

# World Journal of *Orthopedics*

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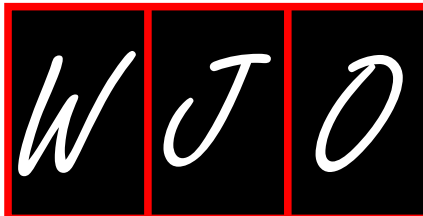
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## Anterior ankle arthrodesis

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**Key words:** Ankle arthrodesis; Customised plate; Anterior plate; Fusion; Synthes plate

**Core tip:** Ankle arthrodesis is a common procedure that resolves many conditions of the foot and ankle; however, complications are common. Complications vary with the technique described and there is not much agreement on the most advantageous method. This study evaluates the efficiency of anterior plating in ankle arthrodesis using customised and Synthes TomoFix plates. We present the outcomes of 28 ankle arthrodeses performed by a single orthopedic surgeon between 2005 and 2012, specifically examining rate of union, patient-reported outcomes scores, and complications. Contoured customised plates offer added compression and provide a rigid fixation for arthrodesis stabilization with few complications.

### Abstract

Ankle arthrodesis is a common procedure that resolves many conditions of the foot and ankle; however, complications following this procedure are often reported and vary depending on the fixation technique. Various techniques have been described in the attempt to achieve ankle arthrodesis and there is much debate as to the efficiency of each one. This study aims to evaluate the efficiency of anterior plating in ankle arthrodesis using customised and Synthes TomoFix plates. We present the outcomes of 28 ankle arthrodeses between 2005 and 2012, specifically examining rate of union, patient-reported outcomes scores, and complications. All 28 patients achieved radiographic union at an average of 36 wk; the majority of patients (92.86%) at or before 16 wk, the exceptions being two patients with Charcot joints who were noted to have bony union at a three year review. Patient-reported outcomes scores significantly increased ( $P < 0.05$ ). Complications included two delayed unions as previously mentioned, infection, and extended postoperative pain. With multiple points for fixation and coaxial screw entry points, the contoured customised plate offers added compression and provides a rigid fixation for arthrodesis stabilization.

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### INTRODUCTION

Ankle arthrodesis is commonly used to resolve conditions including end stage arthritis, failure of total ankle arthroplasty, fracture, osteonecrosis, infection, and Charcot joint<sup>[1]</sup>. Difficulties arise when presented with challenges such as poor bone quality, poor perfusion, gross deformity of the joint, and compromised wound healing. The use of techniques such as intramedullary rodding or external fixation can also be fraught with complications. With an increase in gross deformities of the ankle joint due to diabetes, rheumatoid arthritis, and failed total ankle replacements, surgeons are faced with the need to decrease variables in primary ankle arthrodesis and salvage arthrodesis. This study aims to evaluate the efficiency of customised and Synthes TomoFix plates in 28 ankle fusion patients including time taken to achieve arthrodesis,

patient satisfaction, and complications.

## CHALLENGES IN ARTHRODESIS

Various techniques have been used in the attempt to achieve ankle arthrodesis; however, complications are common. Nonunions are most commonly reported but complications also include tibial stress fractures, malunion, hindfoot arthritis, neurovascular injury, compromised wound healing, and infection<sup>[1-4]</sup>. The operative techniques often studied can involve difficult and complex procedures in order to achieve acceptable fixation of the arthrodesis. These techniques can be technically demanding for the surgeon and involve lengthy operative time.

With the increase of gross deformity and Charcot joint due to diabetes, challenges arise in salvage arthrodesis. In the failure of total ankle replacement, considerable loss of bone stock is common, as well as the presence of necrotic or non-viable bone. When patients present with poor bone quality, for example after a failed ankle arthroplasty, intramedullary nailing may not be possible due to loss of bone stock in the talus<sup>[5]</sup>. A study by Moore *et al*<sup>[4]</sup> that reviewed intramedullary rodding as a salvage procedure reported a 73.7% fusion rate with 81% of patients being ambulatory. One patient developed a deep infection and another sustained a broken rod. In the current study, two total ankle replacements were revised using an anterior plate; one for aseptic loosening, the second for delayed haematogenous sepsis.

## SURGICAL OPTIONS

There are many options for ankle arthrodesis, depending on the patient, diagnosis, and surgeon experience. Techniques of internal and external fixation have been reported with varying degrees of success<sup>[5-20]</sup>.

The outcomes of intramedullary rodding, a common alternative to pantalar arthrodesis with plating, have often been reported in the literature. Mendicino *et al*<sup>[13]</sup> examined one group of 20 patients who underwent tibiototalcalcaneal arthrodesis with retrograde intramedullary rodding and reported a 95% union rate; however, five diabetic patients sustained major complications following the operation and 11 patients had minor complications. Only one of the patients in the current study is diabetic and this patient did not present with any complications following the operation with anterior plating. Another study done by O'Neill *et al*<sup>[16]</sup> which compared locking plates to intramedullary nailing in six fresh frozen cadavers demonstrated that the locking plate provided a significantly higher final stiffness ( $P = 0.01$ ) and thus offered superior rigidity. Chiodo *et al*<sup>[6]</sup> compared intramedullary rodding with the use of a blade-plate and screw in ten matched pairs of fresh frozen cadavers. On one ankle, the intramedullary rod fixed the tibia, talus, and calcaneus. A five-hole plate with a blade was inserted into the contralateral ankle with two or three screws securing the plate to the tibia. The authors found that the blade-plate

and screw construct provided more stiffness than the intramedullary rod.

Currently, techniques using plates and screws are known to further increase compression and consequently increase arthrodesis success rates<sup>[5,9,14,19]</sup>. Plaass *et al*<sup>[5]</sup> studied a series of 29 patients in which an anterior double plating system was used to achieve tibiotalar arthrodesis. This method improves compression and fixation and the authors reported that all patients fused at an average of 13.2 wk. Internal compression is known to improve arthrodesis rates and decrease fusion periods. Mears *et al*<sup>[14]</sup> studied 17 patients whereby an anterior tension plate was found to realign the ankle and transform the otherwise deforming force of the Achilles tendon into a compressing force. The authors of this study achieved an 82% arthrodesis rate. Rowan *et al*<sup>[19]</sup> examined the outcomes of the use of an anterior AO tibial T plate in a retrospective study of 33 patients. In this study, 31 patients (94%) fused and two patients developed tibial stress fractures. The authors of the current study report a 100% union rate.

Arthroscopic ankle arthrodesis is often performed by surgeons as well. An arthroscopic technique allows for the procedure to be minimally invasive, have a shorter recovery period, and have a lower rate of complications<sup>[8]</sup>. In this procedure, the screws are crossed transversely or medially from the tibia into the talus<sup>[8,20]</sup>. Fusion rates have been reported to be high, and a short length of time to fusion has often been reported; Ferkel *et al*<sup>[10]</sup> reported a union rate of 97% at an average of 12 wk. Removal of screws is common in this procedure and has been reported to range from 9% to 31%<sup>[8,10,11]</sup>. The surgeon that performed the procedures in the current study has found the anterior plate to be more rigid and that it provides more consistent results; however, ankle arthrodeses are done arthroscopically if the patient has poor skin.

## PATIENTS

Twenty-eight patients (24 males and 4 females) underwent a unilateral ankle arthrodesis by a single surgeon between 2005 and 2012. Patients ranged in age from 32 to 84 years with a mean age of 61 years. Five of these patients received an anterior customised plate and 23 patients received a modified Synthes proximal-medial tibial plate, based on surgeon preference. Twenty patients were diagnosed preoperatively as having osteoarthritis, three patients had Charcot ankle joints, two had traumatic fractures (one leading to osteoarthritis), one had avascular necrosis leading to ankle collapse, and two patients had a previous ankle replacement (one with aseptic loosening, and one with delayed haematogenous sepsis). Anterior plating was also used in one patient who had a pantalar arthrodesis; the talar screws were continued across into the calcaneus and the subtalar joint was decorticated through a separate lateral incision.

At the initial consultation, prior to any operative measures, patients were given an ankle-hindfoot questionnaire before seeing the surgeon (Figure 1). This questionnaire

**CLINICAL RATING SYSTEM FOR THE ANKLE-HINDFOOT**

Developed by the American Orthopaedic Foot and Ankle Society

This rating system was developed by the American Orthopaedic Foot and Ankle Society to provide a standard method of reporting clinical status of the ankle foot. The system incorporates both subjective and objective factors into numerical scales to describe function, alignment, and pain.

