).

RESULTS

Study population characteristics

Thirty-three patients were included in the final study, 20 were male and 13 were female. There were 14 tears in right knees and 10 tears in left knees. The 9 control patients consisted of 8 right knees and 1 left knee. Nineteen tears were in the medial meniscus and five tears were in the lateral meniscus. The mean time between

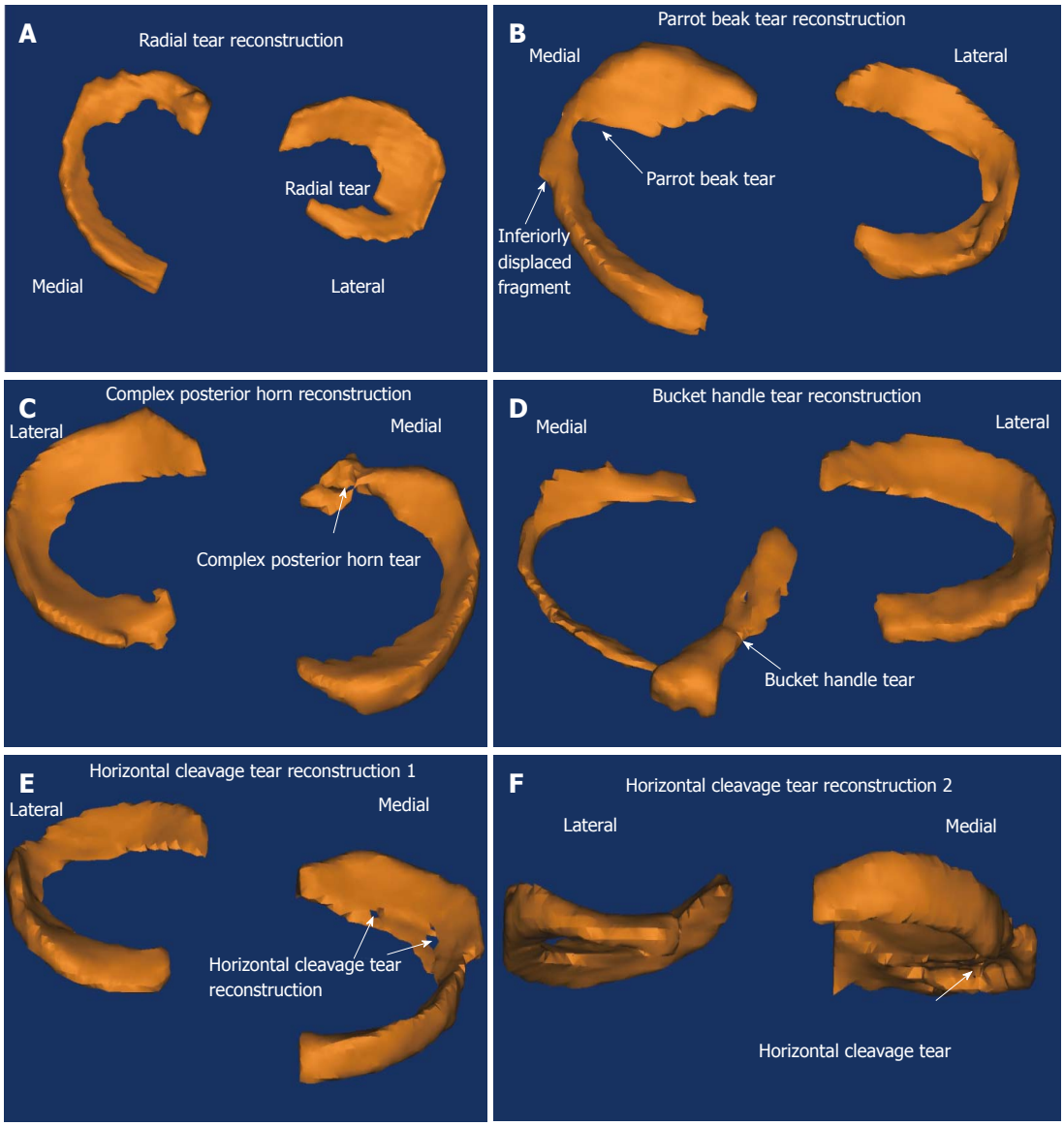

Figure 2 Three-dimensional reconstruction models showing an example of each configuration of meniscal tear identified in the study cohort. Note the two illustrations provided for the horizontal cleavage tear. A: Radial tear reconstruction; B: Parrot bile tear reconstruction; C: Complex posterior horn reconstruction; D: Bucket handle tear reconstruction; E: Horizontal cleavage tear reconstruction 1; F: Horizontal cleavage tear reconstruction 2.

MRI and arthroscopy was 4 mo (Range 1 mo to one year). All cases had arthroscopic validation of their tear configuration.

Results for all reconstructions

The accuracy and predicative values for detecting the presence or absence of a meniscal tear, regardless of tear configuration, were as follows.

Observer 1: The values for detecting tears presence *vs* absence were: Sensitivity 91.7%, specificity 88.9%, PPV 95.7%, NPV 80.0%, and accuracy 90.9%.

Observer 2: The values for detecting tears presence *vs* absence were: Sensitivity 87.5%, specificity 66.7%, PPV 87.5%, NPV 66.7%, and accuracy 81.8%. Both the intra- and inter-observer computed Cohen's Kappa = 0.525, indicating a moderate degree of agreement.

Results for each meniscal tear configuration

Sub-classification for each tear configuration was then calculated for each observer: (1) Observer 1: Accuracy for detecting different tear configurations (Table 1); (2) Observer 2: Accuracy for detecting different tear configurations (Table 2).

As can be seen when comparing these results of the 3D reconstructions by meniscal tear configuration with those obtained on 2D MRI sequences from the literature in the table below, only the detection of bucket handle tears compares favourably (Table 3).

Morphological similarities

Morphological similarities, particularly in 3D reconstruction, between certain tear types exist. As evident from the

Table 1 Observer 1's meniscal tear configuration identification accuracy for all types of tear identified

Observer 1 tear configuration identification accuracy		
	Number of each tear correctly identified	Accuracy
Bucket handle	4 of 5	80%
Radial	1 of 6	16.7%
Cleavage	3 of 5	60%
Parrot beak	2 of 5	40%
Complex	1 of 3	33.3%

Table 2 Observer 2's meniscal tear configuration identification accuracy for all types of tear identified

Observer 2 tear type identification accuracy		
	Number of each tear correctly identified	Accuracy
Bucket handle	4 of 5	80%
Radial	3 of 6	50%
Cleavage	0 of 5	0%
Parrot beak	1 of 5	20%
Complex	2 of 3	66.7%

Table 3 The sensitivities for meniscal tear type detection for previous studies utilizing 2D magnetic resonance imaging as compared to the authors' results using the 3D reconstruction of meniscal tears

	Radial	Bucket-handle	Oblique	Horizontal cleavage	Complex
Jee *et al*[27]	8 of 11 (72.7%)	-[1]	3 of 5 (60.0%)	35 of 44 (79.5%)	18 of 22 (81.8%)
Jung *et al*[28]	26 of 36 (72.2%)	-[1]	2 of 2 (100.0%)	28 of 32 (87.5%)	1 of 2 (50.0%)
Wright *et al*[29]	-[1]	25 of 39 (64.1%)	-[1]	-[1]	-[1]
The present report	1 of 6 (16.7%)	4 of 5 (80.0%)	2 of 5 (40.0%)	3 of 5 (60.0%)	1 of 3 (33.3%)

[1]No such tear configuration specified in the study.

reconstructions, the primary similarities are observed in the parrot beak and radial configurations, and the complex and cleavage tear configurations. Interestingly, when combining each into a single category, the sensitivities rivaled those of the normal and bucket handle tear configurations.

Observer 1: Accuracy when combining parrot beak and radial tears (7 of 11, 63.6%), and complex and cleavage tears (6 of 8, 75%).

Observer 2: Accuracy when combining parrot beak and radial tears (7 of 11, 63.6%), and complex and cleavage tears (7 of 8, 87.5%).

DISCUSSION

The MR diagnosis of a meniscal tear relies both on signal contrast and morphology. In un- or minimally displaced tears, the fluid entering the tear provides the contrasting signal with the surrounding normal meniscus, enabling the diagnosis. In severely displaced tears, the abnormal morphology of the meniscus is the key factor, indicating a tear is present. With 3D reconstruction from the MRI, these signal contrasts are utilised to provide distinct borders during the segmentation process to highlight out the meniscus, leaving only the morphology to interpret. Theoretically then, if the increased signal is seen on the 2D images, it should be reflected in the 3D reconstruction, enabling simpler diagnosis of tear presence and morphology.

In identifying meniscal tear presence or absence, the accuracies, sensitivities and specificities, as well as positive and negative predicative values in this study were equal to those obtained from 2D MRI[18-20]. Advantages of the 3D reconstruction however include presenting the MRI data in a visuospatially simple format and enabling object viewing in any plane to aid pathological identification. Further, it does not rely on radiologic skill or significant experience for interpretation.

Investigating by meniscal tear configuration, 3D reconstruction appeared useful in identifying normal menisci (Observer 1: Accuracy = 90.9%; Observer 2: Accuracy = 81.8%), and the complex configuration of bucket handle tears (Observer 1: Accuracy = 80.0%; Observer 2: Accuracy = 80.0%). However it had a lower accuracy in determining the remaining meniscal tear configurations.

Currently the achievement of adequate fine detail in 3D reconstruction enabling differentiation between morphologically similar tears is not possible using the present standard scan protocols. As can be seen when combining the morphologically similar tears above, the accuracy rivaled that achieved for the bucket handle tear configuration. Obscurations of meniscal tear border definition arise due to inaccuracies in the MRI, and in segmentation. MRI inaccuracies may be attributed to inherent magnetic field inhomogeneities, volume averaging and limited contrast dependent on the signal-to-noise ratio (SNR) maintainable across the FOV. Presently segmentation remains user dependent, time consuming and MRI quality reliant. Accurate tear and meniscal edge definition is still user defined, despite some semi-automated functions facilitating simpler and more efficient segmentation. While these inaccuracies are present, it is not possible to accurately determine meniscal tear extension to the periphery, this having clinical implication on prediction of healing whether or not the tear extends to the white-red zone or not.

Minimising these inaccuracies will increase the MRI quality, and hence the meniscal tear definition in 3D reconstruction. The greatest inaccuracy minimisation

would be achieved by eliminating the volume averaging occurring due to the interslice gaps in current clinical knee MRI sequences. Current clinical MRI knee scan protocols leads to three separate image series, only one of which may be imported and 3D reconstructed at a time. This leads to uni-planar reconstruction, as the interpolated images in the remaining two imaging planes are very pixelated and of poor quality.

Adopting an isotropic volume scan protocol for clinical knee MRI scanning eliminates the interslice gaps, as the whole volume is scanned simultaneously, producing true 3D MRI. Recently this has been investigated as an alternative to conventional knee scanning protocols, with comparable results[21-25] obtained in a shorter scanning time[26]. This has a great impact on 3D reconstruction, as the whole data volume is imported, resulting in equivalent contrast in all three-image window planes, allowing tri-planar 3D reconstructions. This tri-planar reconstruction is anticipated to have finer meniscal tear and border definition, increasing the accuracy in differentiating between the morphologically similar tears.

There are some limitations, both of the study and the practical applicability of the reconstructions, that merit discussion. The time consuming nature of the reconstructions mean that only a low number could be generated and this limits the robustness of the conclusions drawn. It also means that the real time clinical use of being able to present the 3D model on screen to the patient, however much it might aid understanding and appreciation of their pathology, is not presently possible.

The time between the MRI and arthroscopy was significant, and the potential for tear propagation or alteration of configuration exists. All patients however had arthroscopic corroboration of their MRI findings, so, for this patient cohort, there were no alterations in tear configurations, inaccurate tear assessment or false positive or negative diagnoses. Further, no differentiation between traumatic and degenerative tears was made. Although the pathophysiological processes that underpin these two tear types are distinct, as their diagnosis still relies on the separation of the tissue planes at the joint surface with synovial fluid entering the gap and altering the MR signal, this was deemed insignificant.

Lastly, longitudinal undisplaced tears were not included as one of the configurations for assessment, as the postulate was that being undisplaced, there would be too narrow a signal change for the 3D reconstruction to be able to accurately pick up the tear.

In conclusion, uni-planar 3D meniscal tear reconstruction is useful in identifying normal menisci and menisci with bucket handle tears. It however is unable to accurately report the remaining meniscal tear configurations. Significant technological advances need to be made in both MRI and 3D reconstruction, to rival 2D MRI diagnostic accuracy in defining meniscal tear configurations.

COMMENTS

Background

Three-dimensional (3D) imaging and reconstruction technology is becoming more prevalent as an accepted imaging technique and, with respect to the knee meniscus, is attractive in presenting the whole meniscus on a single screen, with simple user functions enabling multiplanar visualization thereof. This technology has predominantly been applied to normal menisci in evaluation of knee kinematics and contact pressures during the gait cycle. However, meniscal tears adopt several different configurations and this abnormal morphology and signal generated on the magnetic resonance imaging (MRI) may complicate the reconstructions, thereby reducing the accuracy. This study aims to investigate whether 3D reconstruction from 2D MR images may presently be used to determine both the meniscal tear presence, and configuration.

Research frontiers

Presently the research emphasis on knee meniscus 3D reconstruction has been focused on generating models of the whole meniscus and its movement with respect to the tibial plateau during the gait cycle. This technology is being used extensively by the Osteoarthritis Initiative in the investigation of meniscal extrusion and its potential causation of osteoarthritis. No application to meniscal tear reconstruction is presently being undertaken.

Innovations and breakthroughs

To the authors' knowledge this is the first study to determine that 3D reconstruction from 2D MRI at present standard meniscal scan sequences is useful in determining normal menisci and menisci with bucket handle tears. It cautions the application to the remaining meniscal tear configurations.

Applications

Present application of the technology to practical diagnosis of a meniscal tear presence or absence appears possible and comparable to MRI. Similarly so in applying it bucket-handle tears, but not in the remaining meniscal tear configurations. Further technological development is needed in both the MRI and 3D reconstruction technology domains in order to improve the signal and contrast ratios, and the automation in tissue border definition to create the complete model respectively. Application of an isotropic voxel scan sequence and transition from 2D to 3D MRI in clinical imaging protocols to detect knee meniscal tears will go some way to improving this. Having the 3D reconstructed images of the meniscus at hand when consulting a patient also greatly aids understanding of their anatomy and hopefully soon, their pathology also.

Peer-review

The authors demonstrated the accuracy for meniscal tears on 3D reconstructed MRI. Uni-planar 3D meniscal tear reconstruction is useful in identifying normal menisci and menisci with bucket handle tears. It however is unable to accurately report the remaining meniscal tear configurations. The authors present an innovative technique in order to improve 3D reconstructed magnetic resonance scans: By adopting an isotropic volume scan protocol, the whole volume is scanned simultaneously enabling true tri-planar reconstruction. This is anticipated to have finer meniscal tear and border definition, increasing the accuracy in differentiating between the morphologically similar tears.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Prosthetic design of reverse shoulder arthroplasty contributes to scapular notching and instability

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Abstract

AIM

To evaluate whether implant design, glenoid positioning, and other factors influenced instability and scapular notching in reverse total shoulder arthroplasty.

METHODS

We retrospectively reviewed records of patients who had undergone reverse total shoulder arthroplasty by the senior author from July 2004 through October 2011 and who had at least 24 mo of follow-up. The 58 patients who met the criteria had 65 arthroplasties: 18 with a Grammont-type prosthesis (Grammont group) and 47 with a lateral-based prosthesis (lateral-design group). We compared the groups by rates of scapular notching and instability and by radiographic markers of glenoid position and tilt. We also compared glenoid sphere sizes and the number of subscapularis tendon repairs between the groups. Rates were compared using the Fisher exact test. Notching severity distribution was compared using the χ^2 test of association. Significance was set at $P < 0.05$.

RESULTS

The Grammont group had a higher incidence of scapular notching (13 of 18; 72%) than the lateral-design group (11 of 47; 23%) ($P < 0.001$) and a higher incidence of instability (3 of 18; 17%) than the lateral-design group (0 of 47; 0%) ($P = 0.019$). Glenoid position, glenoid sphere size, and subscapularis tendon repair were not predictive of scapular notching or instability, independent of implant

design. With the lateral-based prosthesis, each degree of inferior tilt of the baseplate was associated with a 7.3% reduction in the odds of developing notching (odds ratio 0.937, 95%CI: 0.894-0.983).

CONCLUSION

The lateral-based prosthesis was associated with less instability and notching compared with the Grammont-type prosthesis. Prosthesis design appears to be more important than glenoid positioning.

Key words: Arthroplasty; Reverse; Instability; Scapular notching; Shoulder

Core tip: In reverse total shoulder arthroplasty (RTSA), we found that a Grammont-type prosthesis was associated with higher rates of instability and scapular notching and more severe notching compared with a prosthesis with a lateralized center of rotation. This study also suggests that some inferior tilt of the baseplate may decrease the notching rate. For the 2 prosthesis designs studied, neither glenoid sphere size nor repair of the subscapularis tendon was associated with rates of instability, rates of scapular notching, or severity of scapular notching. These findings are important to surgeons considering whether to use a Grammont-type prosthesis or a lateral-based implant when performing RTSA.

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INTRODUCTION

Since reverse total shoulder arthroplasty (RTSA) was approved by the United States Food and Drug Administration in December 2003 for the treatment of arthritis associated with rotator cuff disease, it has rapidly gained popularity for treating patients with various shoulder conditions, including rotator cuff tear arthropathy, degenerative arthritis with rotator cuff deficiency, and pseudoparalysis associated with anterosuperior escape syndrome. Although RTSA provides pain relief in most patients, its associated rate and variety of complications are higher than those for anatomical total shoulder arthroplasty[1,2].

There are 2 designs of reverse total shoulder prosthesis. One is a Grammont-type prosthesis, which has a center of rotation at the level of the glenoid where the baseplate meets the bone[1]. The other, available from various manufacturers, has a center of rotation in a more lateral position, which theoretically increases the shear forces across the baseplate-to-glenoid bone interface[3].