**Ankle-Hindfoot scale (100 Points Total)**

Please circle the point that best describes your ankle-hindfoot

**Pain: (40 Points)**

- None..... 40
- Mild, occasional..... 30
- Moderate, daily..... 20
- Severe, almost always present..... 10

**Function (50 points)****Activity Limitations, support requirement:**

- No limitations, no support..... 10
- No limitation of daily activities, limitation of recreational activities, no support..... 7
- Limited daily and recreational activities, cane..... 4
- Severe limitation of daily and recreational activities, walker, crutches, wheelchair, brace..... 0

**Maximum walking distance, blocks:**

- Greater than 6..... 5
- 4-6..... 4
- 1-3..... 2
- Less than 1..... 0

**Walking surfaces:**

- No difficulty on any surface..... 5
- Some difficulty on uneven terrain, stairs, inclines, ladders..... 3
- Severe difficulty on uneven terrain, stairs, inclines, ladders..... 0

**Gait abnormality:**

- None, slight..... 8
- Obvious..... 4
- Marked..... 0

**Sagittal motion (flexion plus extension):**

- Normal or mild restriction (30° or more)..... 8
- Moderate restriction (15-29°)..... 4
- Marked restriction (less than 15°)..... 0

**Hindfoot motion (inversion plus eversion):**

- Normal or moderate restriction (75%-100% normal)..... 6
- Moderate restriction (25%-74% normal)..... 3
- Marked restriction (less than 25% normal)..... 0

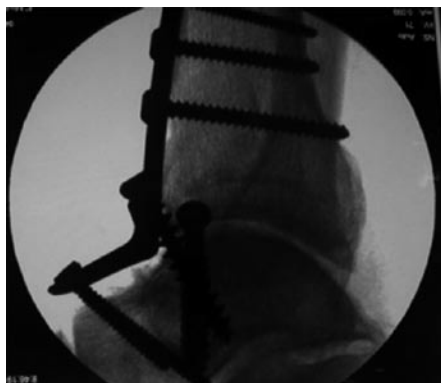
**Ankle-hindfoot stability (anteroposterior, varus-valgus)**

- Stable..... 8
- Definitely unstable..... 0

**Alignment (10 points)**

- Good, plantigrade foot, ankle hindfoot well aligned..... 10
- Fair, plantigrade foot, some degree of ankle hindfoot malalignment observed, no symptoms..... 5
- Poor, non plantigrade foot, severe malalignment, symptoms..... 0

**Figure 1** This shows the American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Scoring System that was used in this study. Patients were given this questionnaire preoperatively and postoperatively to evaluate subjective and objective outcomes.



**Figure 2** This is an intraoperative radiograph showing a customised Hawk plate that was used in five patients in the current study. This plate has multiple entry points for screws, adding the benefit of additional compression.

has been developed by the American Orthopaedic Foot and Ankle Society (AOFAS) as a standardised method of assessing the clinical status of the ankle-hindfoot<sup>[21]</sup>. The scale incorporates both subjective factors from the patient questionnaire, (*e.g.*, pain and activity limitations), and objective factors from the surgeon questionnaire, (*e.g.*, gait abnormality and alignment). This questionnaire was repeated at the eight week stage and at the patient's most recent stage in recovery to evaluate hindfoot function.

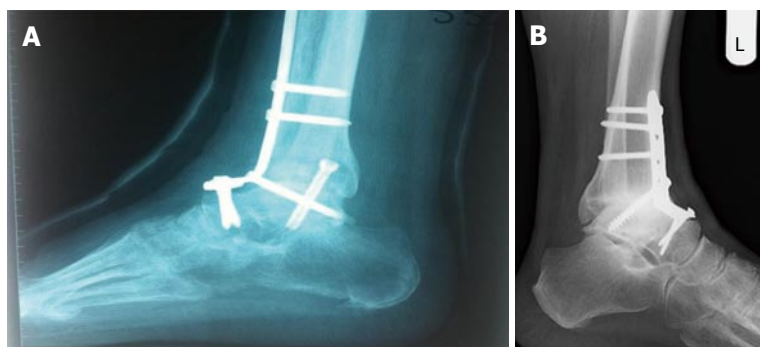
**SURGICAL TECHNIQUE**

Surgery was carried out under general anaesthesia with the additional use of a knee block, administered by the anaesthetist under ultrasound guidance prior to induction. Prophylactic antibiotic therapy was commenced during the procedure and continued for three doses in all patients. An anterior plate was used in all cases; five cases used a customised plate and 23 cases used a modified Synthes proximal-medial tibial plate. An incision was made longitudinally anterior to the ankle joint. Dissection was then made down to the talotibial joint, using a Hintermann distractor to obtain an optimal level of exposure at the joint surface. Hintermann wires were inserted into the talus and the distal tibia. The distractor was then attached and the joint was distracted. The instrument remained in place during decortication of the joint surface. A 4-mm rose bud burr, curette, bone nibblers, and 1-mm Kirschner wires were used to decorticate the joint surface. A customised plate or Synthes plate was then selected (Figure 2).

Modification of the Synthes plate was achieved by applying pressure to the distal end of the plate using a bending press (65°/180°). The joint was then stabilized using 2-mm Kirschner wires and the positioning of these wires was checked using fluoroscopy before proceeding with plate attachment. The anterior plate was screwed into position beginning with the insertion of the 6.5-mm cancellous home run screw of appropriate length through the distal tibia to the talus or, in the cases of pantalar fusion, to the calcaneus. Through the distal end of the plate, two self-tapping screws were inserted into the talus, continuing plantarly into the distal portion of the calcaneus. At the proximal end of the plate, three self-tapping screws were inserted into the tibia. The use of a home run screw allowed for added compression through the entire joint and further accommodated successful arthrodesis. It is important to note that the usage and placement of screws can vary greatly depending on the condition of the ankle; screening is advised throughout fusion for joint replacement as the target zone may present with narrow bone stock. The wound was then closed using a subcuticular, continuous absorbable suture. A size ten French vacuum drain was also inserted. A compression dressing was applied over the wound and a Plaster of Paris splint, not extending over the wound, was then applied. In the case of the patient who had previously had a total ankle replacement with a sepsis, the patient initially had two debridements followed by a gentamicin impregnated cement spacer for eight weeks. To fill the cavity created in the talus by the implant, the distal fibula was harvested through a separate incision and was used as a structured autograft. This technique was also used in the patient with avascular necrosis to maintain hindfoot height.

**POST-OPERATIVE PROTOCOL**

At two weeks post-operatively, the Plaster of Paris splint



**Figure 3** These lateral X-rays show union following anterior plating in ankle arthrodesis. A: A Synthes plate fixes an anterior ankle fusion at four weeks postoperatively; B: Union is achieved following anterior plating in ankle arthrodesis.

and the dressings were removed. X-rays were taken, the wound was checked and redressed, and a fiberglass cast was then applied. In patients who smoke and in patients who have diabetes, rheumatoid arthritis, or a suppressed immune system, a six week course of antibiotic therapy was prescribed. A magnetic implanted bone growth stimulator was used in revision cases and in the Charcot joint cases, as delayed fusion was anticipated. At six weeks postoperatively, patients were seen again for an X-ray. At this time, patients were instructed to partially bear weight in a ski boot orthotic. Patients then returned at 12 wk for X-rays and at 16 wk for X-rays and a computed tomography (CT) scan. Follow-up care after this point depended on fusion and clinical resolution of symptoms. Following this time, X-rays were reviewed at standard intervals ranging from six months consultation to 4.35 years (mean 1.36 years) to ensure that fusion was achieved. CT scans were also performed for all patients at the 12 mo mark to ensure that fusion had occurred.

## OUTCOME

All patients achieved bony fusion at an average of 36 wk (range 6 wk to 3 years). With the exception of three Charcot joints, all patients fused between 12 and 16 wk (Figure 3A). CT examinations were performed for all patients one year postoperatively. CT scans were also performed at four months postoperatively if the arthrodesis appeared to be healing slowly or if the patient was experiencing pain. On occasion, it was found that the ankle looked fused on X-ray, but clinical symptoms differed and a CT scan confirmed that the fusion was not complete. The three Charcot joints initially developed a fibrous fusion, defined as an asymptomatic stable position for one year; at a three year followup, these ankles were determined to have bony fusion. Partial weight bearing was allowed in all patients at six weeks in a controlled ankle motion walker boot.

Vast improvement was found upon comparison of pre-operative and post-operative ankle-hindfoot scale assessments. The mean ankle-hindfoot AOFAS score increased significantly ( $P < 0.05$ ) from 28.89 preoperatively (range 3 to 59) to 82.04 at the last review appointment (range 30 to 96). Time frames for the final review appointment varied greatly and depended on individual patient demands (mean 1.36 years, range 14 wk to 4.35 years).

Complications encountered included infection, delayed union, and extended post-operative pain. Four patients developed superficial infections which resolved with a one week treatment of 500 mg oral Keflex four times daily. One patient developed a wound breakdown which resolved quickly after treatment with standard protocol involving debridement, antiseptic lavage, and primary suture in an operative environment. This patient was then treated using intravenous antibiotic therapy and was discharged with a program of six weeks oral antibiotic therapy. One patient's "Charcot joint" screws began to back out and were reinserted percutaneously at six months postoperatively. Four patients, two of which had Charcot joints, displayed delayed union at 14 wk postoperatively; these patients were given the recommendation to use a magnetic implanted bone growth stimulator. All other patients developed fusion by 36 wk (Figure 3B). Four patients with Synthes plates were recommended for removal of the plate and screws due to residual pain and prominence.

## CONCLUSION

Current studies support the suggestion that internal fixation with plates and screws is superior to intramedullary nailing. Anterior plating provides enhanced compression and rigidity compared to other forms of arthrodesis. The anterior plate is strong enough to secure the ankle even in the case of a delayed union. As patients are always eager to begin weight-bearing, the ability to cease non-weight-bearing at six weeks routinely was beneficial to the current study's patients.

We found anterior plating to be successful even in the cases of failed total ankle replacements and pantalar arthrodeses. Two total ankle replacements were able to be revised using an anterior plate in this study and one patient underwent a pantalar arthrodesis.

The use of an anterior plate has the added benefit of allowing the calcaneus to be incorporated into the arthrodesis in order to increase rigidity and compression and it also provides a variety of screw entry points. Anterior plating is successful in achieving a high rate of fusion with few complications.

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## Hallux rigidus: Joint preserving alternatives to arthrodesis - a review of the literature

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### Abstract

Hallux rigidus describes the osteoarthritis of the first metatarsophalangeal joint. It was first mentioned in 1887. Since then a multitude of terms have been introduced referring to the same disease. The main complaints are pain especially during movement and a limited range of motion. Radiographically the typical signs of osteoarthritis can be observed starting at the dorsal portion of the joint. Numerous classifications make the comparison of the different studies difficult. If non-operative treatment fails to resolve the symptoms operative treatment is indicated. The most studied procedure with reproducible results is the arthrodesis. Nevertheless, many patients refuse this treatment option, favouring a procedure preserving motion. Different motion preserving and joint sacrificing operations such as arthroplasty are available. In this review we focus on motion and joint preserving procedures. Numer-

ous joint preserving osteotomies have been described. Most of them try to relocate the viable plantar cartilage more dorsally, to decompress the joint and to increase dorsiflexion of the first metatarsal bone. Multiple studies are available investigating these procedures. Most of them suffer from low quality, short follow up and small patient numbers. Consequently the grade of recommendation is low. Nonetheless, joint preserving procedures are appealing because if they fail to relieve the symptoms an arthrodesis or arthroplasty can still be performed thereafter.

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**Key words:** Hallux rigidus; Osteoarthritis; First metatarsophalangeal joint; Joint preserving; Operative treatment; Osteotomy

**Core tip:** If nonoperative treatment fails to relieve the symptoms of hallux rigidus surgery is indicated. The procedure with the most evidence for success is the arthrodesis of the first metatarsophalangeal joint. Nevertheless, many patients prefer treatment options which preserve the joint motion. The evidence for different arthroplastic procedures is of low quality. Furthermore, in case the procedure fails to relieve the symptoms to perform an arthrodesis after resection of the joint is much more difficult and may require bone graft. Consequently, joint and motion preserving osteotomies are of great interest for treatment of hallux rigidus. We here provide a review of the different joint and motion preserving alternatives for treating hallux rigidus and the studies available investigating these procedures.

Polzer H, Polzer S, Brumann M, Mutschler W, Regauer M. Hallux rigidus: Joint preserving alternatives to arthrodesis - a review of the literature. *World J Orthop* 2014; 5(1): 6-13 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v5/i1/6.htm> DOI: <http://dx.doi.org/10.5312/wjo.v5.i1.6>



## INTRODUCTION

The term “hallux rigidus” refers to the osteoarthritis of the metatarsophalangeal joint (MTPJ) of the first toe. This disease was first reported in 1887 by Davies-Colley<sup>[1]</sup>. He suggested the name “hallux flexus”. Shortly thereafter Cotterill was the first to introduce the term “hallux rigidus”<sup>[2]</sup>. Since then multiple names have been suggested, such as metatarsus primus elevatus, dorsal bunion, hallux dolorosus, or hallux malleus, to describe the same diagnosis. It is one of the most common problems of the great toe<sup>[3]</sup>.

## ETIOLOGY

Hallux rigidus is a common form of osteoarthritis in the foot<sup>[4]</sup>. Radiographic signs for the disease can be recognized in 10% of people aged 20–34 years and 44% of people over the age of 80 years<sup>[5]</sup>. The exact cause for hallux rigidus is controversial. Coughlin *et al.*<sup>[6]</sup> (2003) demonstrated that 80% of all patients suffering from bilateral hallux rigidus have a family history. Furthermore, in a long term study they could depict that most patients develop a bilateral hallux rigidus over time<sup>[6]</sup>. Some authors blame poor footwear<sup>[1]</sup>, a tight achilles tendon<sup>[7]</sup> or believe in a spontaneous onset<sup>[8]</sup>. Another popular concept is that an elevated first ray, the so called metatarsus primus elevatus, leads to hallux rigidus. While many authors are in favour of this theory<sup>[9–13]</sup>, there are multiple surgeons opposing it<sup>[14–16]</sup>. Coughlin *et al.*<sup>[6]</sup> even propose that the metatarsus primus elevatus might be a secondary change due to hallux rigidus. Taken together, the exact cause leading to hallux rigidus remains controversial. Nevertheless, it is known that females show a higher incidence<sup>[10,14,17,18]</sup> and that it mainly occurs after the age of 40 years<sup>[6]</sup>. The most common cause for unilateral hallux rigidus is believed to be traumatic, either by isolated injury or repetitive microtraumata<sup>[14,19,20]</sup>. These can cause chondral injury and lead to progressive arthritic changes. However, most of these concepts are theoretical and lack scientific evidence.

## CLINICAL FINDINGS

Hallux rigidus is characterised by arthralgia, which is usually worsened by walking. With time the joint enlarges and the symptoms become more pronounced with pain at the dorsal bony prominence of the first MTPJ<sup>[6]</sup> and decreased range of motion, especially dorsiflexion. In this process the destruction of the cartilage commonly starts at the dorsal portion of the metatarsal head<sup>[21]</sup> and the bony prominence might impinge against the proximal phalanx (Figure 1). Physical examination usually shows a painful, tender and swollen first MTPJ with limited motion and pain usually when dorsiflexed.

## RADIOGRAPHIC FINDINGS

Radiographic examination should include weight-bearing

anteroposterior and lateral radiographs<sup>[22]</sup>. The typical radiographic findings are asymmetric joint narrowing and a flattened metatarsal head (Figure 1). With advancement of the disease more of the joint surface is involved and subchondral cysts, sclerosis and bony proliferation at the joint margins occur and the joint narrowing progresses<sup>[22,23]</sup>.

## GRADING

Multiple different grading system for hallux rigidus have been introduced differentiating between two and five different grades<sup>[11,12,21,22,24–30]</sup>. A classification system should aid the decision on treatment and allow a meaningful comparison of different treatment strategies. Furthermore, in order to compare the results of different studies and procedures a consistent classification is crucial. Beeson *et al.*<sup>[31]</sup> (2008) performed a systematic review of the literature to critically evaluate the different classification systems for hallux rigidus. The authors criticize, that none of the classification systems has been tested in regard to reliability and validity. Taking this shortcoming into account they consider the classification system by Coughlin *et al.*<sup>[22]</sup> to be the closest to a “gold standard”. These authors base their classification on subjective and objective clinical and radiographic findings (Table 1).