The most common complications of RTSA are instability and scapular notching. Reported rates of instability range from 0%-31%[4-9]. Instability has been associated with component malposition[10], inadequate tensioning of the soft-tissue envelope[11-13], insufficient subscapularis tendon for repair[14], and use of the deltopectoral approach *vs* the superolateral approach[11,15]. Scapular notching is a concern because of its potential effect on long-term loosening of the prosthesis and on clinical results[16]. Reported rates of inferior scapular notching for a Grammont-type prosthesis range from 13%-67%[12,15-18].

Studies have compared the severity of scapular notching associated with different RTSA designs[19,20]. However, these studies included patients with a variety of diagnoses, as well as patients who underwent revision arthroplasty, which is associated with higher complication rates than primary RTSA[19,20]. They also included patients with a minimum follow-up of only 12 mo[19,20]. Although these studies addressed notching associated with RTSA, they did not address instability factors that might also be related to prosthesis positioning and design[18,20].

In patients with rotator cuff tear arthropathy, osteoarthritis with a rotator cuff tear, or osteoarthritis with glenoid bone loss, we sought to: (1) establish and compare the instability rates of those treated with a Grammont-type prosthesis *vs* a lateral-based prosthesis; (2) establish and compare the rates and severity of scapular notching between the 2 groups; and (3) determine in both groups whether glenoid baseplate position, repair of the subscapularis tendon, and glenoid sphere size were associated with different rates and severity of scapular notching.

MATERIALS AND METHODS

Institutional review board approval was obtained for this retrospective study.

Study population

From July 2004 through October 2011, 324 RTSAs were performed by the senior author, 196 of which had at least 2 years of follow-up. We included only patients undergoing their first RTSA with the diagnosis of rotator cuff tear arthropathy, osteoarthritis with a rotator cuff tear, or osteoarthritis with glenoid bone loss. Of those 196 RTSAs, 131 were excluded for the following reasons: 57 that were revised with a diagnosis of failed arthroplasty (based on clinical history, physical examination, and supporting radiographic studies); 37 for fractures and malunion; 17 for rheumatoid arthritis; 7 for inadequate follow-up data; 5 for avascular necrosis; 5 for dislocation arthroplasty; 2 for psoriatic arthritis; and 1 for hemophilic arthropathy. Therefore, our study group comprised 65 shoulders in 58 consecutive patients with a mean follow-up of 35 mo (range, 24-66 mo). Patients had surgery at a mean age of 70 ± 8.1 years. According to the glenoid

Table 1 Characteristics of 58 adults who underwent 65 reverse total shoulder arthroplasties, 2004-2011

Characteristic	Grammont group (n = 18)		Lateral-design group (n = 47)		P-value
	Mean ± SD	n (%)	Mean ± SD	n (%)	
Male sex		12[1] (67)		31[1] (66)	NA[1]
Age (yr)	69 ± 7.3		70 ± 8.4		0.722
Follow-up (mo)	43 ± 15		32 ± 7.9		0.0004
Dominant side affected		12 (67)		2[1] (45)	NA
Workers compensation		0[2] (0)		2[2] (3.4)	NA
Glenoid sphere diameter					
32 mm		0[1] (0)		28 (60)	NA
⩾ 36 mm		18[1] (100)		19 (40)	NA

[1]Number of shoulders; [2]Number of patients. NA: Not applicable; SD: Standard deviation.

bone loss classification system of Walch *et al*[21], there were 27 A2 glenoids, 15 B1 glenoids, 10 B2 glenoids, and 13 C glenoids.

From 2004 to 2007, we used a Grammont-type prosthesis (Tornier Inc., Stafford, Texas, United States) (the Grammont group, n = 18), and from 2007 to 2011 we used a prosthesis with a lateral-based center of rotation (DJO/Encore Medical Corporation, Austin, Texas, United States) (the lateral-design group, n = 47) (Table 1). There was no significant difference in mean age between groups (P = 0.722), but there was a significant difference in mean length of follow-up was longer in the Grammont group (P = 0.0004).

Surgical and postoperative details

Surgery was performed with patients in a beach chair position. All patients received general anesthesia with a scalene block or indwelling scalene catheter, as well as perioperative antibiotics. All surgical procedures were performed with a deltopectoral approach.

The glenoid was exposed circumferentially, and the glenoid component position was determined with guides provided by the prosthesis manufacturer. An attempt was made to place the glenoid component in approximately 10° of inferior inclination, but this was done visually with no measurement. The size of the glenoid sphere was chosen to best fit the glenoid size and the soft-tissue tension in each patient. In the Grammont group, the glenoid sphere diameters were 36 mm in 16 shoulders, 38 mm in 1 shoulder, and 42 mm in 1 shoulder. In the lateral-design group, the glenoid sphere diameters were 32 mm in 28 shoulders and 36 mm in 19 shoulders. In all patients, regardless of implant type, the humeral components were inserted in 30° of retroversion, and all components were cemented. Stability of the implants after reduction of the humeral component on the sphere was verified by moving the arm in rotation and also with axial distraction. The subscapularis tendon or anterior capsule was secured back to the proximal humerus when possible [in 9 (50%) of 18 shoulders in the Grammont group and 39 (83%) of 47 shoulders in the lateral-design group]. A biceps tenodesis was performed in all shoulders in which the biceps tendon was present.

After surgery, each shoulder was placed in an immobilizer. Unlimited motion was allowed in elevation and internal rotation, but external rotation was limited for 6 wk. Patients were not allowed to lift more than 0.45 kg for 3 mo. No patient had a structured rehabilitation program, but all were encouraged to use the arm for activities of daily living. Radiographs were obtained every 3 mo for the first year and then yearly.

At each follow-up evaluation, 3 conventional radiographs were obtained (a true anteroposterior view in external rotation (Grashey view)[22], an anteroposterior view in internal rotation, and an axillary view). Fluoroscopy was not used for any radiographs.

The presence of notching was evaluated by 2 observers who reached agreement upon the degree of notching using the system of Sirveaux *et al*[15]. Grade 1 was notching limited to the scapular pillar; grade 2 was notching in contact with the inferior screw of the baseplate; grade 3 was notching beyond the inferior screw; and grade 4 was notching that extends under the baseplate approaching the central peg.

Evaluation

Instability was determined using clinical examination and radiographic evidence of component dislocation. Radiographic analysis was performed by an independent observer. Scapular notching was graded according to the 4-grade classification system of Sirveaux *et al*[15] (Figure 1). The vertical position of the glenoid sphere was evaluated using 2 similar methods. First, using a method proposed by Lévigne *et al*[23], we measured the distance between the inferior glenoid osseous rim and the lowest point of the glenoid sphere on the external rotation anteroposterior view (Figure 2). Second, as proposed by Simovitch *et al*[16], we measured the peg-glenoid rim distance on the same view using a point marking the radiographic superior intersection of the central peg (or central screw in the lateral-based implant) and the glenoid sphere, and a point referencing the most inferior bone of the inferior glenoid rim adjacent to the medial surface of the glenoid sphere (Figure 3).

The inclination of the glenoid sphere was measured in 3 ways. The first method, described by Levigne *et al*[23], uses a horizontal line placed on the most superior aspect of the glenoid on the anteroposterior radiograph.

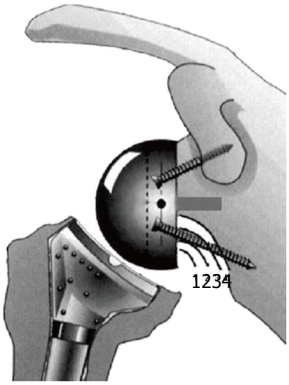

Figure 1 Scapular notching according to the 4-grade Sirveaux classification. Reproduced with permission and copyright of the British Editorial Society of Bone and Joint Surgery (Reprinted with permission from Sirveaux F *et al*[15], Figure 3).

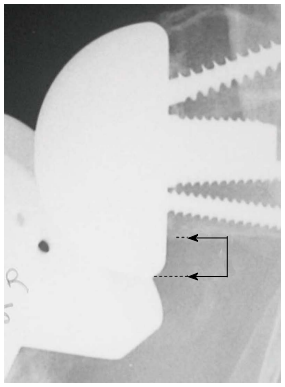

Figure 2 Distance between the inferior glenoid osseous rim (upper arm of the arrow) and the lowest point of the glenoid sphere (lower arm of the arrow) on the external rotation anteroposterior view. Reprinted with permission from Levigne C *et al*[23], Figure 8.

The angle formed between the horizontal line and a line parallel to the back surface of the glenoid sphere is measured; if it is > 90°, it is considered superiorly tilted, and if it is ⩽ 90°, it is considered inferiorly tilted (Figure 4). The second method, described by Simovitch *et al*[16], defines the prosthesis-scapular neck angle as the angle between a line from superior to inferior along the glenoid baseplate and a line from the most inferior point of the baseplate's prosthesis-bone interface to a point 1 cm medially along the inferior scapular neck (Figures 3 and 5A). The third method was described by Kempton *et al*[24], who noted that scapular neck anatomy can be highly variable at 1 cm from the baseplate and may be altered by eccentric reaming or previous surgery. Therefore, they defined a point 6 cm medial along the scapular border to which one draws the second line, which defines the prosthesis-scapular bone angle (Figure 5B).

Statistical analysis

To determine the association of prosthesis design with instability, we used a stepwise logistic regression model that included inferior glenoid notching, glenoid position[23], glenoid inclination[23], peg-glenoid rim distance[16], prosthesis-scapular neck angle[24], and prosthesis-scapular bone angle[24]. Variable selection was made on the basis of a forward stepwise selection method, with marginal significance levels set at 5% for entry and 10% for removal. This approach to model building was selected to minimize collinearity (redundancy) among variables[25].

We calculated the likelihood of instability as a function of subscapularis repair, glenoid sphere diameter, and inferior inclination using logistic regression within each prosthetic group and in the overall cohort. Receiver operating characteristic (ROC) curves were used to determine the optimal inferior tilt according to presence of instability and scapular notching. ROC curves plot sensitivity *vs* 1 - specificity to determine the discrimination threshold.

Rates between design groups were compared using the Fisher exact test. Distribution of notching type was compared between design groups using the χ^2 test of association. Statistical analysis was performed using SAS, version 9.3, software (SAS Institute, Cary,

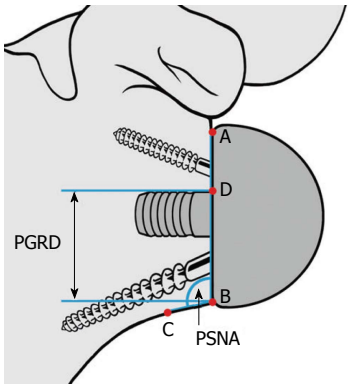

Figure 3 The prosthesis-scapular neck angle (PSNA) is the angle subtended by the intersection of line AB and line BC. Point C is located 1 cm medial to the junction of the glenosphere and the most inferior and lateral bone of the inferior glenoid rim or scapular neck. The peg-glenoid rim distance (PGRD) is the distance between points B and D.. PGRD: Peg-glenoid rim distance; PSNA: Prosthesis-scapular neck angle. Reprinted with permission from Simovitch *et al*[16], Figure 4A.

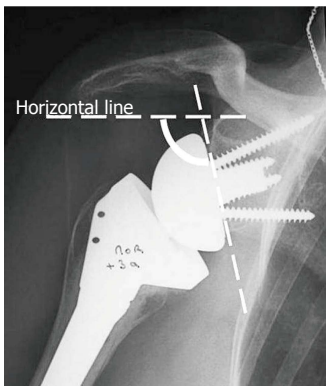

Figure 4 Glenoid inclination is the angle formed between a horizontal line and a line parallel to the back surface of the glenoid sphere. If it is > 90° it is classified as superiorly tilted, and if it is ⩽ 90° it is classified as inferiorly tilted. Reprinted with permission from Levigne *et al*[23], Figure 11.

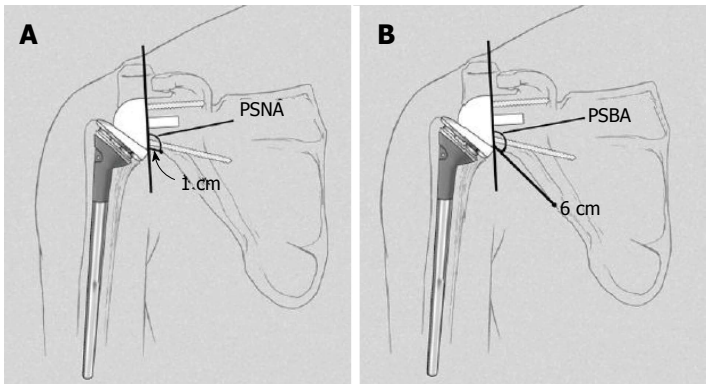

Figure 5 Illustration of measurement of the prosthesis-scapular neck angle and the prosthesis-scapular bone angle. A: The prosthesis-scapular neck angle is the angle between a line from superior to inferior along the glenoid baseplate and a line from the most inferior point of the baseplate's prosthesis-bone interface to a point 1 cm medially along the inferior scapular neck; B: The prosthesis-scapular bone angle uses a point 6 cm medial along the scapular border to draw the second line. PSNA: Prosthesis-scapular neck angle; PSBA: Prosthesis-scapular bone angle. Reprinted with permission from Kempton *et al*[24], Figure 3.

Table 2 Scapular notching and instability by prosthesis design in 65 cases of reverse total shoulder arthroplasty with minimum 2-year follow-up, 2004-2011[1]

Parameter	Grammont group (n = 18), n (%)	Lateral-design group (n = 47), n (%)	P-value
Scapular notching	13 (72)	11 (23)	< 0.001[2]
Notching severity[5]			
Grade 1	7 (39)	8 (17)	> 0.001[3]
Grade 2	2 (11)	1 (2.1)	NA[4]
Grade 3	2 (11)	2 (4.3)	NA[4]
Grade 4	2 (11)	0 (0)	NA[4]
Instability[6]	3 (17)	0 (0)	0.019

[1]NA: Not applicable; [2]P-value from two-tailed Fisher exact test; [3]Adjusted for length of follow-up using general linear model; [4]Small values prevented determination of significant differences; [5]Notching severity was measured according to Sirveaux classification[15]; [6]Instability was determined using clinical examination and radiographic evidence of component dislocation.

North Carolina, United States) and SPSS, version 20.0, software (SPSS, Chicago, IL, United States). Statistical significance was set at $P < 0.05$.

An individual with advanced training in biostatistics was involved in the design or analysis of this work. No additional data are available.

RESULTS

There were 3 dislocations in the Grammont group and none in the lateral-design group, which was a significant difference ($P = 0.014$). There was a significantly higher rate of subscapularis tendon repair in the lateral-design group ($P = 0.008$). However, there was no association between dislocation and the presence of a subscapularis repair in either group ($P = 0.170$). Smaller glenoid spheres were used in the lateral-design group compared with the Grammont group ($P < 0.001$).

The rate of scapular notching was significantly higher in the Grammont group (13 of 18 shoulders, 72%) than in the lateral-design group (11 of 47 shoulders; 23%) ($P < 0.001$) (Table 2). Patients in the Grammont group had higher odds of developing notching [odds ratio (OR), 7.2; 95%CI: 2.1-24.7] and had significantly more severe notching than patients in the lateral-design group ($P = 0.003$). This association between the rate and severity of notching between the 2 implant systems persisted even after adjustment for length of follow-up using a general linear model ($P = 0.001$).

According to the method of Levigne *et al*[23] there were significant differences in glenoid position between the lateral-design group and the Grammont group ($P = 0.004$). There was significantly more glenoid inclination in the lateral-design group than the Grammont group ($P = 0.027$). However, there were no significant differences between the 2 groups for prosthesis-scapular neck angle ($P = 0.368$), prosthesis-scapular bone angle ($P = 0.219$), or peg-glenoid rim distance ($P = 0.066$) (Table 3).

We found no factors to be significantly associated with glenoid notching in the Grammont group. However, in the lateral-design group, glenoid inclination, prosthesis-scapular bone angle, and peg-glenoid rim distance were associated with the rate of notching. In the lateral-design group, for each 1° increase in the angle of glenoid inclination, there was a 7.3% reduction in the odds of developing notching (OR, 0.94; 95%CI: 0.89-0.98); for each 1° increase in the prosthesis-scapular bone angle, there was a 9.7% reduction in the odds of developing notching (OR, 0.09; 95%CI: 0.83-0.98); and for each 1-mm increase in the peg-glenoid rim distance, there was a 34% increase in the odds of developing notching (OR, 1.3; 95%CI: 1.0-1.7). A ROC curve analysis revealed that a glenoid inclination angle of < 99.8° tends to be associated with more notching than an angle of ⩾ 99.8° (sensitivity, 66%; specificity, 75%).

Using ordinal logistic regression, we found that as the glenoid inclination angle increased in the lateral-

Table 3 Glenoid position by prosthesis design in 65 cases of reverse total shoulder arthroplasty, 2004-2011

Parameter	Grammont group (n = 18), mean ± SD	Lateral-design group (n = 47), mean ± SD	P-value
Glenoid position (mm)			
Inferior glenoid osseous rim to lowest point of glenoid sphere[23]	1.5 ± 2.1	-0.6 ± 3.3	0.004
Peg-glenoid rim distance[16]	22.6 ± 1.7	21.4 ± 3.3	0.066
Glenoid inclination (°)			
Inclination angle[23]	93.2 ± 15.3	101 ± 11.7	0.027
Prosthesis-scapular neck angle[16]	102 ± 21.3	106 ± 17.1	0.368
Prosthesis-scapular bone angle[24]	126 ± 16.9	132 ± 11.0	0.219

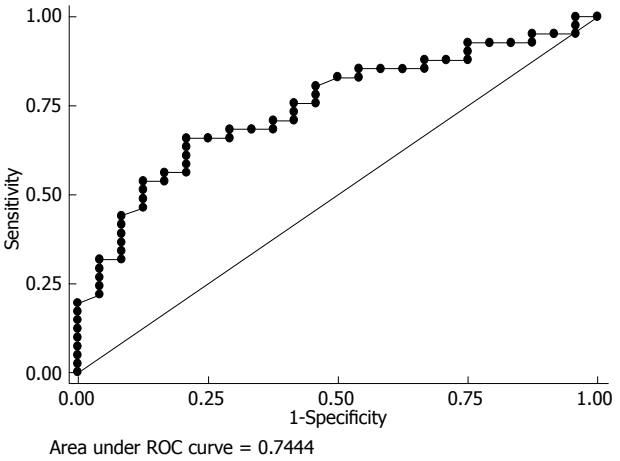

Figure 6 The receiver operating characteristic curve reveals the sensitivity and specificity for predicting the inferior glenoid tilt.

based prosthesis, the likelihood of more severe scapular notching decreased (OR, 0.95; 95%CI: 0.91-0.98).