## NONOPERATIVE TREATMENT

Nonoperative treatment of hallux rigidus should be applied in accordance to the degree of symptoms. Anti-inflammatory medications and strapping of the toe might be sufficient. Furthermore, shoe modification or the use of rigid shoe inserts and modification of activities might be beneficial<sup>[22,32]</sup>. Little evidence is available for injection of sodium hyaluronate, but it seems to be beneficial only in the early state<sup>[33,34]</sup>. Zammit *et al.*<sup>[35]</sup> performed a systematic review and identified only one high class randomised controlled trial evaluating conservative interventions for hallux rigidus. Shamus *et al.*<sup>[36]</sup> compared physical therapy alone to physical therapy combined with sesamoid mobilization, flexor hallucis strengthening exercises, and gait training. The authors concluded that combined multifaceted physical therapy reduces pain and restores function more sufficiently. When nonoperative treatment fails to provide relief, surgery should be performed.

## JOINT DESTRUCTIVE SURGICAL TECHNIQUES

### Arthrodesis

The best evidence available is in support of arthrodesis for the first MTPJ. When compared to total arthroplasty<sup>[37]</sup>, hemiarthroplasty<sup>[38]</sup>, resection arthroplasty<sup>[39]</sup>, interpositional arthroplasty or cheilectomy<sup>[40,41]</sup>, arthrodesis yielded better reduction of pain, better functional satisfaction, shorter hospital stays, lower revision rates and faster return to normal activity<sup>[42]</sup>. Nevertheless, joint and motion preserving operations are appealing, because



**Figure 1** Radiographic images of a hallux rigidus grade 2. A: Dorso-plantar view; B: Oblique view; C: Stress radiographs in dorsiflexion revealing bony impingement.

**Table 1** Clinical and radiographic grading for hallux rigidus

Grade	Dorsiflexion	Radiographic findings	Clinical findings
0	40°-60° and/or 10%-20% loss compared with normal side	Normal	No pain; only stiffness and loss of motion
1	30°-40° and/or 20%-50% loss compared with normal side	Dorsal osteophyte (main finding), minimal joint space narrowing, periarticular sclerosis, flattening of metatarsal head	Mild or occasional pain and stiffness, pain at extremes of dorsiflexion and/or plantar flexion
2	10°-30° and/or 50%-75% loss compared with normal side	Dorsal, lateral, and possibly medial osteophytes (flattened metatarsal head) < 1/4 of dorsal joint space involved (lateral radiograph), mild to moderate joint-space narrowing and sclerosis, sesamoids not involved	Moderate to severe pain and stiffness that may be constant; pain just before maximum dorsiflexion and maximum plantar flexion
3	≤ 10° and/or 75%-100% loss compared with normal side. Notable loss of plantar flexion (often ≤ 10°)	Same as in Grade 2 but with substantial narrowing, possibly periarticular cysts, > 1/4 of dorsal joint space involved (lateral radiograph), sesamoids enlarged and/or cystic and/or irregular	Nearly constant pain and substantial stiffness at extremes of range of motion but not at mid-range
4	Same as in Grade 3	Same as in Grade 3	Same as in Grade 3 but definite pain at mid-range of passive motion

if they fail to relieve the symptoms, an arthrodesis can still be performed.

### Arthroplasty

Different methods of arthroplasty are available. The studies comparing arthroplasty using nontissue implants compared various different implants<sup>[37,43-45]</sup> and produced conflicting results<sup>[40]</sup>. Arthroplasty by resection also seems to be effective for treatment of hallux rigidus<sup>[39,41,46]</sup>, although it could not be demonstrated that it is superior to other techniques. The same applies to the interpositional arthroplasty<sup>[40,46-48]</sup>.

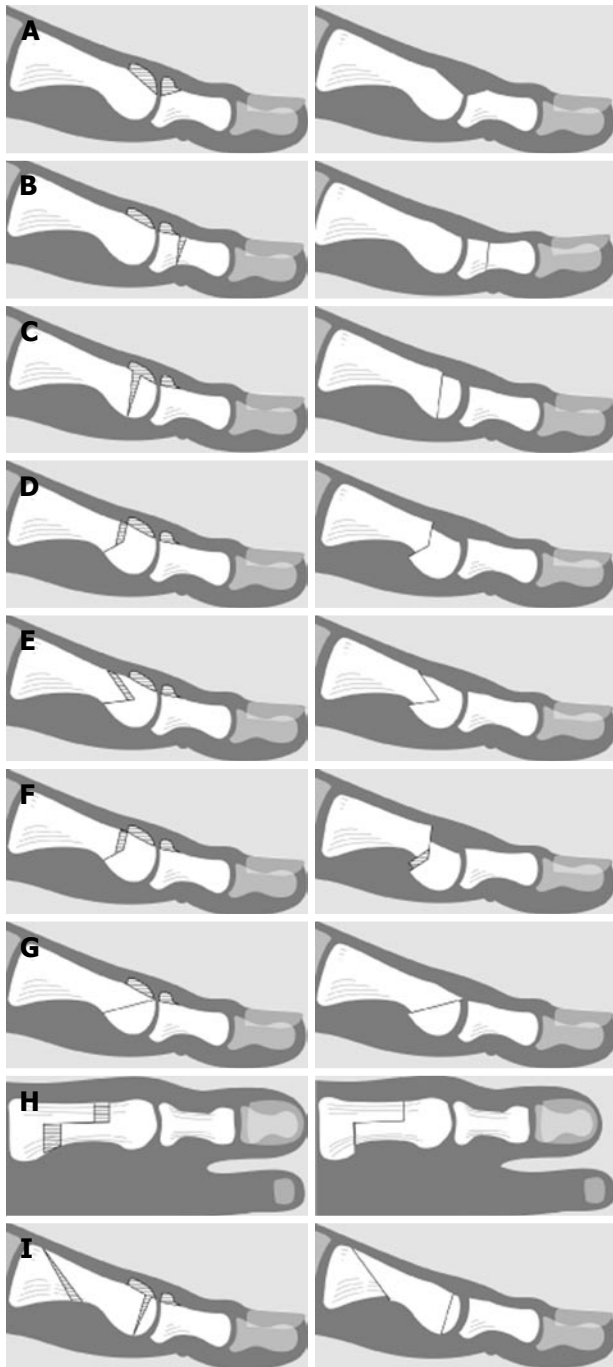
### Cheilectomy

This procedure was introduced in 1979 by Mann *et al.*<sup>[15]</sup>. In addition to the osteophytes of the base of the proximal phalanx 25%-30% of the dorsal metatarsal head are removed (Figure 2A). Consequently, the procedure must be classified as a partially joint sacrificing technique. Too aggressive resection may lead to a MTPJ subluxation. Furthermore, arthrodesis or arthroplasty are more difficult thereafter. Only retrospective trials are available comparing cheilectomy to other surgical interventions<sup>[40,41,44,49]</sup>. There is no consistent evidence that cheilectomy is superior to other operative interventions<sup>[42]</sup>, while it was used mainly in low grades of hallux rigidus.