Based on the ROC curve, an inferior tilt of < 100.5° maximizes the sensitivity (66%) and specificity (79%) of discriminating between shoulders that develop scapular notching and those that do not (area under the curve, 0.74; 95%CI: 0.62-0.87) (Figure 6).

DISCUSSION

We sought to determine whether the design of the RTSA prosthesis and other factors such as subscapularis tendon repair, glenoid positioning, and glenoid sphere size were associated with differences in the rate of prosthesis instability, the rate of scapular notching, and the severity of scapular notching. We found that implant design was a significant factor in the development of instability, the rate of notching, and the severity of notching. Subscapularis repair and glenoid sphere size were not associated with differences in instability rates for either prosthesis design. The baseplate in the lateral-based prosthesis should be placed with some inferior tilt, and a more inferior baseplate position is associated with lower rates of scapular notching.

We observed a 4.5% instability rate (all occurrences in the Grammont group), which is similar to those of previous reports (2.4%-31%)[4,5,7]. However, those studies included revision cases and a wider range of preoperative diagnoses[4,5,7]. Glenoid sphere size and offsets in designs other than the Grammont-type prosthesis may play a crucial role in prosthesis stability; it has been postulated that proper glenoid sphere offset allows the deltoid to provide a compressive force that keeps the ball pressed into the socket[26]. Subsequent prosthetic designs have created offset by increasing the diameter of the glenoid sphere, placing a humeral neck extension beneath the polyethylene cup, and/or increasing the thickness of the polyethylene cup[27]. Our study supports the observation of Clark *et al*[28], who found that repair of the subscapularis tendon does not influence dislocation rates of the Grammont-type prosthesis.

We observed a 72% rate of scapular notching in the Grammont group, which is similar to those reported in the literature (range, 13%-67%)[12,15-17]. However, we found a 23% rate of scapular notching in the lateral-design group, which is higher than those reported in the literature (range, 0%-13%)[6,26,29]. Two factors have been suggested for the lower rates of notching in the lateral-based prosthesis: (1) the design of the glenoid side of the prosthesis; and (2) the humeral head-neck angle. Until a reverse prosthesis is developed that allows surgeons to choose between a lower or higher humeral head-neck angle, it is unlikely that we will know which factor is responsible for lower rates of notching.

Several studies have suggested that prosthesis design and baseplate and glenoid sphere position may influence scapular notching rates[19,20,30]. Our study is consistent with that of Gutiérrez *et al*[31], who found in a biomechanical model that tilting the glenoid component inferiorly might prevent notching by decreasing contact of the humeral component to the scapula. We found that glenoid tilt of < 100° was associated with more, and more severe, notching. We also found that inferior placement of the baseplate was associated with less notching for the lateral-based prosthesis, similar to the findings of Simovitch *et al*[16]. Berhouet *et al*[32] found the most effective way to prevent scapular notching was by using large-diameter glenoid spheres, but our study did not support that finding.

Our study had several limitations. It was neither prospective nor randomized, and because it was a consecutive series, the mean length of follow-up differed between the 2 groups. The rate and severity of notching

in the lateral-design group might have been higher had the follow-up been longer. There were fewer shoulders in the Grammont group than in the lateral-design group, making type-2 error possible. We limited our study to patients undergoing primary RTSA for rotator cuff tear arthropathy, osteoarthritis with a rotator cuff tear, or osteoarthritis with glenoid bone loss. Therefore, our results may not be generalizable to RTSA for other causes or for revisions. It is possible that another design feature-the humeral head-neck angle-is partly responsible for our results. The humeral head-neck angle is 135° in the Grammont-type prosthesis and 155° in the lateral-based prosthesis. It was impossible for us to determine whether the humeral head-neck angle or the location of the center of rotation was the most important factor in our results. In addition, we evaluated only 2 implant systems, so our results may not apply to other systems. Also, variables not studied here such as body mass index, Charlson Comorbidity Index, or other measures of patient health might influence the results.

The surgery was performed by 1 surgeon in a referral practice, which may not be generalizable to other surgical practices. Also, the surgeon changed arthroplasty systems, and the learning curve might have affected the results. Wierks *et al*[33] suggested that the learning curve for a new operation is approximately 10 cases, but Kempton *et al*[34] suggested it might be as high as 40 cases.

Another limitation is that we used standard radiographs not obtained with fluoroscopy. The routine use of fluoroscopy for shoulder radiography has not been the practice at our institution for ethical and financial reasons. Several radiographic measures are described in the literature to assess glenoid position and tilt, but their relation to scapular notching has not been thoroughly studied[16,23,24]. To our knowledge, ours is the first study to correlate the peg-glenoid rim distance and the prosthesis-scapular neck angle with the rate of inferior scapular notching between the Grammont-type prosthesis and the lateral-based prosthesis. Furthermore, unlike previous reports[16], we found no single statistically significant radiographic factor related to glenoid notching in the Grammont group.

In conclusion, we found the Grammont-type of RTSA was associated with significantly higher rates of instability and scapular notching, as well as more severe scapular notching compared with a prosthesis with a lateralized glenoid sphere center of rotation and a decreased humeral head-neck angle. These findings are important to the surgeon when considering whether to use a Grammont-type prosthesis or a lateral-based implant when performing RTSA. This study also suggests that some inferior tilt of the baseplate may decrease the scapular notching rate and that, for the 2 prosthesis designs studied, neither glenoid sphere size nor repair of the subscapularis tendon was associated with different rates of instability, rates of scapular notching, or severity of scapular notching.

COMMENTS

Background

Since reverse total shoulder arthroplasty (RTSA) was approved by the United States Food and Drug Administration in December 2003 for the treatment of arthritis associated with rotator cuff disease, it has rapidly gained popularity for treating patients with various shoulder conditions, including rotator cuff tear arthropathy, degenerative arthritis with rotator cuff deficiency, and pseudoparalysis associated with anterosuperior escape syndrome.

Research frontiers

Although RTSA provides pain relief in most patients, its associated rate and variety of complications are higher than those for anatomical total shoulder arthroplasty.

Innovations and breakthroughs

The authors found the Grammont-type of RTSA was associated with significantly higher rates of instability and scapular notching, as well as more severe scapular notching compared with a prosthesis with a lateralized glenoid sphere center of rotation and a decreased humeral head-neck angle.

Applications

The findings are important to the surgeon when considering whether to use a Grammont-type prosthesis or a lateral-based implant when performing RTSA. This study also suggests that some inferior tilt of the baseplate may decrease the scapular notching rate and that, for the 2 prosthesis designs studied, neither glenoid sphere size nor repair of the subscapularis tendon was associated with different rates of instability, rates of scapular notching, or severity of scapular notching.

Peer-review

As a retrospective cohort study, this is low level evidence. However, it does provide clinically relevant information for surgeons who perform RTSA surgery and is worthy of publication.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Return to physical activity after gastrocnemius recession

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Abstract

AIM

To prospectively investigate the time taken and patients' ability to resume preoperative level of physical activity after gastrocnemius recession.

METHODS

Endoscopic gastrocnemius recession (EGR) was performed on 48 feet in 46 consecutive sportspersons, with a minimum follow-up of 24 mo. The Halasi Ankle Activity Score was used to quantify the level of physical activity. Time taken to return to work and physical activity was recorded. Functional outcomes were evaluated using the short form 36 (SF-36), American Orthopedic Foot and Ankle Society (AOFAS) Hindfoot score and modified Olerud and Molander (O and M) scores respectively. Patient's satisfaction and pain experienced were assessed using a modified Likert scale and visual analogue scales. *P*-value < 0.05 was considered statistically significant.

RESULTS

Ninety-one percent (n = 42) of all patients returned to their preoperative level of physical activity after EGR. The mean time for return to physical activity was 7.5 (2-24) mo. Ninety-eight percent (n = 45) of all patients were able to return to their preoperative employment status, with a mean time of 3.6 (1-12) mo. Ninety-six percent (n = 23) of all patients with an activity score > 2 were able to resume their preoperative level of physical activity in mean time of 8.8 mo, as compared to 86% (n = 19) of patients whose activity score was $\leq$ 2, with mean time of 6.1 mo. Significant improvements were noted in SF-36, AOFAS hindfoot and modified O and M scores. Ninety percent of all patients rated good or very good outcomes on the Likert scale.

CONCLUSION
The majority of patients were able to return to their pre-operative level of sporting activity after EGR.

Key words: Endoscopic gastrocnemius release; Time return to work; Return to physical activity; Post-operative outcomes; Foot and ankle

Core tip: Whilst the biomechanical advantage of surgical off-loading from gastrocnemius recession is well proven, the potential for weak push-off strength post-operatively continues to be debated. We are not aware of any published literature investigating the impact of the gastrocnemius recession procedure on the ability to return to physical activity. This study aims to investigate the hypothesis that the majority of patients will be unable to return to their pre-operative level of physical activity after a gastrocnemius recession procedure.

Tang Qian Ying C, Lai Wei Hong S, Lee BH, Thevendran G. Return to physical activity after gastrocnemius recession. *World J Orthop* 2016; 7(11): 746-751 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i11/746.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i11.746

INTRODUCTION

Gastrocnemius recession has evolved into a well-established surgical procedure that is increasingly performed in orthopaedic foot and ankle surgery. It is indicated primarily in individuals who experience symptoms from biomechanical overload caused by an equinus ankle resulting from a tight superficial posterior compartment musculature that restricts ankle dorsiflexion[1]. Gastrocnemius contracture may result in an ankle equinus deformity which in turn alters the foot biomechanics and increases forefoot pressures[2]. Gastrocnemius contracture has been implicated as the cause of a variety of foot and ankle pathologies including metatarsalgia[3], diabetic foot ulcer[4], pes planus deformity[5], hallux valgus[6] and plantar fasciitis[7]. It is postulated this may be secondary to excessive forefoot loading and heel hypervalgus[8]. The diagnosis of gastrocnemius tightness is primarily clinical using the Silfverskiold test[8]. The test is positive when an ankle dorsiflexion of less than or equal to 10° on knee extension is increased to more than 10° on knee flexion whilst the hindfoot is held in neutral[9].

With the advent of minimally invasive surgical techniques and instruments to support it, an endoscopic approach to gastrocnemius recession has been proposed as an alternative to open gastrocnemius recession[10]. The efficacy and safety profile of endoscopic gastrocnemius recession (EGR) has been investigated in a number of case series with the procedure being associated with a shorter postoperative recovery, fewer wound-related complications and greater patient satisfaction[10,11].

Complications of gastrocnemius recession has been well documented in the literature[12]. Of these, the potential for significant plantarflexion weakness attributed to lengthening of the gastroc-soleus muscle unit[13] has generated much concern amongst orthopaedic surgeons and sports medicine practitioners alike. Whilst the biomechanical advantage of surgical off-loading from gastrocnemius recession is well proven, the potential for weak push-off strength when performed in a sportsperson continues to remain a concern. We are not aware of any published literature investigating the impact of the gastrocnemius recession procedure on the ability to return to preoperative level of physical activity.

The primary aim of this study was to prospectively evaluate a consecutive series of patients undergoing gastrocnemius recession with regards to the time taken and their ability to return to preoperative level of physical activity. The secondary aim of the study was to evaluate the functional outcome and complication profile of the gastrocnemius recession procedure when performed endoscopically in a consecutive series of patients.

MATERIALS AND METHODS

Subjects

With Institutional Review Board approval, 48 feet (25 left and 23 right) in 46 consecutive patients (34 female and 12 male; mean age 49.7 ± 18.6 years; range 21 to 83 years) who underwent EGR through a single lateral portal using the Smart Release Endoscopic Carpal Tunnel Release System were included in the study (Table 1). All patients who were recruited for the procedure had an isolated gastrocnemius contracture which was confirmed clinically with the Silfverskiöld test. Patients with ankle joint pathology resulting in an equinus or spastic contractures secondary to neurological injury were excluded.

The same operative technique was applied to all patients and all procedures were performed by 2 senior foot and ankle fellowship trained orthopaedic surgeon at a single institution within a 3-year period. In all patients, the aponeurosis for both the medial and lateral heads of the gastrocnemius was released at the distal muscle-tendon junction.

Follow-up

The mean follow-up period was 32 ± 7.7 mo, with minimum duration of 24 mo (range 24 to 60 mo). The primary outcome measure recorded was the time taken from the operative day to a point in the future when the patient was able to participate in their preferred physical activity or sport at a level that was similar to their preoperative level of activity. In order to evaluate and stratify the level of physical activity pursued by the individual patient, the ankle activity score developed and validated by Halasi and associates[14] was used. This 10-point scoring system is based on the type and level of physical activity, with 0 points indicating the lowest

Table 1 Patient demographics

Demographic	Value
No. of patients	46
No. of feet/recessions	48
Age	Mean: 49.73 ± 18.59 yr
	Range: 21 to 83 yr
Gender	Female: 35
	Male: 13
Side of operation	Left: 25 (52.1%)
	Right: 23 (47.9%)
Follow-up months	Mean 32 ± 7.66 mo
	Range 24-60 mo

activity level and 10 points indicating the highest activity level. Time taken before patients returned to the same level of physical activity based on the Halasi score was recorded. As a surrogate marker of return to activity, time taken to return to full time employment was also recorded.

Secondary outcome measures were evaluated using validated scoring systems. Functional evaluation was carried out preoperatively, at 1 year and 2 years postoperatively using the short form 36 (SF-36), American Orthopaedic Foot and Ankle Society (AOFAS) Hindfoot score and Modified Olerud and Molander (O and M) Score. The Likert scale and visual analogue pain scores (VAS) were used to evaluate patient satisfaction and pain scores respectively.

The preoperative scoring was done during the preoperative clinic consultations whilst the postoperative scores were tabulated during postoperative consultation visits.

Statistical analysis

IBM SPSS Statistics version 20 was used to perform statistical analysis of the collected data. The analysis aimed to identify any significant change between the preoperative and 2-year postoperative scores of SF-36, AOFAS Hindfoot score, Modified O and M and VAS Scores. Paired parametric Student *t*-test was performed on the data sets. Descriptive statistics were used for the demographic variables. Results were expressed as means ± SD. A *P*-value of < 0.05 was considered statistically significant.

RESULTS

Functional outcome

Forty-two out of the 46 patients (91%) were able to return to their preoperative level of physical activity after EGR at the time of final follow-up. The mean duration of time taken to return to preoperative level of physical activity was 7.5 mo (range 2 to 24 mo). Of the 4 patients who failed to return to preoperative level of physical activity, at the 2-year follow-up, the first patient had dropped from a Halasi score of 4 to 2, the second patient a Halasi score 2 to 1 and the last two patients also dropped from Halasi scores 2 to 1. These final 2 patients were unable to return to physical activity due to other concomitant musculoskeletal problems (back and knee pathologies).

Table 2 Demographics of patients who successfully returned to preoperative level of physical activity and preoperative employment status

Halasi ankle activity score	No. of patients	Mean time to return to physical activity (mo)	Mean time to return to work (mo)
0	0	-	-
1	0	-	-
2	22	6.1	4.1
3	7	14.0	3.1
4	13	8.3	3.7
5	3	6.0	2.3
6	0	-	-
7	0	-	-
8	1	3.0	3.0
9	0	-	-
10	0	-	-
Total	46	7.5	3.6

The mean duration of time taken to return to preoperative employment status for those who were engaged in employment (n = 37) was 3.6 mo (range 1 to 12 mo). Of the 37 patients analysed, 20 patients held sedentary desk-bound jobs. The time return to employment for this subset was 3.3 mo. In a further subset of 17 patients (35%) who held more physically demanding employment that necessitated them being on their feet for prolonged periods or performing manual tasks (salesperson, fitness instructors) the time return to employment was 3.9 mo. Overall, only 1 patient was unable to return to his original employment as a chef at the time of final follow-up due to persistent leg pains from prolonged standing.

When stratifying the level of physical activity using the Halasi ankle activity score, 22 patients (48%) claimed to participate only in low-intensity physical activity (defined as Halasi ankle activity score $\leqslant$ 2) whilst the remaining 24 patients (52%) participated in higher-intensity physical activity (defined as Halasi ankle activity score > 2) (Table 2).

Overall, 96% (n = 23) of those engaging in higher intensity activity (Halasi ankle activity score > 2) were able to return to their preoperative level of physical activity whilst only 86% (n = 19) of patients with Halasi ankle activity score $\leqslant$ 2 were able to do so. When comparing these 2 categories of patients, those with a Halasi ankle activity score of more than 2 reported a mean time return to activity of 8.8 mo (range 2 to 24 mo). In contrast, those with a Halasi ankle activity score of 2 or less reported a mean time return to activity of 6.1 mo (range 2 to 12 mo).

Secondary outcome measure

Preoperative, 1-year postoperative and 2-year postoperative SF-36, AOFAS, Modified O and M and VAS scores were obtained in all 46 patients. The preoperative and 1-year postoperative scores were compared and evaluated (Table 3).

Table 3 Summary of results (preoperative and 1-year postoperative)

Parameter	Preoperative Mean ± SD	1 yr post-op Mean ± SD	Improvements Mean ± SD	*P*-value
SF-36				
Physical functioning	64.79 ± 27.58	84.58 ± 15.74	19.79 ± 26.74	< 0.001
Role limitations due to physical health	45.83 ± 41.68	84.38 ± 23.98	38.54 ± 42.83	< 0.001
Role limitation due to emotional problems	61.10 ± 44.21	89.92 ± 24.26	28.82 ± 51.32	< 0.001
Energy/fatigue	60.42 ± 18.24	65.63 ± 15.80	5.21 ± 14.95	0.02
Emotional well-being	74.00 ± 16.46	74.04 ± 17.40	0.04 ± 18.46	0.988
Social functioning	74.79 ± 21.23	96.25 ± 7.20	21.46 ± 22.51	< 0.001
Pain	60.78 ± 21.38	91.30 ± 12.48	30.52 ± 24.17	< 0.001
General health	68.33 ± 18.73	73.27 ± 17.25	4.94 ± 13.37	0.014
AOFAS Hindfoot Score	71.60 ± 18.89	91.79 ± 7.24	20.19 ± 19.89	< 0.001
Modified Olerud and Molander score				
Pain	13.23 ± 6.32	22.19 ± 4.72	8.96 ± 6.99	< 0.001
Stiffness	6.56 ± 4.15	8.44 ± 2.76	1.88 ± 4.33	0.004
Swelling	7.60 ± 3.57	8.54 ± 2.91	0.94 ± 4.46	0.152
Stair climbing	6.67 ± 2.79	8.33 ± 2.60	1.67 ± 3.15	0.001
Running	1.56 ± 2.34	2.29 ± 2.52	0.73 ± 1.78	0.007
Jumping	2.19 ± 2.51	2.92 ± 2.49	0.73 ± 2.06	0.018
Squatting	4.38 ± 1.67	4.48 ± 1.54	0.10 ± 1.93	0.71
Supports	7.92 ± 3.69	8.85 ± 2.78	0.94 ± 3.67	0.083
Activities of daily life	0.00 ± 0.00	17.08 ± 4.59	17.08 ± 4.59	< 0.001
Total	50.10 ± 15.89	83.13 ± 15.73	33.02 ± 18.09	< 0.001
VAS	5.00 ± 2.38	1.21 ± 1.79	3.79 ± 2.60	< 0.001

VAS: Visual analogue score; AOFAS: American Orthopedic Foot and Ankle Society.

When comparing functional outcomes at 1-year postoperative, there were significant improvements in all domains of the SF-36 questionnaire except for emotional well-being. There was significant improvement in AOFAS Hindfoot score of 20.19 ± 19.89 ($P < 0.001$), from a mean of 71.60 ± 18.89 preoperatively to 1-year postoperative mean of 91.79 ± 7.24. There was also significant improvement in modified O and M score at the 1-year postoperative mark, with significant improvements in 7 out of the 9 domains of the O and M score.

Comparing 1-year postoperative and 2-year postoperative scores (Table 4), there were no statistically significant improvements in the domains of SF-36 questionnaire as well as the AOFAS Hindfoot scores. The modified O and M Score showed significant improvements in only the total score and in 2 out of 9 domains. This suggests that there are no significant ongoing improvements beyond the first year postoperative mark.

Analysis of the VAS score showed significant improvements at both the 1-year and 2-year postoperative marks, with a mean score improvement of 3.79 ± 2.60 ($P < 0.001$) and 4.31 ± 2.45 ($P < 0.001$) respectively. Beyond the first year, there was significant improvement of pain reduction between the first year and second year postoperatively, with improvements of 0.52 ± 1.17 ($P = 0.003$). Ninty percent of all cases reported good or very good outcomes on the Likert scale at the 2-year postoperative follow-up.

DISCUSSION

To ensure a more clinically relevant measurement of return to physical activity, the level of physical activity was first stratified in this study. The Halasi Ankle Activity score is a validated tool designed specifically for the ankle and enabled a more accurate stratification of the intensity of physical activity pursued by individual patients. Time taken before being able to return to the same intensity of ankle activity postoperatively was used as an objective measure of time taken to return to physical function and a surrogate marker of any permanent functional deficit that may have resulted from the procedure. Similarly, time taken to return to preoperative level of employment was measured to reflect on the economic burden this procedure may have on an individual patient.

In this study, patients with a preoperative Halasi ankle activity score of more than 2 required a longer time to resume their physical activity to the same intensity level when compared to those with Halasi ankle activity score of 2 or less. However, 96% of all patients in the higher level activity group successfully regained their preoperative intensity of physical activity in contrast to only 86% in the second group. This result suggests gastrocnemius recession is unlikely to result in any permanent functional deficit that may compromise return to a higher level of physical activity or sport. We postulate the difference in time taken to return to physical activity in the two groups is likely attributable to higher levels of physical activities necessitating a more prolonged rehabilitation period.

For the cohort of employed patients ($n = 37$), the mean time to return to full time preoperative employment status was 3.6 mo (range 1 to 12 mo). This information is important to highlight to patients, especially those concerned about the ability to resume their occupation, during the peri-operative counselling period when

Table 4 Summary of results (1-year postoperative and 2-year postoperative)

Parameter	1 yr postoperative Mean ± SD	2 yr postoperative Mean ± SD	Improvements Mean ± SD	*P*-value
SF-36				
Physical functioning	84.58 ± 15.74	87.08 ± 14.40	19.79 ± 26.74	0.144
Role limitations due to physical health	84.38 ± 23.98	88.13 ± 23.58	38.54 ± 42.83	0.169
Role limitation due to emotional problems	89.92 ± 24.26	90.26 ± 18.16	28.82 ± 51.32	0.880
Energy/fatigue	65.63 ± 15.80	63.85 ± 15.51	5.21 ± 14.95	0.290
Emotional well-being	74.04 ± 17.40	76.02 ± 13.50	0.04 ± 18.46	0.274
Social functioning	96.25 ± 7.20	95.63 ± 9.07	21.46 ± 22.51	0.566
Pain	91.30 ± 12.48	92.43 ± 13.72	30.52 ± 24.17	0.401
General health	73.27 ± 17.25	74.44 ± 18.23	4.94 ± 13.37	0.469
AOFAS Hindfoot Score	91.79 ± 7.24	93.48 ± 7.81	1.69 ± 5.83	0.051
Modified Olerud and Molander score				
Pain	22.19 ± 4.72	22.71 ± 4.37	0.52 ± 2.36	0.133
Stiffness	8.44 ± 2.76	8.85 ± 2.58	0.42 ± 2.27	0.209
Swelling	8.54 ± 2.91	8.85 ± 2.36	0.31 ± 1.90	0.261
Stair climbing	8.33 ± 2.60	8.75 ± 2.19	0.42 ± 2.02	0.159
Running	2.29 ± 2.52	3.23 ± 2.42	0.94 ± 1.97	0.002[a]
Jumping	2.92 ± 2.49	3.23 ± 2.42	0.31 ± 1.90	0.261
Squatting	4.48 ± 1.54	4.48 ± 1.54	0.00 ± 1.03	1
Supports	8.85 ± 2.78	9.58 ± 1.74	0.73 ± 2.06	0.018[a]
Activities of daily life	17.08 ± 4.59	17.71 ± 3.85	0.63 ± 3.66	0.243
Total	83.13 ± 15.73	87.08 ± 15.74	3.96 ± 10.05	0.009[a]
VAS	1.21 ± 1.79	0.69 ± 1.72	0.52 ± 1.17	0.003[a]

[a]Denotes significant *P* values. VAS: Visual analogue score; AOFAS: American Orthopedic Foot and Ankle Society.

discussing the anticipated time away from work. Only 1 patient was unable to return to employment at the 2-year follow-up due to leg pains from prolonged standing as part of his job as a chef. The same patient was unable to return to his preoperative level of physical activity and this was attributed to the presence of other concomitant lower back pain and not the gastrocnemius recession procedure alone.

The functional outcomes related to the single portal EGR was also evaluated in this study. The SF-36 scores showed statistically significant improvements in 6 out of 8 components while the modified O and M score revealed statistically significant improvements in 7 out of 9 domains. The AOFAS Hindfoot scores revealed significant improvements between preoperative and 2-year postoperative scores as well. Significant pain relief and high satisfaction rates were reflected by improvements in the VAS score and either good or very good outcomes on the Likert scale. These results are consistent with those from other studies in the current literature[12,13].

Limitation and strength of the study

There are several limitations to this study. Firstly, this is a single centre series of 46 patients. A larger pool of patients would increase the power of analysis for return to physical activity. Secondly, there were no comparisons made with alternative techniques for gastrocnemius recession and it is conceivable that a different surgical technique may influence time return to physical activity, though there is a paucity of evidence to substantiate this. Finally, patients were not matched for other concurrent musculoskeletal pathology and it is feasible that time return to physical activity may be influenced by other co-morbidities.

The primary strength of this study is its novelty in addressing the clinically relevant question of what is the likelihood of return to physical functional activity after a gastrocnemius recession procedure. The minimum follow-up of 24 mo, use of validated functional and activity scoring plus consistency in the surgical technique substantiates the role of this procedure in our therapeutic armamentarium.

The result of this study shows that a vast majority (91%) of patients post gastrocnemius release regained their preoperative level of physical activity after a mean of 7.5 mo. As expected, there is a trend towards a longer recovery period for those who participate in higher level of physical activity. There are significant functional improvements and pain relief following this procedure as assessed at the 2-year postoperative mark.

COMMENTS

Background

Endoscopic gastrocnemius release (EGR) has evolved into a popular procedure that reliably treats ankle equinus from a tight gastrocnemius contracture. There is however considerable anxiety amongst surgeons who perform this procedure that it may result in permanent ankle plantarflexion weakness, thereby preventing return to pre-operation level of physical activity.

Research frontiers

The efficacy and safety profile of EGR has been investigated in a number of case series with the procedure being associated with a shorter postoperative recovery, fewer wound-related complications and greater patient satisfaction.

Innovations and breakthroughs

The potential for significant plantarflexion weakness attributed to lengthening of the gastroc-soleus muscle unit has generated much concern amongst orthopaedic surgeons and sports medicine practitioners alike. This study aims to evaluate the novel clinical question of time taken to return to pre-operative

level of physical activity after EGR.

Applications

The majority of patients are able to return to their pre-operative level of sporting activity after EGR. Ninety-one percent (n = 42) of all patients returned to their preoperative level of physical activity after EGR. The mean time for return to physical activity was 7.5 (2-24) mo. Ninety-eight percent (n = 45) of all patients were able to return to their preoperative employment status, with a mean time of 3.6 (1-12) mo. Ninety-six percent (n = 23) of all patients with an activity score > 2 were able to resume their preoperative level of physical activity in mean time of 8.8 mo, as compared to 86% (n = 19) of patients whose activity score was ≤ 2, with mean time of 6.1 mo.

Terminology

About endoscopic gastrocnemius recession: A variety of muscle-tendon unit release procedures along the calf such as Silfverskoid, Baumann, Vulpius, Baker and Strayer procedure, have been described over the past century. These involve at least a partial or complete release of the gastrocnemius muscle to diminish its role as the primary plantarflexor of the ankle. Of the many recession techniques that have been described, the one described by Strayer has gained most popularity. Traditionally performed as an open procedure, the Strayer procedure involves making an incision on the ventral surface of the calf and releasing only the gastrocnemius aponeurosis just distal to its muscle belly. With the advent of minimally invasive surgical techniques and instruments to support it, an endoscopic approach to gastrocnemius recession has been popularised as an alternative to open gastrocnemius recession.

Peer-review

This is an interesting research article on the return to physical activity after gastrocnemius recession procedure. In general, the methodology is appropriate, the results are clinically significant, and the implication for clinical practice is quite useful.

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ORIGINAL ARTICLE

Retrospective Study

Improvements after mod Quad and triangle tilt revision surgical procedures in obstetric brachial plexus palsy

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Author contributions: Nath RK conceived of the study, performed all the surgeries and revised the manuscript; Somasundaram C participated in the design of the study, performed the statistical analysis and drafted the manuscript; both authors read and approved the final manuscript.

Institutional review board statement: This was a retrospective study of patient charts, which exempted it from the need for IRB approval in the United States. Patients were treated ethically in compliance with the Helsinki declaration. Documented informed consent was obtained for all patients.

Informed consent statement: Written informed consent was obtained from all patients for publication and accompanying images. A copy of the written consent is available for review on request.

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Abstract

AIM

To compare outcomes of our revision surgical operations in obstetric brachial plexus palsy (OBPP) patients to results of conventional operative procedures at other institutions.

METHODS

We analyzed our OBPP data and identified 10 female and 10 male children aged 2.0 to 11.8 years (average age 6.5 years), who had prior conventional surgical therapies at other clinics. Of the 20 patients, 18 undergone triangle tilt, 2 had only mod Quad. Among 18 patients, 8 had only triangle tilt and 10 had also mod Quad as revision surgeries with us. We analyzed the anatomical improvements and functional modified Mallet statistically before and after a year post-revision operations.

RESULTS

Pre-revision surgery average modified Mallet score was 12.0 ± 1.5. This functional score was greatly improved to 18 ± 2.3 ($P < 0.0001$) at least one-year after revision surgical procedures. Radiological scores (PHHA and glenoid version) were also improved significantly to 31.9 ± 13.6 ($P < 0.001$), -16.3 ± 11 ($P < 0.0002$), at least one-year after triangle tilt procedure. Their mean pre-triangle tilt (yet after other surgeon's surgeries) PHHA, glenoid version and SHEAR were 14.6 ± 21.7, -31.6 ± 19.3 and 16.1 ± 14.7 respectively.

CONCLUSION

We demonstrate here, mod Quad and triangle tilt as

successful revision surgical procedures in 20 OBPP patients, who had other surgical treatments at other clinics before presenting to us for further treatment.

Key words: Revision surgery; Obstetric brachial plexus palsy; Shoulder movements; Joint incongruity; Upper limb

Core tip: We compared functional and anatomical improvements from our revision surgical treatment experiences to outcomes of other surgical treatments at other institutions in 20 obstetric brachial plexus palsy (OBPP) children. Pre-revision surgery mean modified Mallet scores and shoulder anatomical measurements were improved statistically highly significantly at least one-year after revision surgeries. We demonstrate here, mod Quad and triangle tilt as successful revision surgical procedures in 20 OBPP patients, who had other surgical treatments at other clinics before presenting to us for further treatment.

Nath RK, Somasundaram C. Improvements after mod Quad and triangle tilt revision surgical procedures in obstetric brachial plexus palsy. *World J Orthop* 2016; 7(11): 752-757 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i11/752.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i11.752

INTRODUCTION

Poor recovery of neurological function in obstetric brachial plexus palsy (OBPP) results in muscle weakness and imbalances around the shoulder[1-3]. Progressive muscle imbalance causes bony deformities at the shoulder joint, affecting it's movements and functions[4,5]. Many traditional surgical interventions have been reported to improve the upper extremity functions in OBPP patients[6-11].

Muscle release and tendon transfer procedures have been shown[12-19] to reduce the muscle contractures and improve shoulder movements. Humeral rotational osteotomy corrects the arm at resting position, but does not address the glenohumeral and *Scapular Hypoplasia, Elevation and Rotation* (SHEAR) deformities. These surgical treatments do not address these two osseous deformities.

We have published extensively the effectiveness of triangle tilt surgery in correcting glenohumeral joint incongruity and thereby improving upper extremity functions in OBPP patients[20-28]. Here, we show both functional and anatomical improvements significantly after triangle tilt and or mod Quad as revision surgeries in 20 OBPP patients, who had other surgical treatments at outside clinics before visiting our clinic for further treatment.

MATERIALS AND METHODS

We analyzed our OBPP data and identified 10 female and 10 male patients, aged 2.0 to 11.8 years (average age 6.5 years), who had operative procedures at other clinics.

Of the 20 OBPP patients in our present study group, 8 patients undergone only the bony procedure, triangle tilt and 10 had both triangle tilt and mod Quad (Tables 1 and 2). Therefore, these 18 patients (Table 2) have anatomical and radiological scores (PHHA, SHEAR and glenoid version), in addition to functional modified Mallet scale (Table 1). Two patients, number 19 and 20 in Table 1, underwent only mod Quad procedure, as they did not have shoulder subluxation. Therefore, these two patients did not need to undergo triangle tilt procedure, which addresses shoulder subluxation. Modified Mallet and radiological scores were measured, statistically analyzed to compare. All measurements were done at least one-year after surgical treatments.

The nerve involvement was C5-6 (n = 5), C5-7 (n = 8), and total (n = 7). Traditional operative procedures that these OBPP children had in the past at other clinics are nerve transfer/graft, neurolysis, brachial plexus exploration, botox, muscle/tendon transfer and release, humeral osteotomy and anterior capsule release. Outcomes of our revision procedures in OBPP patients were compared to the results of other traditional surgical treatments at other clinics. Further, these patients' radiological scores were measured from computed tomography and magnetic resonance images and statistically compared.

Patient examination

We examined physically all OBPP children and their video recordings pre- and post-operatively, scoring their modified Mallet parameters on a scale between one and five. One and five denote lack of movement and normal function respectively.

Anatomical measurements of shoulder

We measured PHHA, glenoid version[29] and Scapular hypoplasia, elevation and rotation[30] using computed tomography and magnetic resonance imaging pre- and post-TT operative procedure.

Operative technique

Triangle tilt[20-28] and mod Quad procedures[14,31,32] have been demonstrated successful outcomes in OBPP.

We used the student's t test and compared pre- and post-operative results in this group of OBPP. $P < 0.05$ was considered statistically significant.