## JOINT PRESERVING SURGICAL TECHNIQUES

### Proximal phalanx osteotomy (Moberg)

One of the main clinical findings in hallux rigidus is the painful limited range of motion, especially of dorsiflexion. Therefore, the concept of the proximal phalanx osteotomy is to reset the arc of motion by placing the toe into a more extended position (Figure 2B). This should better accommodate the need for dorsiflexion<sup>[50]</sup>. Bonney *et al.*<sup>[51]</sup> were the first to describe this concept in 1952 and called it “greenstick extension osteotomy of the proximal phalanx”. Kessel *et al.*<sup>[52]</sup> and Moberg<sup>[3]</sup> were the first to perform retrospective case series reporting promising results and suggesting “that further testing of this method should be worthwhile”. The only prospective trial investigating proximal phalanx osteotomy was performed by Kilmartin<sup>[53]</sup>. They compared the proximal phalanx osteotomy (49 joints) to different metatarsal decompression osteotomies (59 joints). Unfortunately the sample size for each procedure in the metatarsal decompression osteotomy group was decreased by mixing the proximal plantar displacement osteotomy, the modified Reverdin Green osteotomy and the shortening scarf osteotomy. In both groups a significant increase of the AOFAS score could be noted. A higher satisfaction rate and a lower



**Figure 2 Diagrammatic presentations.** A: A Cheilectomy; B: A proximal phalanx osteotomy (Moberg); C: A dorsal closing wedge osteotomy (Watermann); D: A Watermann Green procedure; E: A Youngswick procedure; F: A Reverdin Green osteotomy; G: A distal oblique sliding osteotomy; H: The Sagittal Z osteotomy; I: A Drago procedure.

complication rate were observed for the proximal phalanx osteotomy although without significant differences. In a retrospective long term follow up study Citron *et al*<sup>[54]</sup> found complete pain relief shortly after the operation compared with 50% pain relief after an average follow up of 22 years (10 joints). Blyth *et al*<sup>[55]</sup> retrospectively analysed 18 osteotomies with a follow up period of four years and found significant improvement for pain, footwear difficulties and range of motion. Fourteen of

the eighteen patients evaluated the result of the surgery as good or excellent. Southgate *et al*<sup>[56]</sup> retrospectively compared the proximal phalanx osteotomy (10 joints) to arthrodesis (20 joints) with an average follow up of 12 years. Without performing statistical analysis they found comparable results for both procedures, with less complications but greater changes of the foot pressure for the osteotomies. Mesa-Ramos *et al*<sup>[57]</sup> evaluated 26 minimal invasive procedures including a proximal phalanx osteotomy in combination with a capsular release and resection of bony spurs. The authors also found a good pain reduction with an increasing AOFAS score and a high patient satisfaction. Furthermore, few low quality retrospective case series investigated either only the proximal phalanx osteotomy<sup>[55]</sup> or the combination with cheilectomy<sup>[58]</sup>. Due to the low quality the only conclusion from these trials is, that the procedure is safe and that it seems to provide relief of symptoms.

Taken together, the evidence available is not good enough to draw a definitive conclusion, whether the proximal phalanx osteotomy is superior to other operative techniques. Nevertheless, the procedure seems to be safe and to reduce pain.

#### **Dorsal closing wedge osteotomy (Watermann)**

Watermann was the first to report a dorsal closing wedge trapezoidal osteotomy of the distal metatarsal (Figure 2C)<sup>[59]</sup>. It was designed to relocate the viable plantar cartilage to a more dorsal location, thereby allowing more dorsiflexion of the hallux<sup>[60]</sup>. It further causes a decompression of the joint<sup>[61]</sup>. Cavolo *et al*<sup>[61]</sup> reported two cases and found an increased range of motion and a high patient satisfaction. To our knowledge there are no further studies available evaluating this technique. From our point of view the major disadvantage is that the osteotomy is relatively unstable due to the perpendicular orientation of the osteotomy in relation to the metatarsal shaft and the resulting difficult fixation<sup>[60]</sup>. Furthermore, some authors state that this procedure is contraindicated in metatarsus primus elevates, as it could increase the symptoms<sup>[60]</sup>. From the little evidence available, no recommendation for this procedure can be made.

#### **Watermann Green**

The name Watermann Green is misleading as the procedure originally was not designed to rotate the articular cartilage compared to the original Watermann procedure. The procedure describes a 2-arm osteotomy. The dorsal arm consists of two incomplete osteotomies 0.5 cm proximal to the articular cartilage of the first metatarsal head in order to shorten the first metatarsal. If these two cuts form a trapezoid, the proximal articular set angle can be changed. The plantar osteotomy was originally angled 135 degrees to the dorsal arm and causes a plantar transposition (Figure 2D). This angle can be modified thereby changing the ratio of the first metatarsal shortening to the plantar transposition of the capital fragment. It is often combined with a cheilectomy. It is difficult to



clearly delineate this procedure from the Youngswick osteotomy as the angle between the two limbs can vary depending on whether the shortening or the plantar translation is more important<sup>[62]</sup> for both procedures resulting in comparable osteotomies.

Dickerson *et al.*<sup>[63]</sup> also retrospectively analysed 28 Watermann Green procedures with an average follow up of four years. Ninety-four percent of all patients reported an extensive relief of pain and 75% experienced a subjective increase of the range of motion. Roukis *et al.*<sup>[43]</sup> prospectively compared the periarticular osteotomy either according to Watermann Green or Youngswick (16 patients) to a resurfacing endoprosthesis (9 patients). The authors did not find significant differences for subjective and objective measures. The only difference found was a reduced metatarsal protrusion distance, but due to the limited follow up of one year, the importance of this finding could not be delineated. Furthermore, the authors do not state how many Watermann Green and how many Youngswick procedures were performed and do not evaluate the results for the two procedures independently. Consequently, the conclusions drawn are limited.

### Youngswick

This procedure was introduced by Youngswick<sup>[64]</sup> in 1982 as a modification of the Chevron osteotomy. First a V-shaped osteotomy is performed with the apex directed distally and two diagonal arms are directed dorsal proximal and plantar proximal at a 60 degree angle. Then, a second osteotomy is performed parallel to the dorsal limb of the first osteotomy (Figure 2E). This results in a shortening of the first metatarsal thereby leading to a decompression of the first MTPJ. Further it tries to plantar translate the first metatarsal head which may decrease metatarsalgia and dorsal impingement.

Giannini *et al.*<sup>[65]</sup> retrospectively evaluated eight patients with less severe hallux rigidus and found an improvement of both the AOFAS score as well as joint motion. Unfortunately no statistical analysis was performed and the results of this procedure were not clearly confined from the results of other osteotomies. Oloff *et al.*<sup>[66]</sup> retrospectively evaluated the outcome of the Youngswick procedure in 28 feet in late stage hallux rigidus. The operation led to a significant improvement of pain, function, range of motion in pain, the AOFAS score and significant less shoe restrictions. The authors reported an overall patient satisfaction of more than 85%, with the patients' chief complaint alleviated in more than 75%. Yet, the authors included combinations of the osteotomy with or without cheilectomy and/or chondroplasty and do not specify the number of these adjunct procedures. This makes the interpretation of these results difficult. Roukis *et al.*<sup>[43]</sup> conducted a prospective trial comparing the Youngswick as well as the Watermann Green osteotomy to a resurfacing endoprosthesis. The authors did not find significant differences for the AOFAS scores between the two study groups, while the AOFAS score in both groups significantly increased from pre- to postoperatively. Main limitations of the study were, that it was not identified how

many Youngswick and Watermann Green osteotomies were performed. Furthermore, they did not provide a detailed statistical analysis and only performed a follow up to twelve months. They concluded that further long-term studies are needed in order to draw a definitive conclusion. Bryant *et al.*<sup>[67]</sup> demonstrated that the Youngswick procedure changes the plantar peak pressure distribution in the forefoot. Yet, the importance of this finding is still unclear.

### Reverdin Green

The Reverdin Green osteotomy is a modification of the Youngswick procedure. After performing the V-shaped osteotomy a second osteotomy is performed parallel to the dorsal limb of the V-shaped osteotomy and the excised bone block is implanted in the plantar limb of the osteotomy to further translate the metatarsal head plantarwards (Figure 2F). The only prospective trial investigating the Reverdin Green osteotomy was performed by Kilmartin<sup>[53]</sup>. They included three different metatarsal decompression osteotomies, namely the Reverdin Green, the plantar proximal displacement and the shortening Scarf osteotomy and compared them to the proximal phalanx osteotomy. The authors performed 30 Reverdin Green osteotomies, but due to complications they instead continued with a plantar proximal displacement osteotomy. Unfortunately the authors do not state the nature of the complications. Furthermore, they do not report the results of the different osteotomies. The authors state that the decompression osteotomies resulted in a lower patient satisfaction rate and a higher complication rate when compared to the phalangeal osteotomy and conclude that neither of the procedures could be considered definitive for hallux rigidus.

We believe that the results of the Reverdin Green procedure cannot be judged due to the low quality of the data available. Nevertheless, the high rate of reported but not further specified complications must be noted.

### Distal oblique sliding osteotomy

This osteotomy is carried out in a distal to proximal direction beginning slightly proximal of the articular surface in an angle of 35°-45° oblique to the sagittal plane. The capital fragment is then displaced proximally and thereby leading to plantar displacement (Figure 2G). Consequently this procedure leads to both a decompression of the first MTPJ and a plantar displacement of the first metatarsal head. Lundeen *et al.*<sup>[13]</sup> initially introduced this concept for treatment of hallux valgus associated with hallux limitus, but it has been adopted for treatment of hallux rigidus only.