RESULTS

Pre-revision surgery mean modified Mallet score was 12.0 ± 1.5 (Table 1 and Figure 1 upper panels). This functional score was greatly improved to 18 ± 2.3 ($P <$

Table 1 Comparing functional improvements of other surgeon's surgeries to mod Quad and/or triangle tilt in obstetric brachial plexus palsy

Patients	Other surgeons' surgery	Gender	Age (yr)	Nerve involved	TT/MQ	Total Mallet pre-revision surgery	Total Mallet post-revision surgery
1	Botox	F	2.5	C5-C7	TT	13	23
2	Partial MQ, subscap release lat dorsi rerouting	M	6.4	C5-C7	TT	11	16
3	Neurolysis/nerve graft	F	4.2	Total	TT and MQ	13	18
4	Humeral osteotomy	F	11.1	C5-C7	TT and MQ	11	15
5	Neuroma excision, nervegraft	M	11.8	Total	TT	11	14
6	Nerve graft, HO, botox	F	7.1	Total	TT	11	17
7	Coracoacromial release/coracoid resection	M	5.5	C5-C7	TT	14	21
8	Botox	M	11.3	C5-C7	TT and MQ	10	15
9	Sural nerve graft	F	5.0	Total	TT	10	17
10	Botox	M	3.5	C5-C6	TT and MQ	12	20
11	Botox	M	4.3	Total	TT and MQ	12	18
12	Neurolysis	F	2.0	C5-C6	TT and MQ	11	17
13	Capsule release	F	8.5	Total	TT and MQ	13	19
14	Tendon transfer, neurolysis	M	4.3	C5-C8	TT and MQ	14	20
15	Neurolysis and botox	F	5.0	C5-C6	TT	13	20
16	Muscle transfer	M	7.9	C5-C7	TT	14	21
17	BP exploration	M	2.0	C5-C6	TT and MQ	15	20
18	Steindler flexorplasty	F	10.0	C5-C7	TT and MQ	13	18
19	Humeral osteotomy	M	14.0	C5-C6	MQ	12	18
20	Tendon transfer	F	3.0	C5-C7	MQ	14	20
	Mean ± STD		6.5			12 ± 1.5	18 ± 2.3
	P value					< 0.0001	

MQ: Mod Quad; HO: Humeral osteotomy.

Table 2 Comparing anatomical improvements of triangle tilt to other surgeon surgeries in obstetric brachial plexus palsy

Patients	Other surgeons and previous surgeries	PreTT-PHHA	PostTT-PHHA	PreTT-Version	PostTT-Version	PreTT-SHEAR	PostTT-SHEAR
1	Subscap release and lat dorsi rerouting	8	33	-47	-14		
2	Neurolysis, MQ, HO	16	14	-41	-35	24	10
3	MQ	-12	19	-65	-33	40	39
4	Nerve graft, FO, BTL, MQ	32	37	-21	-10	3	1
5	Botox, MQ	33	45	-18	-15	15	3
6	Nerve graft	47	48	-10	-1	5	14
7	Neurolysis, nerve graft	-7	22	-62	-12	8	22
8	Neuroma excision, nerve graft	34	35	-20	-11	0	0
9	Nerve transfer	33	29	-16	-21	15	12
10	Coracoacromial release/resection	-12	17	-51	-35	30	15
11	Neurolysis, nerve graft	13	4	-20	-15	7	4
12	Wrist Caps, HO	39	50	0	0	9	0
13	Sural nerve graft	38	51	-10	-4	0	1
14	Botox, MQ	-8	44	-38	-22	11	2
15	Neurolysis, MQ	-14	35	-33	-10	25	30
16	Muscle release	0	19	-45	-27	32	8
17	Anterior capsule release	-11	34	-53	-22	48	41
18	Tendon transfer and neurolysis	33	39	-18	-7	1	1
Mean		14.6 ±	31.9 ±	-31.6 ±	-16.3 ±	16.1 ±	11.9 ±
STD		21.7	13.6	19.3	11.0	14.7	13.5
P value			0.001		0.0002		0.087

Normal values are PHHA 50, glenoid version and SHEAR 0. TT: Triangle Tilt; MQ: Mod Quad; HO: Humeral Osteotomy; FO: Forearm Osteotomy; BTL: Biceps Tendon Lengthening; PHHA: Percentage of the Humeral Head Anterior.

0.0001) at least one-year after our revision surgeries (Table 1, Figure 1 lower panels). Furthermore, their shoulder anatomical scores were improved significantly to 31.9 ± 13.6 ($P < 0.001$) and -16.3 ± 11 ($P < 0.0002$) at least one-year after triangle tilt operation (Table 2 and Figure 2, lower panels). This was in comparison to their radiological outcomes of other procedures before having triangle tilt with us (mean PHHA, glenoid version and SHEAR were 14.6 ± 21.7, -31.6 ± 19.3 and 16.1 ± 14.7 respectively; Table 2 and Figure 2 upper panels).

DISCUSSION

Twenty OBPP children in our present study had one or

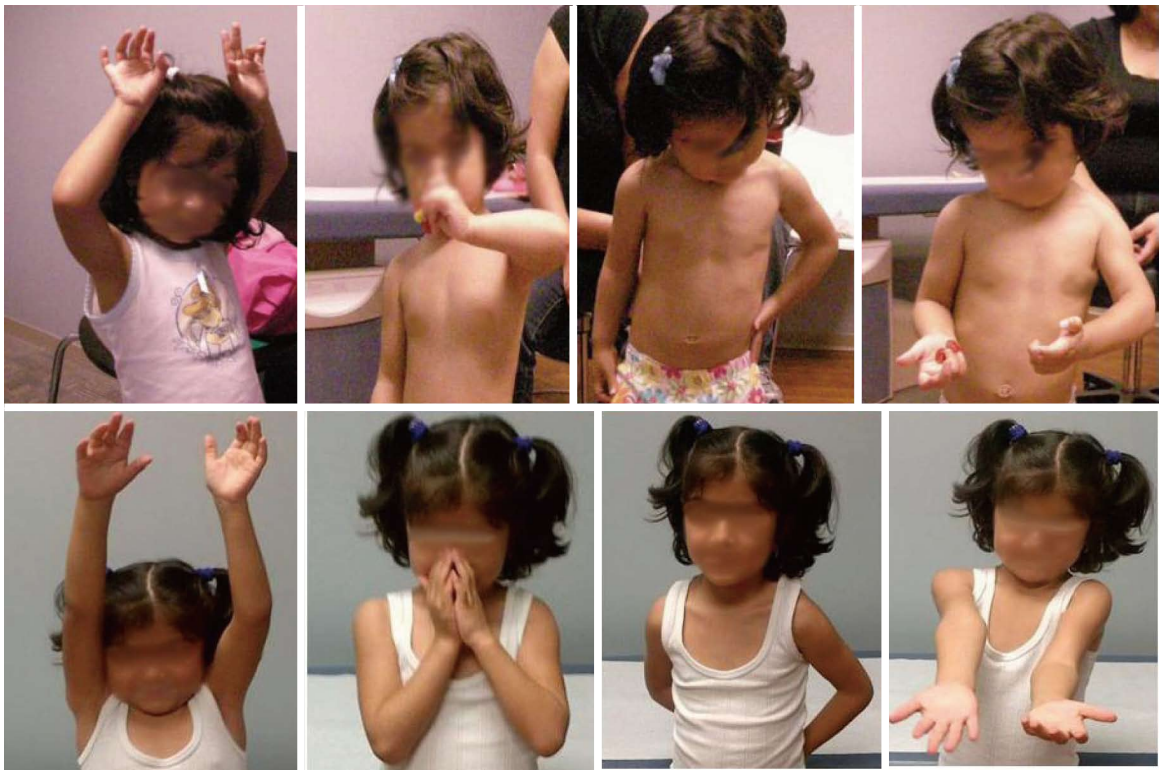

Figure 1 Modified Mallet functions performed by an obstetric brachial plexus palsy child, who had surgeries at other clinics before presenting to us (upper panels) and the same child, at least one-year after having mod Quad and triangle tilt as revision surgeries at our clinic (lower panels).

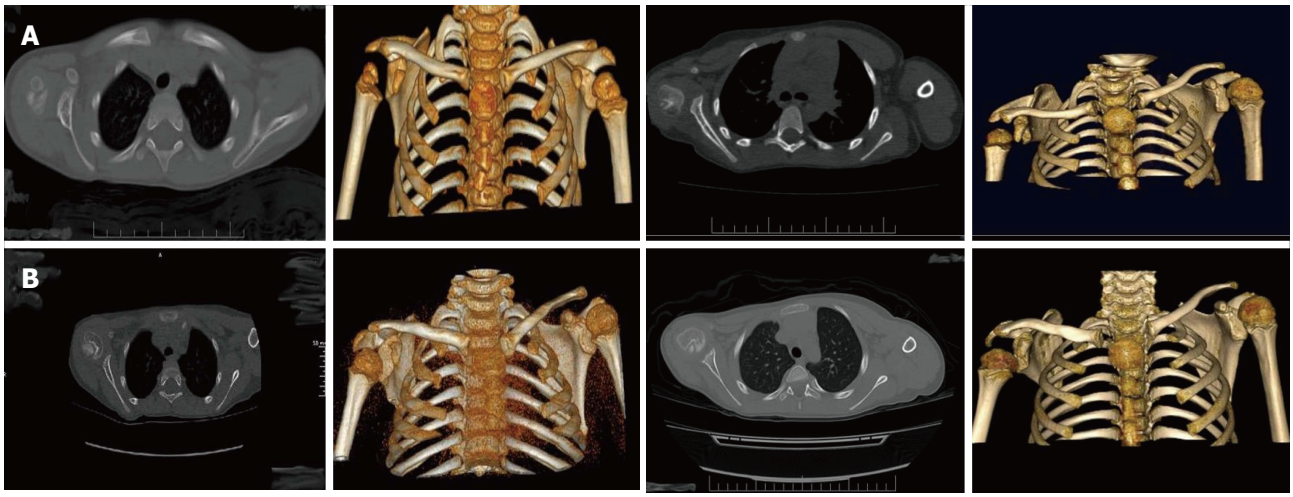

Figure 2 Comparison of computed tomography images of obstetric brachial plexus palsy children, who had surgeries at other clinics before presenting to us (A) and the computed tomography images of the same children at least one-year after having triangle tilt as revision surgery at our clinic (B).

multiple operative procedures at other clinics before visiting our institute for further treatments (Table 1). One patient in our study group had Steindler flexoroplasty, which improves active flexion of the elbow. These conventional treatments fail to address the SHEAR deformity[30] associated with majority of OBPP patients. Therefore, these OBPP patients in our study had persistent shoulder contractures and joint incongruency. Hence, they also had poor upper extremity functions. (Tables 1 and 2; upper panels in Figures 1 and 2).

Mod Quad procedure addresses poor shoulder abduction in permanent OBPP. However, this procedure is ineffective to correct the glenohumeral joint and SHEAR deformities. Eighteen OBPP children, who had shoulder joint incongruency and SHEAR undergone TT bony operation with us. We demonstrated that this procedure effectively addressed the bony deformities of the affected upper extremity and improved it's anatomy and functions[20-28]. After undergone these two revision surgical procedures with us, these twenty patients had better results both functionally and anatomically. This is highly significant in comparison to the outcomes of

other surgical treatments at other clinics.

There was statistically significant improvement anatomically, after having triangle tilt compared to the radiological outcomes of other operative procedures.

In conclusion, we demonstrate here that mod Quad and triangle tilt as successful revision surgical procedures in 20 OBPP patients, who had conventional surgical therapies at other clinics before presenting to us for further treatment.

COMMENTS

Background

Many traditional surgical interventions such as posterior glenohumeral capsulorrhaphy, biceps tendon lengthening, humeral osteotomy, anterior capsule release, nerve transfer/graft, botox, muscle and or tendon transfer and release have been reported to improve upper limb functions in obstetric brachial plexus palsy (OBPP) patients.

Research frontiers

The authors compared functional and anatomical improvements from the revision surgical treatment experiences to results of other traditional surgeries at other clinics in 20 children with OBPP.

Innovations and breakthroughs

Pre-revision surgery mean mod Mallet scores and radiological scores such as posterior subluxation and glenoid version were improved statistically highly significantly at least one-year after mod Quad and or triangle tilt revision surgeries.

Applications

The authors demonstrate here, the triangle tilt and mod Quad as successful revision surgeries in OBPP patients, who had other surgical treatments at other clinics.

Terminology

SHEAR: Scapular Hypoplasia, Elevation and Rotation; Triangle tilt surgery: This surgical procedure includes osteotomies of the clavicle, neck of the acromion and scapula in order to release the distal acromioclavicular triangle and allow it to reorient itself in a more neutral position into the glenoid.

Peer-review

This is an informative paper, generally well-written and of interest to readers.

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ORIGINAL ARTICLE

Randomized Controlled Trial

Stochastic resonance whole body vibration increases perceived muscle relaxation but not cardiovascular activation: A randomized controlled trial

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Abstract

AIM

To investigate the acute effects of stochastic resonance whole body vibration (SR-WBV), including muscle relaxation and cardiovascular activation.

METHODS

Sixty-four healthy students participated. The participants were randomly assigned to sham SR-WBV training at a low intensity (1.5 Hz) or a verum SR-WBV training at a higher intensity (5 Hz). Systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR) and self-reported muscle relaxation were assessed before and immediately after SR-WBV.

RESULTS

Two factorial analyses of variance (ANOVA) showed a significant interaction between pre- *vs* post-SR-WBV

measurements and SR-WBV conditions for muscle relaxation in the neck and back [F(1,55) = 3.35, P = 0.048, η^2 = 0.07]. Muscle relaxation in the neck and back increased in verum SR-WBV, but not in sham SR-WBV. No significant changes between pre- and post-training levels of SBD, DBD and HR were observed either in sham or verum SR-WBV conditions. With verum SR-WBV, improved muscle relaxation was the most significant in participants who reported the experience of back, neck or shoulder pain more than once a month (P < 0.05).

CONCLUSION

A single session of SR-WBV increased muscle relaxation in young healthy individuals, while cardiovascular load was low. An increase in musculoskeletal relaxation in the neck and back is a potential mediator of pain reduction in preventive worksite SR-WBV trials.

Key words: Musculoskeletal system; Prevention; Blood pressure; Heart rate; Low back pain

Core tip: This randomized controlled trial shows musculoskeletal relaxation to increase after application of a single training of stochastic resonance whole body vibration (SR-WBV). SR-WBV increased muscle relaxation especially in those who suffered from musculoskeletal pain in the last year. Participants reported improved muscular relaxation while the cardiovascular activation as indicated by blood pressure and heart rate was very low. In addition to ergonomic interventions SR-WBV contributes to prevent muscle related pain at work.

Elfering A, Burger C, Schade V, Radlinger L. Stochastic resonance whole body vibration increases perceived muscle relaxation but not cardiovascular activation: A randomized controlled trial. *World J Orthop* 2016; 7(11): 758-765 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i11/758.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i11.758

INTRODUCTION

Whilst evidence for long-lasting vibration exposure at work, as a risk factor for musculoskeletal disease (MSD), is substantial[1], recent research also showed the beneficial training effects of brief vibration experiences[2]. It is noteworthy that it is low frequency vibration exposure (5-12 Hz) that is more promising and seems safer than high frequency exposure at 20 to 60 Hz[3,4]. Stochastic resonance whole body vibration training (SR-WBV) consists of low frequency exposure and has been shown to reduce pain in those with chronic MSD[5]. The outcome of SR-WBV at the worksite is promising. Four weeks of SR-WBV were reported to increase musculoskeletal well-being in the workers of a steel manufacturing company[6], but also in employees that engage in sedentary work, especially those who suffered from back pain prior to SR-WBV[7]. The latest randomised controlled trial with eight weeks of SR-WBV also showed the positive effects of SR-WBV in the employees of a university hospital, especially in those with baseline health restraints[8]. In the same population, SR-WBV was also shown to increase posture control, which was assessed by mediolateral sway on a force plate before and after the eight-week trial[9]. The positive effects of SR-WBV were also shown in the musculoskeletal function of young healthy adults[10], and one more study confirmed electromyographically that activation of the descending trapezius muscle decreased after SR-WBV, while blood flow and skin temperature also increased in this area, and the energy cost of SR-WBV was low[11]. A change in back muscle activation from induced SR-WBV training for the sensorimotor system, and not primarily from an increase in fitness, seemed to be involved in the overall positive effects of SR-WBV on musculoskeletal well-being and function[7]. Therefore, it is a plus of SR-WBV that the self-reported physical demands seemed to be small for most participants, and no sweating was reported. Even so, not only the muscle relaxation that followed the activation of the descending trapezius muscle, but also the change in blood pressure and heart rate from SR-WBV, should be evaluated to estimate the overall demands of SR-WBV training. The current randomized controlled trial tests the hypothesis that 5Hz-SR-WBV improves muscle relaxation (H1), and that 5Hz-SR-WBV triggers cardiovascular activation (H2), whereas 1.5 Hz-SR-WBV (sham condition) has no effect on muscle relaxation or cardiovascular activation. Therefore, 5 Hz-SR-WBV should have the greatest effect on muscle relaxation in those who reported back, neck or shoulder pain in last 12 mo (H3). The test of the second hypothesis is essential. Minimal cardiovascular activation would allow individuals at modest cardiovascular risk to perform SR-WBV.

How SR-WBV works

SR-WBV benefits from the effects of stochastic resonance by applying vibrations of low frequency with a maximal degree of complexity and unpredictability. Ward and colleagues defined stochastic resonance as "a nonlinear cooperative effect wherein the addition of a random process, or 'noise' to a weak signal, or stimulus results in improved detectability or enhanced information content in some response"[12]. SR-WBV differs completely from simple frequency fast sinusoidal vibrations, like the ones applied by the most common and conventional sinusoidal vibration training devices. During SR-WBV, the human body cannot anticipate the upcoming vibration movements, and therefore, the body is constantly challenged to adapt its neural and muscular reactions and shows no muscular fatigue during the application[13-16]. SR-WBV seems to provoke an interaction of different types of neurophysiologic sensors and the

adjustment of afferent and efferent signals, which probably acts as exercise for the sensorimotor system[13]. The observed increase in strength is mainly attributed to neural adaptation, which leads to improved inter- and intramuscular coordination, which, in turn, allows the increased activation of prime movers in specific movements, and better coordination in the activation of all relevant muscles[17] or a higher muscular activity in insufficient muscles, when compared to sinusoidal vibration[18]. A low risk of injury and only the rare manifestation of side-effects make SR-WBV an attractive preventive intervention[5,19].

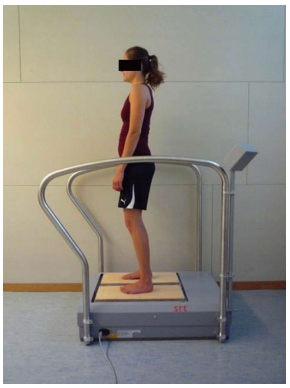

Figure 1 Starting position on stochastic resonance whole body vibration device.