Giannini *et al.*<sup>[65]</sup> retrospectively analysed ten joints with low grade hallux rigidus treated by distal oblique sliding osteotomy. The AOFAS score as well as joint motion could be improved. As stated above no statistical analysis was performed and the results of this procedure were not clearly confined from the results of the Youngswick osteotomy. Ronconi *et al.*<sup>[68]</sup> retrospectively evaluated 30 osteotomies with a mean follow up of 21

mo. They demonstrated an increased range of motion of the first MTPJ and a high patient satisfaction rate, while the number of patients with excessive pressure on the second and third metatarsal head increased and the forefoot supination angle decreased postoperatively. Gonzalez *et al.*<sup>[69]</sup> performed a retrospective study of 25 joints. They included less and more severe grades (II-III according to Drago *et al.*<sup>[11]</sup>). The authors report a subjective satisfaction rate of 96% with a return to normal activity within two months for 80% of all patients and a significant increase of dorsiflexion of 41.2° in average, while 28% reported subjective limitation of joint motion. The authors do not comment on metatarsalgia of the lesser toes. Further limiting is the short follow up of twelve months only, consequently it cannot be evaluated whether this gain in motion can be maintained over time. Malerba *et al.*<sup>[70]</sup> retrospectively analysed 20 joints treated with a distal oblique sliding osteotomy with an average follow-up of 11.1 years. They found a significant increase of the AOFAS score as well as in the range of motion and concluded that the procedure is safe and reliable and provides a high patient satisfaction. Kilmartin<sup>[53]</sup> operated 15 patients with grade II hallux rigidus. The authors state that metatarsal decompression is associated with a high risk of transfer metatarsalgia, but as pointed out above they used three different techniques and do not state the results for each procedure individually. None of these authors observed severe complications such as head necrosis or non-union of the osteotomy.

### Sagittal Z osteotomy

The sagittal Z osteotomy also aims at shortening and thereby decompressing the first MTPJ (Figure 2H). Further it allows plantarflexion of the MTPJ. The greatest advantages of this procedure are the high cross-sectional area for bone healing, the great shortening potential and the ability to be fixated with multiple screws in combination with a low risk for avascular necrosis<sup>[60]</sup>. This procedure was always performed in combination with a cheilectomy. This combinatory approach makes it difficult to determine the outcomes of the osteotomy and cheilectomy. The evidence for this procedure is low. Kissel *et al.*<sup>[71]</sup> evaluated the results of the sagittal Z osteotomy in combination with cheilectomy and chondroplasty and found good patient satisfaction rate without performing statistical analysis. Viegas<sup>[72]</sup> performed 13 procedures and found only good and excellent results. Again the authors did not acquire objective measurements and consequently they could not perform statistical analysis.

### Drago

Drago *et al.*<sup>[11]</sup> presented a double osteotomy consisting of a Watermann procedure at the distal end of the first MT and a proximal plantarflexing osteotomy. The idea was to perform a proximal osteotomy in order to allow more plantarflexion compared to the distal osteotomy. The authors hypothesised, that this could lead to a dorsal jamming of the first MTPJ. In order to prevent this effect and to rotate the articular surface dorsally, they combined

this osteotomy with a Watermann procedure (Figure 2I). To our knowledge no study has yet evaluated the results of this procedure.

### Modifications

Furthermore, there are various modifications of the previously depicted osteotomies. All studies evaluating such procedures were retrospectively performed without a control group. Yet, all authors claim good results for their procedures.

Derner *et al.*<sup>[73]</sup> presented a modification of the Youngswick procedure. Their first cut is straight in contrast to the V-shaped osteotomy by Youngswick. The second osteotomy is performed parallel to the dorsal two thirds of the first osteotomy. The authors report an increase of the range of motion of 38° with an excellent patient satisfaction of 85%.

Selner *et al.*<sup>[74]</sup> performed a retrospective analysis of a tricorrectional osteotomy (18 joints) with an average follow up of 32 mo. It is basically a modified Youngswick procedure but it allows to change the orientation of the first MTPJ.

Kilmartin<sup>[53]</sup> performed a shortening Scarf osteotomy in 14 patients. They state that the increase in range of motion is limited but a high number of patients suffered from transfer-metatarsalgia without specifying these results. As depicted above this study suffers multiple shortcomings.

## CONCLUSION

The evidence currently available investigating the different procedures is poor. Especially the clinical heterogeneity and the low number of prospective trials are the reason why it is not possible to compare outcomes for patients undergoing the different surgical procedures. Consequently the grade of recommendation for each procedure is low and the choice of the procedure still is an individual decision of the treating surgeon until better prospective trials are available. Nevertheless, joint preserving operations are appealing, because if they fail to relieve the symptoms, joint sacrificing operations can still be performed.

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## Triple pelvic osteotomy: Report of our mid-term results and review of literature

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### Abstract

A wide variety of pelvic osteotomies have been developed for the treatment of developmental dysplasia of the hip (DDH). In the present paper, we present a detailed review of previous studies of triple osteotomy as an alternative treatment for DDH. We also report our experience treating 6 adult cases of DDH by triple osteotomy in order to highlight the various aspects of this procedure. The mean age of our patients was 31.2 years with a mean follow-up period of 6 years. We assessed range of motion, center-edge angle, acetabular index angle, Sharp angle, acetabulum head index, head lateralization index, Japanese Orthopedic Association score, Harris hip score, patient satisfaction, and the difference between lower limb lengths before and after the procedure. At final follow-up, clinical scores were significantly improved and radiographic parameters also showed good correction of acetabulum.

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**Key words:** Pelvic osteotomy; Triple osteotomy; Developmental dysplasia of the hip

**Core tip:** Various pelvic osteotomies have been developed for treating developmental dysplasia of the hip (DDH). In the present paper, we review previous studies on triple osteotomy as an alternative treatment for DDH and also report our experience with 6 DDH cases treated by triple osteotomy in order to highlight the various aspects of this procedure. In our cases, clinical scores as well as radiographic parameters were significantly improved. We found that the clinical results of triple osteotomy were satisfactory and it should be considered as an alternative pelvic osteotomy procedure in adults with DDH.

Mimura T, Mori K, Kawasaki T, Imai S, Matsusue Y. Triple pelvic osteotomy: Report of our mid-term results and review of literature. *World J Orthop* 2014; 5(1): 14-22 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v5/i1/14.htm> DOI: <http://dx.doi.org/10.5312/wjo.v5.i1.14>

### INTRODUCTION

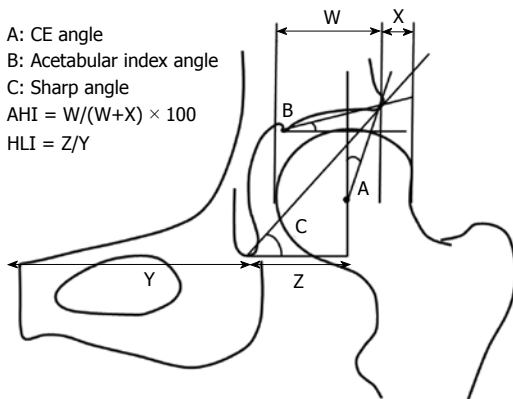
Developmental dysplasia of the hip (DDH) is well known as a cause of secondary osteoarthritis of the hip. In Japan, approximately 80%-90% of hip osteoarthritis cases occur secondary to DDH.

An acetabular osteotomy to treat DDH is a clinically important therapeutic modality especially in young adults with low-grade osteoarthritis, pre-osteoarthritis. Restoration of the anatomical and biomechanical relationship in cases of DDH may delay or prevent development of coxarthrosis<sup>[1]</sup>. To date, a variety of acetabular osteotomies of the adult pelvis have been reported, including the Bernese periacetabular osteotomy<sup>[2]</sup>, rotational acetabular osteotomy (RAO)<sup>[3]</sup>, and triple osteotomy procedure<sup>[4]</sup>. The aims of these osteotomies have been to achieve acquire good containment of the femoral head and stability of the hip joint.

**Table 1** Pre-operative angle values and scores of all cases

	Age, yr	CE angle	Acetabular index	Sharp angle	AHI	HLI	JOAS	HHS
Case 1	19	-9	31	48	44.2	0.63	63	70
Case 2	20	13	20	46	65.8	0.54	73	80
Case 3	27	5	20	45	57.8	0.71	52	59
Case 4	29	9	19	45	60.0	0.69	52	59
Case 5	43	16	14	47	70.5	0.65	80	93
Case 6	43	0	26	54	52.2	0.56	54	73

CE angle: Center-edge angle; AHI: Acetabular head index; HLI: Head lateralization index; JOAS: Japanese Orthopedic Association score; HHS: Harris hip score.



**Figure 1** The center-edge angle, acetabular index angle, Sharp angle, acetabular head index, and head lateralization index were evaluated in anteroposterior X-ray images. CE: Center-edge; AHI: Acetabular head index; HLI: Head lateralization index.

A triple osteotomy is widely employed for treating DDH in adolescents and young adults, especially in those in whom the triradiate cartilage remains unfused<sup>[5-9]</sup>.

The limited number of existing reviews of triple osteotomy prompted us to write an up-to-date review. In addition, few studies of triple osteotomy in older patients (age > 30 years) have been reported. In the present study, we also report a case series of triple osteotomy in relatively older patients (> 30 years of age).

## OUR CASES

We performed 6 triple osteotomies in 4 adult patients with DDH, with bilateral osteotomies performed in 2 patients. The average age of the patients was 31.2 years (19-49 years) and all were female in the pre-osteoarthritis stage. The mean follow-up was 6 years. The center-edge (CE) angle<sup>[10]</sup>, acetabular index angle<sup>[11]</sup>, Sharp angle<sup>[12]</sup>, acetabular head index (AHI)<sup>[13]</sup>, and head lateralization index (HLI)<sup>[3]</sup>, were evaluated on anteroposterior (AP) X-ray images (Figure 1). Range of motion (ROM), Japanese Orthopedic Association score (JOAS), Harris hip score (HHS), patient satisfaction (well satisfied, satisfied, and dissatisfied), and difference in lower limb lengths before and after the procedure were also assessed. JOAS consists of the items pain (0-40), ROM (0-20), walking ability (0-20), and activities of daily living (ADL; 0-20), with a total of 100 indicating the best hip function. Student's *t*-test was used to determine significant differences

**Table 2** Post-operative angle values and scores of all cases

	CE angle	Acetabular index	Sharp angle	AHI	HLI	JOAS	HHS
Case 1	25	9	26	80.0	0.52	95	100
Case 2	53	-12	12	97.7	0.63	95	100
Case 3	10	15	36	66.7	0.70	91	100
Case 4	21	15	37	73.9	0.70	91	100
Case 5	26	2	35	80.0	0.70	88	96
Case 6	18	9	35	72.3	0.65	78	96

CE angle: Center-edge angle; AHI: Acetabular head index; HLI: Head lateralization index; JOAS: Japanese Orthopedic Association score; HHS: Harris hip score.

between groups, with a *P* value of < 0.05 considered significant.

## OPERATIVE TECHNIQUES

Arthroscopy was performed in all cases to evaluate the condition of cartilage and acetabular labrum, as well as the degree of osteoarthritis before the osteotomy procedure. All cases were in the pre-osteoarthritis stage and there were no acetabular labral tear. The triple osteotomy sites were nearly the same as those reported by Töninis<sup>[14-16]</sup>. First, an ischial osteotomy was performed in a side-up position with 90° hip flexion. Next the position was changed to a supine position, and pubic and iliac osteotomies were performed through two independent skin incisions. The iliac osteotomy was performed using a Gigli saw, using a technique similar to that of Salter osteotomy. For the acetabular osteotomy, the acetabulum was initially rotated laterally. Then an iliac wedge graft was obtained and grafted between the acetabulum and the ilium. Three 3.0 mm K-wires were used for fixation of the acetabulum. Hip spicas were not required for postoperative immobilization.

## RESEARCH

Pre-operative ROM was full in all patients. At the final follow up examination, mean flexion was 108.3° (100°-120°), abduction was 33.3° (30°-40°), external rotation was 58.3° (50°-60°), and internal rotation was 35° (20°-50°). Details follow-up findings are presented in Tables 1 and 2. With regard to acetabular coverage, HHS and JOAS were both improved. The average pre-

**Table 3** The mean values of pre-operative and post-operative angles and scores

	Pre-op (mean $\pm$ SD)	Post-op (mean $\pm$ SD)	P value
CE angle	5.67 $\pm$ 8.26	25.5 $\pm$ 13.4	0.0184 <sup>1</sup>
Acetabular index	21.7 $\pm$ 5.44	6.33 $\pm$ 9.0	0.0098 <sup>1</sup>
Sharp angle	47.5 $\pm$ 3.09	30.2 $\pm$ 9.0	< 0.0001 <sup>1</sup>
AHI	58.4 $\pm$ 8.60	78.4 $\pm$ 9.8	0.0063 <sup>1</sup>
HLI	0.63 $\pm$ 0.06	0.65 $\pm$ 0.1	0.6286
JOAS	62.3 $\pm$ 10.9	89.7 $\pm$ 6.5	0.0006 <sup>1</sup>
HHS	72.3 $\pm$ 11.9	98.7 $\pm$ 1.9	0.0006 <sup>1</sup>

CE angle: Center-edge angle; AHI: Acetabular head index; HLI: Head lateralization index; JOAS: Japanese Orthopedic Association score; HHS: Harris hip score. <sup>1</sup>P < 0.05 based on a Student's *t*-test.

operative CE angle, acetabular index angle, Sharp angle, AHI, and HLI value were 5.67, 21.7, 47.5, 58.4, and 0.63, respectively, with the corresponding postoperative values being 25.5, 6.33, 30.2, 78.4, and 0.65, respectively (Table 3). HLI showed no improvement, suggesting that medialization of the femoral head was not achieved, whereas HHS, JOAS, CE angle, acetabular index angle, Sharp angle, and AHI were all significantly improved (*P* < 0.05). JOAS was improved from 62.3 to 89.7 and HHS from 72.3 to 98.7. The average operative time was 5 h and 25 min, including arthroscopy and changing of position. All patients chose “well satisfied” for the satisfaction score. The average lower limb elongation was 12 mm. Two complications were encountered in 1 patient (case 6), temporary lateral femoral cutaneous nerve (LFCN) dysfunction and delayed union of the ischium. No patients had infection, non-union, other nerve injuries, vascular injury, or osteonecrosis of the acetabulum.