MATERIALS AND METHODS

Ethics

The study was performed in consensus with all requirement defined by the Swiss Society of Psychology. The study was conducted with the understanding and the consent of the human subject. The Ethical Committee of the responsible University faculty has approved the study.

Participants

Expecting a moderate effect size for the repeated measures, within-between interaction and a requirement of a 90% power to detect an existing difference, the required sample size was 64 participants. Sixty-four undergraduate and graduate students were asked for participation and all agreed to participate (34 female and 30 male psychology majors, mean age = 27.6 years, SD = 5.0 years). The inclusion criterion was acute health status. The exclusion criteria for participation were recorded anamnestically, and comprised acute, past or chronic arthropathologies, troubles in the cardiovascular system, psychopathology, spondylolysis, spondylolisthesis, tumors, disc prolapse with neurological failure, rheumatism, articular gout, osteoporosis, activated arthritis with inflammatory signs, stage 4 arthritis, fever, cold, *etc.* No participant had to be excluded from the study. All participants finished the study protocol.

Procedure

The study was conducted at a University facility. The participants completed a single SR-WBV training session. A special device was applied for SR-WBV (©Zeptor med plus Noise, FreiSwiss AG, Zurich, Switzerland). Its key features were two independently and one-dimensional (up/down) stochastically oscillating floorboards, with two passive degrees of freedom (forward/backward and right/left). Each SR-WBV session was supervised, and the participants were instructed to stand in an upright position on the footboards with their arms hanging loose to the side and with slightly bent knees and hips (Figure 1). Both legs should have contact to the plates. It was permitted to change the knee angle but participants were instructed not to stand up straight because in that position vibration is conducted to the head. Figure 1 was shown to demonstrate the posture to participants. The participants were randomly allocated to SR-WBV groups (5 Hz verum condition or 1.5 Hz sham condition). The randomisation was based on the use of a list of random numbers[20]. The session consisted of three series of SR-WBV, which lasted one minute each, with a one-minute break between them. The 5 Hz verum condition was used as the minimum effective SR-WBV stimulation loading parameter, while the 1.5 Hz sham condition can be expected to have no training effect[10,21]. Participants were blind with respect to their training frequency condition. The investigator did the setting of the frequency before the training session started. The setting-screen was additionally covered by a piece of paper so that the participants never knew the exact vibration frequency.

Blood pressure and heart rate

The blood pressure cuff was put into place at the beginning of the session before the participants filled out the questionnaire. Participants wore the ambulatory blood pressure device (blood pressure monitor Spacelabs © model 90207; readings taken by the Korotkoff method) throughout the experimental session. Blood pressure was recorded one minute before and after the SR-WBV session. In an ambulatory blood pressure assessment, the Spacelabs 90207 often is denoted as the "gold standard"[22]. To ensure the comparability of blood pressure levels measured during the presentations, all analyses are based on data recorded in a sitting position.

Muscular pain and relaxation assessment

Musculoskeletal pain was assessed with a question that addressed musculoskeletal pain in the back or neck/shoulders in the last 12 mo (never, less than monthly, less than weekly, less than daily, daily). It is part of a scale that measures psychosomatic complaints that was developed by Mohr *et al*[23] based on the previous work of Fahrenberg *et al*[24]. Muscular relaxation was assessed by a short version of the self-administered questionnaire of Burger *et al*[6] that was completed

Table 1 Mean values of study variables in verum stochastic resonance whole body vibration and sham stochastic resonance whole body vibration groups

Variable	Verum-SR-WBV (5 Hz SR-WBV) (n = 34)		Sham SR-WBV (1.5 Hz SR-WBV) (n = 30)		t	P
	Mean	SD	Mean	SD		
Systolic blood pressure						
Pre-training	129.67	12.78	120.9	9.68	3.05	0.003
Post-training	126.97	11.54	120.57	10.43	2.32	0.024
Diastolic blood pressure						
Pre-training	78.61	11.00	75.27	7.64	1.39	0.171
Post-training	79.00	8.92	75.13	8.37	1.78	0.080
Heart rate						
Pre-training	71.09	12.03	69.1	15.67	0.57	0.572
Post-training	69.94	11.51	68.4	13.25	0.50	0.620
Muscle relaxation						
Pre-training	6.47	2.06	6.87	2.47	0.70	0.488
Post-training	7.00	2.10	6.7	2.59	0.51	0.611
Age (yr)	27.76	3.70	27.4	6.15	0.28	0.779[1]
Sex	18 f, 16 m		16 f, 14 m		χ^2 = 0.001	0.975
BMI	22.58	2.59	21.68	2.80	1.34	0.187
Fitness	3.65	0.65	3.66	0.72	-0.05	0.963
Smoker (10 cigarettes or more)	12 (6)		7 (3)		χ^2 = 1.09	0.296
Smoking (cigarettes)	3.53	6.33	2.30	6.98	0.74	0.463
Cups of coffee before training	1.50	1.11	1.67	1.47	-0.52	0.608
Back, neck or shoulder pain in last 12 mo	2.71	1.00	2.63	1.40	0.24	0.815[1]

[1]Corrected for unequal variances. BMI: Body mass index; SR-WBV: Stochastic resonance whole body vibration; f: Female; m: Male.

before and after SR-WBV. The participants were asked to rate muscle relaxation on a 10-point Likert scale. The question was introduced, "At the moment, how do you rate your personal sensation in your muscles and joints (back, shoulder and neck, leg muscles, *etc.*)?", which was followed by "Relaxation in the muscles and joints", and the corresponding 10-point rating scale from "no relaxation" to "strongest imaginable relaxation".

Statistical analysis

Self-reported muscle relaxation, systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate (HR) were analysed in a two-factorial ANOVA, including the repeated measurement (pre- *vs* post-session measurement) of SBP, DBP, HR and self-reported muscle relaxation as a within-subjects factor, and the SR-WBV training group condition (verum: 5 Hz, sham: 1.5 Hz) as a between factor.

We tested hypothesis 3 - expected gain in muscle relaxation to be the largest in verum SR-WBV and among those with musculoskeletal pain, compared with verum SR-WBV with no pain, and sham SR-WBV with and without pain - by planned contrasts as recommended by Strube *et al*[25]. The change in muscle relaxation (post-SR-WBV minus pre-SR-WBV) was the dependent variable. *P*-values were two-tailed with α set to 5%.

RESULTS

Participant characteristics

Before the training study started, the participants reported the frequency of musculoskeletal pain episodes in the back, neck or shoulders in the last 12 mo. Thirteen participants (20.3%) reported that they had never experienced pain during this period of time. Fifteen participants (23.4%) reported pain episodes less than monthly, and 21 participants (32.8%) reported pain episodes less than weekly. Ten participants (15.6%) reported pain episodes that occurred every week, but less than daily. Five participants (7.8%) experienced pain every day in the last 12 mo. Sixty-four healthy students participated in this study. Table 1 depicts the descriptive study results. The 64 participants were randomly assigned to SR-WBV conditions, and no significant differences in musculoskeletal pain episodes in the back, neck or shoulders in the last 12 mo were observed between the groups of verum SR-WBV and sham SR-WBV (Table 1). Thirty-four participants were assigned to verum SR-WBV, and 30 participants were assigned to sham-SR-WBV. The verum and sham SR-WBV groups did not differ significantly in any demographic characteristics or in baseline muscle relaxation or DBD and HR. However, the baseline and follow-up SBP was significantly higher in verum SR-WBV than in sham SR-WBV (Table 1). Table 2 shows the correlations between study variables. Pain episodes in the back, neck or shoulders in the last 12 mo were negatively related to sex, showing higher pain in women than in men. Fitness was negatively related to pain episodes in the back, neck or shoulders.

SR-WBV and improved muscle relaxation (H1)

The ANOVA results for the test of the first hypothesis are shown in Table 3. A significant interaction term indicated that verum SR-WBV improved muscle relaxation, while

Table 2 Correlations between study variables

Variables	SR-WBV condition	SBP pre	SBP post	DBP pre	DBP post	HR pre	HR post	Relax pre	Relax post	Age	Sex	BMI	Fitness	Smoking	Coffee
SR-WBV Condition															
SBP pre	-0.36[c]														
SBP post	-0.28[a]	0.83[e]													
DBP pre	-0.18	0.63[e]	0.57[e]												
DBP post	-0.22	0.59[e]	0.71[e]	0.68[c]											
HR pre	-0.07	0.02	0.01	0.22	0.22										
HR post	-0.06	0.03	0.07	0.21	0.24	0.76[e]									
Relaxation pre	0.09	0.02	0.22	-0.04	0.01	0.04	-0.01								
Relaxation post	-0.07	0.09	0.24	0.03	0.03	0.01	-0.04	0.84[e]							
Age	-0.04	0.36[c]	0.40[c]	0.24	0.23	-0.03	-0.11	0.26[a]	0.26[a]						
Sex	-0.01	0.26[a]	0.36[c]	-0.07	0.05	-0.16	-0.1	0.28[a]	0.15	0.29[a]					
BMI	-0.17	0.08	0.14	-0.14	0	-0.32[c]	-0.19	-0.01	0.02	0.15	0.45[e]				
Fitness	0.01	0.15	0.19	-0.13	-0.2	-0.19	-0.16	0.41[c]	0.38[c]	0.30[a]	0.34[c]	0.24			
Smoking (number of cigarettes)	-0.09	0.10	0.07	-0.12	0.06	0.25[a]	0.37[c]	-0.01	-0.07	0.07	0.36[c]	0.28[a]	-0.02		
Cups of coffee before training	0.07	0.09	0.01	-0.01	0.01	0.07	0.16	-0.28[a]	-0.28[a]	0.20	0.16	0.16	-0.18	0.33[c]	
Back, neck or shoulder pain in last 12 mo	-0.03	-0.18	-0.30a	-0.04	-0.14	-0.08	0.03	-0.55[e]	-0.59[e]	-0.09	-0.27[a]	0.02	-0.26[a]	-0.03	0.24

[a]$P < 0.05$, [c]$P < 0.01$, [e]$P < 0.001$: Correlations coefficients that significantly differ from zero. SR-WBV: Stochastic resonance whole body vibration; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; HR: Heart rate.

Table 3 Results of two-factorial ANOVA

	Sum of squares	*df*	Mean square	*F*	*P*	Partial eta-square
Inner-subject effects						
Pre- *vs* post-training (n = 64)	1.05	1	1.05	1.32	0.255	0.021
Training group (5 Hz *vs* 1.5 Hz)	3.86	1	3.86	4.85	0.031	0.073
Within subjects error	49.32	62	0.80			
Between subjects effects						
Constant	8.91	1	8.91	1.18	0.282	0.021
Training group (5 Hz *vs* 1.5 Hz)	0.74	1	0.74	0.01	0.931	0.000
Between subjects error	608.92	62	9.82			

no change appeared in sham SR-WBV [$F(1,62) = 3.86$, $P = 0.031$, $\eta^2 = 0.069$]. Figure 2 shows the change in muscle relaxation in both study groups.

SR-WBV and increase in cardiovascular activation (H2)

In verum and sham SR-WBV, the mean levels in SBP, DBP and HR were almost the same before and after SR-WBV (Table 1). The ANOVAs of SBP, DBP and HR did not show significant interaction effects [SBP: $F(1,61) = 1.92$, $P = 0.171$, $\eta^2 = 0.030$; DBP: $F(1,61) = 0.07$, $P = 0.792$, $\eta^2 = 0.001$; HR: $F(1,61) = 0.010$, $P = 0.919$, $\eta^2 = 0$].

SR-WBV and back, neck or shoulder pain in last 12 mo (H3)

Verum SR-WBV was expected to have the greatest effects on muscle relaxation in those who reported back, neck or shoulder pain in last 12 mo. These individuals should benefit more from 5Hz SR-WBV than those without pain and those with and without pain in the sham SR-WBV condition. Figure 3 shows the change in the musculoskeletal relaxation for SR-WBV groups separately, for those with and without back, neck or shoulder pain in last 12 mo. As expected, the increase in muscle relaxation was the greatest in those with pain in the verum SR-WBV group, and was significantly greater than in all other groups, as shown in the planned contrast analysis [$F(1,60) = 5.30$, $P = 0.025$, $\eta^2 = 0.081$].

DISCUSSION

The current findings showed self-reported musculoskeletal relaxation increased significantly after verum SR-WBV, but not after sham SR-WBV, while SBP, DBP and HR did not change in either verum SR-WBV or sham SR-WBV. The current results confirm a recent more explorative investigation on acute effects of SR-WBV that showed increased muscle relaxation measured by electromyography and low cardiac activation measured by heart rate variability[11]. Confirmation was important

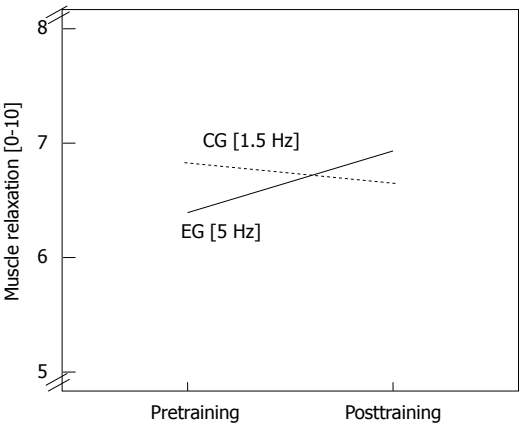

Figure 2 Self-reported muscle relaxation before and after stochastic resonance whole body vibration.

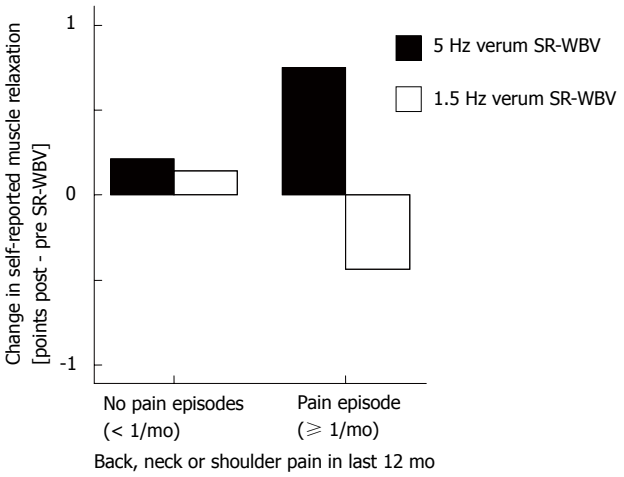

Figure 3 Change in self-reported muscle relaxation by stochastic resonance whole body vibration and back, neck or shoulder pain in last 12 mo before stochastic resonance whole body vibration.

because the previous investigation was based on a comparably small sample (one third of the sample size of the current study) and was based solely on a repeated measurements design[11]. Hence, the current randomized controlled trial increased the evidence that one trial of SR-WBV has beneficial musculoskeletal effects while cardiovascular load is moderate. Muscle relaxation after SR-WBV prevents musculoskeletal pain that may arise from consistently high muscle tension[1]. Repeated SR-WBV may decrease muscle tension and musculoskeletal pain. The present findings showed that participants who reported back, neck and shoulder pain episodes in the last 12 mo were the main beneficiaries of the overall positive effects of SR-WBV on muscle relaxation. Using repeated SR-WBV Elfering and colleagues found in a four-week worksite study that SR-WBV was more clearly linked to reduced pain in those who suffered from musculoskeletal pain prior to training, while those who were pain-free benefited less[15]. Thus, SR-WBV seems to have specific positive effects on the neuro-muscular system, while the absence of cardiovascular activation indicates that the positive effects are unlikely to be mediated by changes in overall fitness.

Four and eight-week worksite training studies showed SR-WBV can easily be done before, during or after work without having to change clothes or take a shower afterwards[6-9]. Further, the low cardiovascular demands of SR-WBV make SR-WBV a safe worksite prevention tool.

Even so, the beneficial effects of SR-WBV seem to contradict evidence of the harmful effects of vibration exposure at work[1]. However, a distinction should be made between SR-WBV and harmful vibration at work[26]. The damaging effects of vibration at work are caused by chronic exposure - with long exposure and short rest cycles - to a rather regular vibration that is often oscillating at a large amplitude or at frequencies of mechanical resonance[27]. In contrast, SR-WBV training efficiency and its therapeutic effects were summarised recently[5,27]. SR-WBV may have risks and benefits, and both should be studied. A review of 112 studies on whole body vibration reported very few side effects (0.00120% in 104 studies that used sinus whole body vibration, and 0.00069% in eight studies that used SR-WBV)[19]. More serious side effects have been exclusively found in studies that used sinusoidal whole body vibration, but not in studies that used SR-WBV[19]. SR-WBV seems to be a safe training intervention with usually harmless adverse effects when a careful evaluation of the medical history is performed before SR-WBV to evaluate contraindications or the potential risk factors of the subjects. In addition, one should avoid unnecessarily intense exposure to keep the risk of side-effects as low as possible. Therefore, we did 60-s trainings, which is the shortest period known to have a training effect. The next step in the evaluation should test worksite SR-WBV to reduce MSD, but it should also include an economic evaluation[28].

This study had an experimental design, and many potential confounders were controlled by randomisation. However, unexpectedly, baseline differences in SBP were observed between the SR-WBV groups, with higher SBP levels in verum SR-WBV. Thus, a regression to mean levels cannot be excluded in SBP measurement after SR-WBV. This is noteworthy; because of frequent measurement artefacts, SBP and DBP could only be measured after SR-WBV and not during SR-WBV. The participants were blind with respect to their verum *vs* sham SR-WBV condition. However, a blinding of the primary investigator was not feasible.

The participants benefited from low frequency 5 Hz SR-WBV after three one-minute trials within one 10-min training session. The participants with a frequent experience of back, neck and shoulder in last 12 mo had improved muscular relaxation after SR-WBV, whilst blood pressure levels and heart rate were nearly unchanged by SR-WBV. In addition to ergonomic intervention, training and participatory work redesign SR-WBV may help to

prevent and reduce MSD at work.

COMMENTS

Background

Musculoskeletal pain is common and so far no experiment tested the acute effects of a single stochastic resonance whole-body vibration training (SR-WBV) on muscle relaxation and blood pressure.

Research frontiers

There is need for research on short, economic, and effective training intervention. In this experiment, author(s) showed a single short SR-WBV training to increase musculoskeletal relaxation.

Innovations and breakthroughs

The experiment showed benefits were higher in those with experience of musculoskeletal pain while cardiovascular activation was low.

Applications

In previous works including 4 or even 8 wk of SR-WBV was found to improve musculoskeletal pain and body balance, measured as self-report and as recorded body sway on a balance platform. Improved body balance is connected to a lower risk of slips and falls. Short trials of SR-WBV that amount to less than 10 min can be done at a worksite without a change of clothes or shoes. Cardiovascular demand with 5 Hz SR-WBV is low and permits SR-WBV in the untrained or elderly workforce.

Terminology

SR-WBV constantly challenges the neuromusculoskeletal coordination to adapt to unforeseeable change.

Peer-review

This is an interesting investigation and the authors are experts in stochastic resonance whole body vibration.

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SYSTEMATIC REVIEWS

Spinal gout: A review with case illustration

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Abstract

AIM

To summarize clinical presentations and treatment options of spinal gout in the literature from 2000 to 2014, and present theories for possible mechanism of spinal gout formation.

METHODS

The authors reviewed 68 published cases of spinal gout, which were collected by searching "spinal gout" on PubMed from 2000 to 2014. The data were analyzed for clinical features, anatomical location of spinal gout, laboratory studies, imaging studies, and treatment choices.

RESULTS

Of the 68 patients reviewed, the most common clinical presentation was back or neck pain in 69.1% of patients. The most common laboratory study was elevated uric acid levels in 66.2% of patients. The most common diagnostic image finding was hypointense lesion of the gout tophi on the T1-weighted magnetic resonance imaging scan. The most common surgical treatment performed was a laminectomy in 51.5% and non-surgical treatment was performed in 29.4% of patients.

CONCLUSION

Spinal gout most commonly present as back or neck pain with majority of reported patients with elevated uric acid. The diagnosis of spinal gout is confirmed with the presence of negatively birefringent monosodium urate crystals in tissue. Treatment for spinal gout involves medication for the reduction of uric acid level and surgery if patient symptoms failed to respond to medical treatment.

Key words: Spinal; Gout; Tophi; Monosodium urate

Core tip: Gout is a common inflammatory arthritis that rarely affects the spine. In such cases, patients may experience back pain, myelopathic symptoms and radiculopathy. Clinical findings are non-specific. Therefore, it is necessary to have an awareness of the diagnosis,

especially in patients with a clinical history of gout and/or elevated inflammatory markers and hyperuricemia. While magnetic resonance imaging is the major non-invasive diagnostic method, all suspicious findings on imaging require surgical sampling for pathological confirmation. While typical uric acid lowering medications are first-line therapy, cord compression or continued symptoms may necessitate operative intervention if medications fail.

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INTRODUCTION

Gout is a common inflammatory arthritis with an increase in prevalence over the last 20 years. It currently affects over 8 million Americans. The clinical presentation of gout depends on the site of monosodium urate (MSU) crystals precipitation and the subsequent inflammatory response that ensues in the synovial joints and soft tissues. Gout usually manifests as a monoarticular arthritis in the lower extremities. If untreated, nodular masses of MSU crystals called tophi may eventually deposit in extraarticular locations, such as, the axial skeleton. Although traditionally thought of as a rare complication, recent study suggests that axial gout may be more prevalent than suspected[1]. Gout affecting the spinal column will typically present with neurological compromise, localized pain, and lytic vertebral lesions[2,3]. Spinal gout can affect the facet joint, laminae, ligamentum flavum, as well as the epidural space[4].

From 2000 to 2014, approximately 68 case reports have been published on spinal gout. The current manuscript summarizes the most common presenting features, imaging findings, and treatment choices based on the 68 published cases. A case is also presented to provide illustration on the topic.

MATERIALS AND METHODS

Literature review

A PubMed literature search using the key words spinal gout, from January 2000 to December 2014, limited to human studies and restricted to English language literature resulted in 221 publications. Abstracts and articles were then reviewed for content. Articles kept for review included patients who underwent treatment for spinal gout. Furthermore, data required for inclusion in the study included: Patient demographics, clinical presentation, laboratory findings, imaging studies, and treatment methods were collected (Table 1). Articles excluded from the study were those that did not have patients diagnosed with spinal gout and those that did not include patient demographics, clinical presentation, laboratory findings, imaging studies, and treatment methods. After review, a total of 54 peer reviewed articles met the above criteria and were included for data collection.

RESULTS

The 54 articles accounted for 68 cases of spinal gout with 51 (75%) males and 17 (25%) females and an average age of 59.2 years, 41(60.3%) had prior history of peripheral gout (Table 1).

Clinical presentations

Of the 68 spinal gout patients reviewed, 47 (69.1%) presented with localized back/neck pain, 38 (55.9%) with some form of spinal cord compression, defined as weakness, numbness, loss of bladder or bowel control, and decreased sensation below the compression level, 17 (25%) with spinal nerve root compression or radiculopathy, defined as motor dysfunction or dysesthesia along the course of a specific nerve caused by compression of its root, 13 (19.1%) with fever, 1 (1.5%) with cranial nerve palsy, and 2 (3.0%) with atlanto-axial subluxation (Table 2). Furthermore, among the sites of involvement in the 68 spinal gout patients, 38 (55.9%) were located in the lumbar region, 15 (22.1%) in the thoracic region, 15 (22.1%) in the cervical region, and 1 (1.4%) in an unspecified region (Table 3). One patient demonstrated soft tissue nodularity consistent with gouty tophi on biopsy in both the thoracic and lumbar spinal segments.

Laboratory studies

Laboratory studies of the 68 recorded cases showed 45 (66.2%) with elevated uric acid level at the time of diagnoses, 17 (25%) had elevated erythrocyte sedimentation rates (ESR), 19 (27.9%) had increased C-reactive proteins (CRP) level, 11 (16.2%) had renal insufficiency, 9 (13.2%) had leukocytosis, and 5 (7.4%) had anemia (Table 4).

Imaging studies

On the T1-weighted magnetic resonance imaging (MRI) images, 28 (41.2%) did not report findings, 31 (45.5%) were hypointense, 8 (11.8%) were isointense, and 1 (1.5%) was heterointense. On T2-weighted images, 24 (35.3%) did not report findings, 18 (26.5%) were hypointense, 12 (17.6%) were heterointense, 11 (16.2%) were hyperintense, and 4 (5.9%) were isointense. A gadolinium (Gd)-enhanced MRI scan was obtained from 32 (47.1%) patients. These findings are referenced in (Table 5).

Thirty-seven cases (54.4%) did not report X-ray findings, 12 (17.6%) showed spondylosis or spondylisthesis, 8 (11.8%) showed bony erosion, 6 (8.8%) were unremarkable, and 5 (7.4%) showed degenerative changes. In addition, 35 (51.5%) did not report computed tomography (CT) findings, 13 (19.1%) showed bony erosion and high density attenuation, 13 (19.1%)

Table 1 List of patient cases of spinal gout in the literature since 2000

No.	Year	Ref.	Age/ sex	Site	Sx/Signs	Duration	Hx Gout	Tophi	Relevant Hx	Hi Urate	MRI T1	T2	Gad	Tx
1	2000	Kao *et al*[5]	82 M	T10-T11	LE weakness	1 mo	Y	NA	NA	Y	Iso	Hypo	NA	T9-T11 lamina
2	2000	Mekelburg *et al*[6]	60 M	L2-3	Back pain	5 mo	Y	NA	NA	Y	NA	NA	NA	Cervical lamina
3	2000	Paquette *et al*[7]	56 M	L3	Back pain, radicular pain	6 yr	N	NA	Arthritis	NA	NA	Hypo	NA	Surgery
4	2000	Thornton *et al*[8]	27 M	L3-L4	Back pain	1 d	Y	NA	RT	Y	Hypo	NA	Y	Medical NOS
5	2001	Barrett *et al*[9]	70 M	L5-S1	Back pain, radicular pain, fever	2 d	Y	NA	RI	N	NA	Hyper	Y	Lamina
6	2001	St George *et al*[10]	60 M	T1-T2	LE weakness, BBD	6 wk	Y	N	NA	NA	NA	Hypo	NA	T1-T2 lamina
7	2001	Wang *et al*[11]	28 M	T9-T10	LE weakness	1 d	Y	N	NA	NA	NA	NA	NA	T9-T10 lamina
8	2002	Hsu *et al*[12]	72 M	L4-S1	Back pain, radicular pain	18 mo	Y	NA	NA	Y	Hypo	Hyper	Y	Lamina
9	2002	Hsu *et al*[12]	77 M	L3-L5	Back pain, radicular pain	12 mo	N	NA	NA	Y	Hypo	Hypo	Y	Lumbar lamina
10	2002	Hsu *et al*[12]	83 M	T9-T11	LE weakness	1 mo	Y	NA	NA	N	Hypo	Hypo	Y	Lamina
11	2002	Hsu *et al*[12]	27 M	L2-S1	Back pain	6 mo	Y	NA	NA	Y	Hypo	Hyper	Y	Medical NOS
12	2002	Souza *et al*[13]	49 M	T9-T10	Back pain, LE weakness	6 mo	Y	NA	NA	NA	Iso	Hypo	Y	T9-T11 lamina
13	2002	Yen *et al*[14]	68 M	C4-C5	Quadriparesis	2 wk	Y	NA	RI	Y	Hypo	Hypo	NA	Surgery
14	2003	Diaz *et al*[15]	74 M	C4-C5	Quadriparesis	1 wk	Y	Y	NA	Y	NA	NA	NA	C4-C5 lamina
15	2004	Draganescu *et al*[16]	48 F	L4	Radicular pain	1 d	Y	Y	Diuretic	Y	NA	Hetero	Y	L4-L5 lamina
16	2004	El Sandid *et al*[17]	32 M	T7-T9	Back pain, fever	Acute	Y	NA	NA	Y	NA	NA	NA	Lamina
17	2004	Nakajima *et al*[18]	39 M	L4-5	Low back pain	NA	Y	Y	Arthritis	Y	NA	NA	Y	Medical
18	2005	Beier *et al*[19]	29 M	L4-L5	Back pain, L5 radiculopathy	Acute	N	N	NA	Y	NA	NA	NA	L4-L5 lamina
19	2005	Celik *et al*[20]	48 M	C1-C2	Neck pain, radiculopathy, paresthesias	2 mo	N	Y	Alcohol	Y	Hypo	Hyper	Y	Medical NOS
20	2005	Chang[21]	60 M	L3-L4	B/L L4 radiculopathy	NA	Y	NA	NA	Y	Hypo	Hypo	Y	Surgery
21	2005	Chang[21]	72 M	L4-S1	Back pain, claudication	2 wk	Y	NA	NA	Y	Hypo	Hypo	Y	Surgery
22	2005	Chang[21]	66 F	L4-L5	Back pain, claudication	1 mo	Y	NA	NA	Y	Hypo	Hypo	Y	Surgery
23	2005	Chang[21]	63 M	L3-S1	Back pain, claudication, fever	2 wk	NA	NA	NA	N	Hypo	Hypo	Y	Surgery
24	2005	Kelly *et al*[22]	56 F	L4	Back pain, LE weakness	1 mo	Y	NA	RA, DM, RI	NA	Iso	Hypo	Y	L4-L5 lamina
25	2005	Mahmud *et al*[23]	47 M	L4-L5	Radiculopathy	3 mo	Y	NA	NA	Y	NA	NA	NA	L4-L5 lamina/ facet
26	2005	Mahmud *et al*[23]	71 F	L4-L5	Back pain, radiculopathy	4 mo	N	NA	NA	N	NA	Hetero	NA	L4-L5 lamina/ fusion
27	2005	Mahmud *et al*[23]	58 M	L4-L5	Back pain, claudication	6 mo	N	NA	NA	N	NA	Hyper	NA	L5 lamina
28	2005	Wazir *et al*[24]	66 F	C1-C2	Chronic neck pain, A-A subluxation, quadriparesis	2 mo	N	N	Arthritis	Y	NA	NA	NA	Lamina/ fusion
29	2005	Yen *et al*[25]	65 F	L5-S1	Back pain, LE weakness	10 mo	N	NA	NA	NA	Iso	Hetero	Y	L5-S1 lamina
30	2006	Dharmadhikari *et al*[26]	66 F	C3-C7	Cord compression, quadriparesis, falls	2-3 mo	N	N	NA	NA	Hypo	Hypo	N	C3-C6 vertebrectomy
31	2006	Hou *et al*[27]	37 M	L5-S1	Back pain, fever	5 d	Y	N	RT	Y	Iso	Iso	Y	Medical NOS
32	2006	Oaks *et al*[28]	32 M	T5-T8	Back pain, myelopathy	NA	Y	NA	NA	NA	Hetero	Hetero	Y	Lamina
33	2006	Pankhania *et al*[29]	68 M	C4-C5	Neck pain, quadriparesis, sensory dysfunction	1 mo	N	N	NA	N	Iso	Hetero	Y	Lamina
34	2006	Popovich *et al*[30]	36 F	T2-T9	Paraplegia	2 wk	Y	NA	NA	Y	Hypo	Hypo	Y	T5-T7 lamina
35	2007	Adenwalla *et al*[31]	77 M	L5-S1	Severe low back pain, LE weakness	1 wk	N	N	Diurectic	Y	NA	NA	NA	Prednisone and colchicines
36	2007	Lam *et al*[32]	65 M	L3-L4	LE pain and numbness, BBD	Acute	Y	Y	RI	Y	NA	NA	NA	L3-L4 lamina
37	2007	Lam *et al*[32]	63 M	L4-S1	Chronic LE pain and paresthesia, claudication	1 yr	Y	N	NA	N	NA	NA	NA	L4-L5 lamina/ fusion

38	2007	Suk *et al*[33]	55 M	L4-L5	Back pain, LE weakness and paresthesia, fever	1 wk	N	N	Alcohol	Y	Hypo	Hetero	Y	L4-L5 lamina/ fusion
39	2008	Fontenot *et al*[34]	85 F	L3-L4	Low back pain	2 mo	N	N	Diuretics	Y	NA	Hyper	NA	Prednisone and colchicines
40	2009	Chan *et al*[35]	76 M	T8, T10	LE weakness		Y	Y	NA	Y	Iso	Hetero	NA	Medical NOS
41	2009	Nygaard *et al*[36]	75 M	L4-L5	Low back pain, fever	5 d	Y	N	NA	Y	NA	NA	NA	NA
42	2009	Tsai *et al*[37]	64 F	T8-T9	Fever, low back pain, LE weakness	1 d	N	N	DM, RI	N	Hypo	Iso	Y	T8-T9 discectomy and partial corpectomy
43	2010	Coulier *et al*[38]	62 F	C6-C7	Neck pain	NA	N	Y	NA	Y	NA	NA	NA	NA
44	2010	Ko *et al*[39]	63 M	L5-S1	Low back pain	2 mo	N	N	NA	Y	Hypo	Hypo	Y	Lamina
45	2010	Murphy *et al*[40]	82 M	NA	Back pain	3 mo	N	Y	NA	NA	NA	NA	NA	NA
46	2010	Ntsiba *et al*[41]	43 M	T9-T10	Spastic paraplegia	6 mo	Y	Y	Alcohol	NA	Hypo	Hyper	NA	T10 lamina
47	2010	Samuels *et al*[42]	75 M	L5-S1	Low back pain, radiculopathy, b/l groin pain	Acute	Y	N	DM, RI, arthritis	NA	NA	NA	NA	Steroid injection and allopurinol
48	2011	Ibrahim *et al*[43]	70 F	T1-T2	UE and LE weakness	1 yr	Y	N	RI	Y	Hypo	Hyper	NA	Lamina/fusion
49	2011	Levin *et al*[44]	34 M	T2-T5	Paraplegia	Acute	Y	N	RI, DM	Y	NA	NA	NA	Lamina
50	2011	Thavarajah *et al*[45]	57 M	C1-C2	Neck pain, UE and LE tingling	1 yr	Y	N	NA	NA	NA	NA	NA	C0-C6 fusion
51	2011	Tran *et al*[46]	73 M	C1-C2	CN IX, X, XII palsies, fever, cough,	3 d	Y	Y	RI	Y	NA	Hetero	NA	Allopurinol, rasburicase
52	2012	Federman *et al*[2]	66 M	C4-C6	Neck pain	4 mo	N	N	DM	Y	Hypo	Hetero	NA	Allopurinol, colchicine, narcotic analgesics
53	2012	Hasturk *et al*[4]	77 F	L4-L5	Low back pain, radiculopathy	5 mo	N	N	NA	N	Hypo	Hypo	Y	Surgery
54	2012	Sakamoto *et al*[3]	69 M	L1-L2	Back pain, radiculopathy	Acute	N	N	Heart Failure	Y	Hypo	Hypo	Y	Medical NOS
55	201	Yamamoto *et al*[47]	58 F	C4-C7	Malaise, fever, back pain	3 yr	N	Y	Arthritis, RI	Y	NA	NA	NA	Prednisolone, allopurinol, benzbromarone
56	2012	Lu *et al*[48]	29 M	L4-S1	Severe pain, paresthesia, acratia of LLE	3 yr	Y	Y	Chronic alcohol abuse, chronic gout	Y	Hypo	Hypo	NA	L4-L5/L5-S1 decompression/ fusion
57	2012	Sanmillan *et al*[49]	71 M	C3-C4	Progressive Quadriparesis	4 mo	Y	Y	Hypertension, dislipidemia	Y	Hypo	Hyper	NA	C3-C4 micro-discectomy/ fusion
58	2013	Wendling *et al*[50]	54 M	C5-C6	Inflammatory neck pain and cervicobrachial neuralgia	Acute	Y	N	Hyperch-olesterolemia	Y	Hypo	NA	Y	Colchicine
59	2013	Wendling *et al*[50]	52 F	Lumbar posterior facet joint	Low back pain	NA	N	Y	Polychondritis	N	NA	NA	NA	Surgery
60	2013	Wendling *et al*[50]	72 M	C5-C6	Acute neck pain, knee arthritis	Acute	Y	N	Hypertension	Y	NA	NA	NA	Colchicine
61	2013	Wendling *et al*[50]	65 M	L4-L5	Inflammatory low back pain	Acute	Y	Y	Cardio-myopathy, hypertension	Y	NA	NA	NA	Colchicine
62	2013	Wendling *et al*[50]	87 M	L3-L5	Inflammatory low back pain	Acute	N	Y	Hypertension, heart failure, chronic kidney failure	Y	Hypo	NA	Y	Colchicine
63	2013	Komarla *et al*[51]	69 F	L3-S1	Back pain, fever	Acute	N	Y	Alchohol abuse, chronic low back pain	N	NA	Hyper	NA	Allopurinol, colchicine, glucocorticoids
64	2013	de Parisot *et al*[52]	60 M	C1-C2	Walking disorders, urinary and bowel incontinence	6 mo	Y	Y	NA	Y	Hypo	Hyper	Y	C1-C2 Arthrodesis
65	2013	Kwan *et al*[53]	25 M	T9-T10, L3-S1	Pain, swelling, and decreased ROM in multiple joints	1 wk	N	Y	CKD	Y	Hypo	Hetero	NA	Prednisone, allopurinol

66	2013	Yoon *et al*[54]	64 M	T5-T7	Weakness B/L LE, back pain rad to left anterior chest, paraparesis	Weakness: 1 wk; back pain 1 mo	Y (8 yr ago)	Y	Acute gout arthritis 8 yr prior	Y	Hypo	Hetero	Y	T5-T7, laminectomy, facetectomy, pedicle screw fixation w/PL fusion
67	2013	Jegapragasan *et al*[55]	24 M	L4-S1	Progressively worsening LBP w/rad, weakness of RLE, fever	3 yr LBP rad lat thight	Y (4 yr Hx)		4 yr Tophaceous gout, CKD, 3 yr LBP, rad pain down later thigh (Rt > Lf)	Y	Iso	Hetero	NA	Decompressive laminectomy L4-S1, resection of intraspinal canal and perineural lesion; post-op: colchicine, allopurinol, brief burst of prednisone
68	2014	Cardoso *et al*[56]	69 W	L4-5, SI joints	LBP rad to buttocks and hips, low fever	NA	N	Y	Constrictive pericarditis, chronic renal insufficiency, HTN, DM	Y	Hypo	Iso	Y	Colchicine, allopurinol

M: Male; F: Female; Sx: Symptoms; Hx: History; RT: Renal transplant; Hi: High; R: Right; LE: Lower extremity; RI: Renal insufficiency; BBD: Bowel/bladder dysfunction; Y and N: Yes and no; Hypo: Hypointense; Iso: Isointense; Hyper: Hyperintense; Hetero: Heterointense; UE: Upper extremity; Lamina: Laminectomy; Tx: Treatment; Gad: Gadolinium.

Table 2 Clinical features

No. of patients	
Localized back/neck pain	47
Spinal nerve root compression, in general	14
Radicular pain	6
Radiculopathy NOS	8
Spinal cord compression, in general	38
LE weakness	19
Quadriparesis	6
Claudication	5
Paraplegia	4
BBD	3
Myelopathy NOS	1
Cranial nerve palsy	1
Atlanto-axial subluxation	2
Fever	13

NOS: Not otherwise specified; UE: Upper extremity; LE: Lower extremity; BBD: Bowel/bladder dysfunction.

Table 3 Anatomic location of spinal gout

No. of patients	
Lumbar spine	38
Thoracic spine	15
Cervical spine	15
Not mentioned	1
Total[1]	68

[1]Patient No. 65 had gout in two sites, thoracic and lumbar regions.

displayed bony erosion only, 5 (7.4%) demonstrated lytic lesions, and 2 (2.9%) were unremarkable.

Treatments

Forty-five (66.2%) patients had surgical treatment. Thirty-five (51.5%) patients had laminectomies, 8 (11.8%) of whom also had fusions with laminectomies, 7 (10.3%) had surgeries not otherwise specified, 1 (1.5%) had a vertebrectomy, 2 (2.9%) had discectomies with partial corpectomies. Twenty (29.4%) received medical treatment alone and 3 (4.4%) did not report any treatment (Table 6).

Table 4 Laboratory studies

No. of patients	
Elevated uric acid	45
Elevated ESR	17
Elevated CRP	19
Renal insufficiency	11
Leukocytosis	9
Anemia	5

ESR: Erythrocyte sedimentation rate; CRP: C-reactive protein.

Case illustration

A 58-year-old female presented with a chief complaint of low back and radicular pain over left L4, 5 dermatomes that had been progressively worsening over a four-month duration to the point where she was unable to walk. The patient denied any saddle paresthesia or change in bowel and bladder function. She has a history of cardiovascular disease, chronic kidney disease (stage Ⅰ), type Ⅱ diabetes mellitus, hypertension, obesity, and obstructive sleep apnea. The patient also described an acute gouty arthropathy that was diagnosed in her right hand about 4 mo prior for which she was taking colchicine. An inflammatory workup was ordered which showed CRP of 3.58 (n < 1.0), ESR 25 (0-20), WBC 6.2 (4.0-10.0), uric acid 11.4 (2.5-6.8); HLA-B27, anti-DNA, Rheumatoid factor, and complement labs were negative.

Plain radiograph of the lumbar spine was unremark-

Table 5 Imaging studies

No. of patients	
X-ray	
Not performed	37
Spondylosis/-listhesis	12
Bony erosion	8
Unremarkable	6
Degenerative changes	5
CT	
Not performed	35
BE and HDA	13
BE only	13
Lytic lesions	5
Unremarkable	2
MRI	
T1	
Not reported	28
Hypointense	31
Isointense	8
Heterointense	1
T2	
Not reported	24
Hypointense	18
Heterointense	12
Hyperintense	11
Isointense	4
Gadolinium enhancement	
No	36
Yes	32

BE: Bony erosion; HAD: High density attenuation; CT: Computed tomography; MRI: Magnetic resonance imaging.

Table 6 Treatment

No. of patients	
Laminectomy only	24
Nonsurgical treatment	20
Surgery not specified	7
Laminectomy and fusion	5
Not reported	3
Fusion only	2
Laminectomy and facetectomy	3
Laminectomy and facetectomy and fusion	1
Vertebrectomy	1
Discectomy and partial corpectomy	2
Total	68

able. Plain radiograph of the right hand showed osseous erosive changes at the 4th finger distal interphalangeal (DIP) joint (Figure 1). MRI showed intraspinal extradural lesion causing spinal canal stenosis at L4-S1 (Figure 2). A CT showed that the lesion was calcified with erosive changes noted at the left L4-5 facet joint and L 4 lamina (Figure 3). The patient was treated with L4-S1 decompression, instrumentation and fusion. The surgical microscope was used during excision of the intraspinal lesion, which appeared chalky white, non-adherent and easily pealed off the thecal sac without sustaining dural tear (Figure 4). Postoperatively the patient noted significant improvement in both low back and radicular pain. The patient received allopurinol treatment for gout and remained asymptomatic at the last follow up two years after the index procedure.

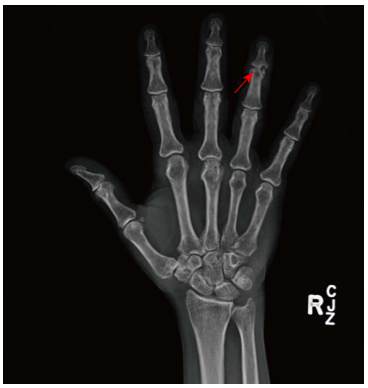

Figure 1 Plain radiograph anteroposterior view right hand showed osseous erosive changes at the 4th finger distal interphalangeal joint (arrow).

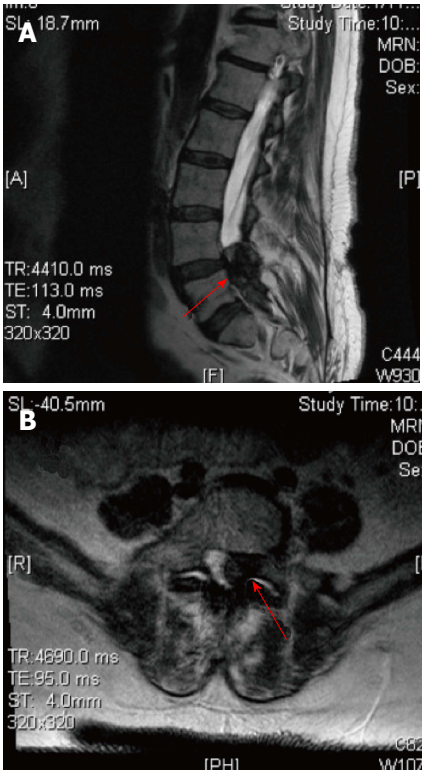

Figure 2 T2 weighted magnetic resonance imaging scan mid sagittal (A) and axial (B) showed intraspinal extradural hypodense lesion causing spinal canal stenosis at L4-S1.

DISCUSSION

Gout is a common form of inflammatory arthritis caused by the deposition of MSU crystals in synovial joints that result into erosion and joint damage. Soft tissue masses of MSU crystals known as tophi are usually found in the hand and extensor surface of the forearm[4,32,57]. Tophi are seen in patients with long-standing gout, but can also be one of the first symptoms amongst a cluster of metabolic disorders leading to hyperuricemia, especially

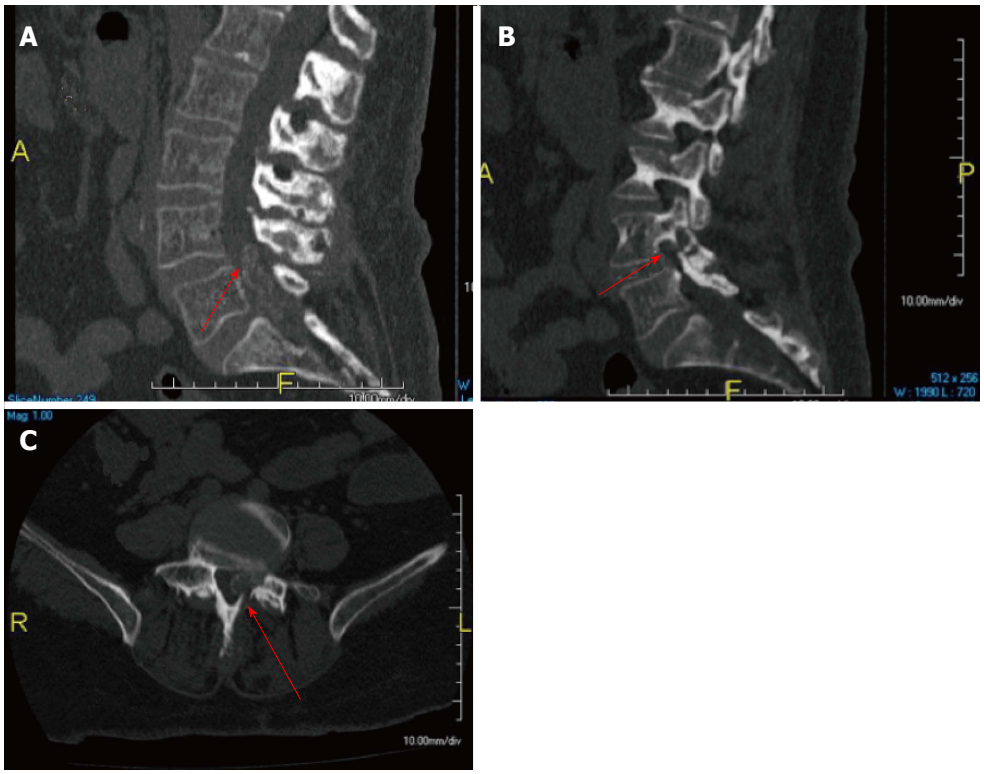

Figure 3 Computed tomography scan mid sagittal (A), left parasagittal (B), and axial (C) views showed the intraspinal lesion was calcified with erosive changes at the left L4-5 facet joint and L4 lamina (arrows).

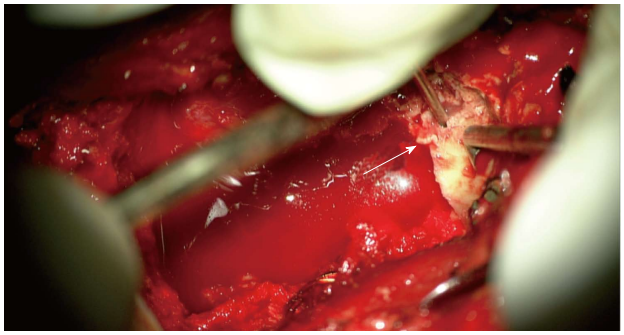

Figure 4 Intraoperative photograph taken by the surgical microscope showed a well-demarked chalky white tophous lesion (arrow).

among those with long-standing renal impairment[2,33]. Tophi are a common manifestation of gout, but spinal manifestations are considered rare. Recent research by de Mello *et al*[1], however, suggests that tophi in the axial skeleton may be more prevalent than first suspected.

Although no studies have been able to conclude the exact mechanism for axial involvement in gout, the likely theory is, as gout usually involves joint spaces, facet joint may be the initial deposition location for MSU crystals. Another theory is based on the fact that high uric acid and other inflammatory markers are often elevated in gout. This increase in uric acid in the blood could signal a corresponding increase in cerebrospinal fluid (CSF) leading to the obstruction of the canal or foramen.

Literature review showed that the lumbar spine was the most commonly involved region followed by thoracic and cervical regions. The most common clinical presentation was back pain associated with lumbar radiculopathy, or neurogenic claudication. The most frequent laboratory finding was hyperuricemia defined as uric acid above 7 mg/dL. Renal insufficiency was also found in many patients. Plain radiograph findings are usually non-specific. The most consistent image findings of the intraspinal extradural tophi were hypointense signal on the T1-weighted MRI and heterointense signals on the T2-weighted MRI. Spinal gout is usually diagnosed with cytological or histopathological studies. However, for patients treated with surgery, a pasty chalk-white mass are usually present. Clinical presentations and radiological findings of spinal gout are often non-specific and one has to consider the differential diagnoses of intraspinal extradural mass. The most frequent etiology with similar clinical presentations and imaging findings is herniated disc. Other causes include synovial cyst, tumor, epidural abscess, arteriovenous malformation.

Pharmacotherapy for spinal gout is the same as those used for gout involving typical joints. Acute gouty attack is most often treated with nonsteroidal anti-inflammatory drugs (NSAIDs), such as, naproxen or indomethacin. In patients with chronic kidney disease, duodenal or gastric ulcer, heart disease or hypertension, NSAID allergy, or anticoagulant treatment, colchicine is an alternative treatment. While NSAIDs and colchicine are effective in symptomatic reduction during an acute attack, they do not prevent the development of bony

erosions or tophi deposits in tissues. To prevent further gouty attack, maintenance medications are often prescribed with the goal of keeping uric acid level less than 6 mg/dL. Xanthine oxidase inhibitors, such as allopurinol, febuxostat, and oxypurinol, are the first line choices for reduced production of uric acid. Allopurinol can precipitate gouty attack or worsen current attack, thus, it is used for maintenance after acute attack has resolved. Uricosuric agents, such as, probenecid and sulfinpyrazone, are second line prophylactics aimed to increase uric acid excretion since decreased uric acid excretion is responsible for 85% to 90% of primary or secondary hyperuricemia[58].

Surgical interventions may be needed if patient has symptoms of spinal cord or nerve root compression. The mainstay of surgical treatment is decompression and excision of the tophi. The role of fusion at the time of the decompression remains controversial. The need for fusion is influenced by symptomatic preoperative instability as evidenced by dynamic radiographs, erosion of the facet joint seen on CT scan, or intraoperative instability that may be created by iatrogenic resection of spinal structures such as the pars interarticularis or the facet joints.

Although this article provides a broad overview of cases involving spinal gout since January 2000, there are some limitations. The absence of certain information, such as the post-treatment outcomes, limited the depth of our analysis in certain cases. Furthermore, the literature review could not always account for individual variation among the 68 cases reviewed including the particular method of diagnosis, which was not standardized across all patients included in the study. In addition, the individual articles did not provide information regarding prior uric acid lowering treatments, which could possibly inflate the number of spinal gout cases with normal uric acid levels.

The majority of clinical features for spinal gout such as back pain and neurological symptoms are nonspecific. Thus, one must rule out other common diagnoses, such as disc herniation, tumor, infection prior to diagnosing a patient with spinal gout. Laboratory study indicative of gout is elevated uric acid levels. In this literature review, the majority of the cases utilized MRI as the radiological study of choice in detecting spinal gout. While MRI was the major non-invasive diagnostic method, all suspicious findings on imaging required surgical sampling for pathological confirmation of negatively birefringent MSU crystals presence.

COMMENTS

Background

Gout is a common inflammatory arthritis with an increase in prevalence over the last 20 years. It currently affects over 8 million Americans. The primary aim of this review is to summarize the most common presenting features, imaging findings, and treatment choices based on the 68 published cases.

Research frontiers

Literature review showed that the lumbar spine was the most commonly involved region followed by thoracic and cervical regions. The most common clinical presentation was back pain associated with lumbar radiculopathy, or neurogenic claudication. The most frequent laboratory finding was hyperuricemia defined as uric acid above 7 mg/dL.

Innovations and breakthroughs

Traditionally gout thought of as a rare problem characterized by a sudden, severe attacks of pain, redness and tenderness in joints, often the joint at the base of the big toe. Recent studies suggest that axial gout may be more prevalent than suspected. Spinal gout can affect the facet joint, laminae, ligamentum flavum, as well as the epidural spaces.

Applications

The majority of clinical features for spinal gout such as back pain and neurological symptoms are nonspecific. Suspicious findings on MRI imaging required surgical sampling for pathological confirmation of negatively birefringent monosodium urate crystals presence.

Peer-review

It is a good review concerning the spinal gout consisting of the symptom and signs, treatment option and lab data analysis.

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