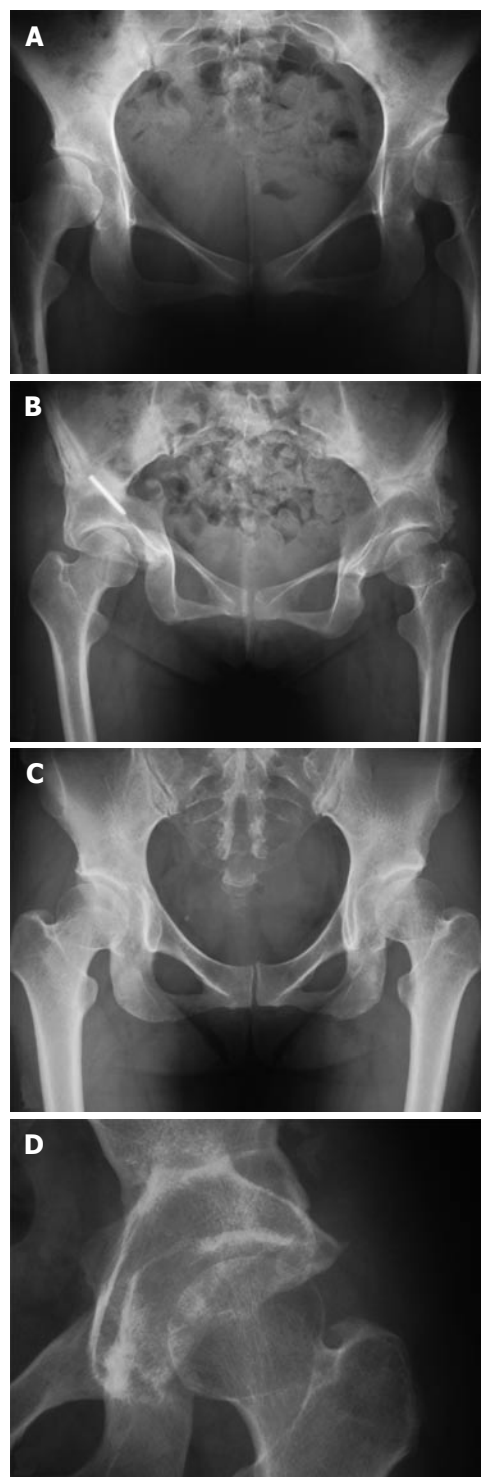
## REPRESENTATIVE CASES

### Cases 1 and 2

Patient at age at the time of surgery was 19 years old. The same patients underwent a triple osteotomy for the left hip (case 1), which was followed by a right hip osteotomy the next year (case 2; Figure 2A, B). The follow-up period for the right hip was 6 years. Pre-operative JOAS in the left hip was 63 (pain 20, ROM 20, walking ability 5, ADL 18), whereas that in the right was 73 (30, 20, 5, 18). At the final follow-up examination, post-operative JOAS in the left and right hips was 95 (35, 20, 20, 20) and 95 (35, 20, 20, 20), respectively. Pre-operative HHS was 70 in the left hip and 80 in the right, whereas both the corresponding post-operative values were 100. The operating time for the left and right sides was 5 h 21 min and 6 h 28 min, respectively, whereas bloodloss was 340 mL and 220 mL, respectively, and elongation of the lower limbs 15 mm and 20 mm, respectively. Patient satisfaction scores for both hips corresponded to “well satisfied”.

### Case 5

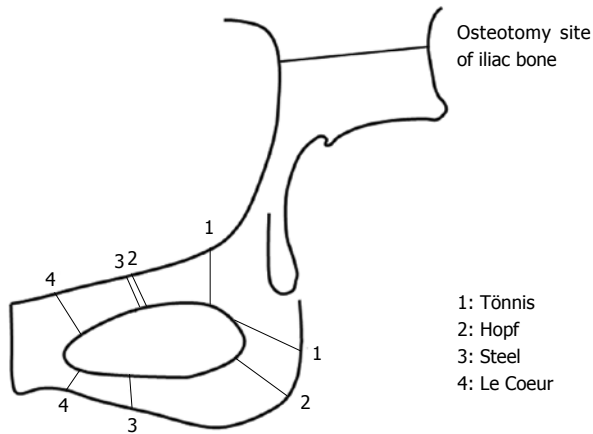
Patient at age at the time of surgery was 43 years and the follow-up period was 3 years (Figure 2C, D). Triple osteotomy was performed on the left hip. Pre-operative



**Figure 2** Anteroposterior X-ray images of cases 1, 2 and 5. A: Pre-operative anteroposterior (AP) X-ray images of cases 1 and 2 showing pre-osteoarthritis in a patient with bilateral developmental dysplasia of the hip (DDH); B: Post-operative AP X-ray image at the final follow-up examination. Three 3.0 mm K-wires were used for fixation of the acetabulum. One of the K-wire was remained at the right hip; C: Pre-operative AP X-ray image showing pre-osteoarthritis in a patient with bilateral DDH; D: Post-operative AP X-ray image at the final follow-up examination.

JOAS was 80 (30, 20, 10, 20), whereas post-operative JOAS was 88 (30, 18, 20, 20). HHS values before and after surgery were 93 and 96, respectively. The operating time was 4 h 22 min, whereas blood loss was 830 mL,





**Figure 3** Several major modifications of triple osteotomy have been presented, and osteotomy line of the Bernese osteotomy and rotational acetabular osteotomy was also presented. In Steel's triple osteotomy, the pubic ramus and ischium in front of the tuberosity are osteotomized. The site of the ischial and pubic osteotomy in the method of Tönnis is closer to the acetabulum compared with Steel's osteotomy. In a Hopf triple osteotomy, the ischial tuberosity is osteotomized closer to the center of the hip joint than in Steel's procedure. In a Le Coeur osteotomy, the pubis and ischial ramus are osteotomized closer to the pubic symphysis as compared with Steel's procedure.

and elongation of the lower limbs was 8 mm. The values for the CE angle, acetabular index, Sharp angle, and AHI improved from 16, 14, 47, and 70.5 to 26, 2, 35, and 80, respectively.

## THE HISTORY OF TRIPLE OSTEOTOMY

The first report of pelvic osteotomy as a treatment for DDH dates back to the classical report by König<sup>[17]</sup>. Long after this original report, Blavier *et al.*<sup>[18]</sup> reported a circular osteotomy used to rotate the acetabulum over the femoral head. The concept of rotating the acetabulum over the femoral head developed into triple pelvic osteotomy first described by Le Coeur in 1965<sup>[19]</sup>. Hopf further developed the ideas of pelvic osteotomy and reported double osteotomy and triple osteotomy in 1965 and 1966, respectively<sup>[20]</sup>. Steel further modified the triple osteotomy procedure for the easier surgical access to the ischium<sup>[21]</sup>.

Since then, a wide variety of studies on pelvic osteotomies for adult DDH have been reported, including the Chiari osteotomy<sup>[22-24]</sup>, RAO<sup>[3]</sup>, Bernese periacetabular osteotomy<sup>[2]</sup>, eccentric RAO<sup>[25]</sup>, curved periacetabular osteotomy<sup>[26]</sup>, and a modification of the Ganz osteotomy<sup>[2]</sup>. The surgical sites of a triple osteotomy are the ilium, ischium, and pubis. The procedure provides improved coverage of the acetabulum along with biomechanical stability to the hip equivalent to that of an RAO.

## MODIFICATION OF TRIPLE OSTEOTOMY

Steel's triple osteotomy reported in 1973 has probably been the most popular and has undergone substantial modifications (Figure 3). Tönnis invented a major modification of Steel's triple osteotomy<sup>[27]</sup>, in which the site of the ischial osteotomy, closer to the acetabulum than in Steel's osteotomy, is just adjacent to the hip joint, allow-

**Table 4** The advantages and demerits of triple osteotomy

Advantages	Demerits
Easier than Bernese osteotomy or RAO	Risk of non-union of pubis and ischium
Applicable regardless of whether the triradiate cartilage remains fused or not	Require the long period before weight bearing
Low risk	Difficulty and limitation of sufficient acetabular correction and femoral head medicalization
Osteonecrosis of acetabulum	Possibly narrowing the pelvic cavity for childbirth
Major vessel injury	
No shortening of lower limb	

RAO: Rotational acetabular osteotomy.

ing an easier rotation of the acetabulum. The contact area is superior to that of the Steel's osteotomy. Kotz's polygonal triple osteotomy was described<sup>[28-32]</sup>, in which the osteotomy lines of the innominate and ischial are polygonal, and the axis of rotation of the acetabulum is parallel to the superior pubic ramus. The rotated acetabulum is relatively stable and fixed with an internal fixation plate. Wall reported an endoscopic triple pelvic osteotomy in 2001<sup>[33]</sup>, whereas Lehman described an "almost" percutaneous triple pelvic osteotomy in 2004<sup>[34]</sup>. With those, a 2-incision surgical approach is employed and the iliac osteotomy is performed using a Gigli saw. They reported that their osteotomy method is safe and has a relatively shallow learning curve compared with other triple pelvic osteotomy procedures. Kumar *et al.*<sup>[8]</sup> also reported a modified triple osteotomy, which adds a shelf procedure to the triple osteotomy to achieve further stability of the hip joint and coverage of the femoral head.

A variety of devices have been invented to provide stability of the osteotomy site. Eren reported an "incomplete" triple pelvic osteotomy<sup>[35]</sup>, in which a greenstick fracture was created in the remaining portion of the ischial body without a total iliac osteotomy. This highly stable osteotomy allowed early weight bearing. In turn, Lipton reported a different modification of the triple osteotomy, in which a wedge osteotomy was performed at the proximal part of the ilium<sup>[36]</sup>. The resection of the wedge from the outer cortex created a slot, with the intact inner cortex serving as a stabilizing buttress where the distal posterior aspect of the ilium fits. This osteotomy allows for extensive coverage of the femoral head along with a greater stability.

We summarized the advantages and demerits of triple osteotomy in Table 4. After this paragraph, we in detail discussed these concerns point by point.

## DEGREE OF CORRECTION AND ACETABULAR RETROVERSION

A number of the previous studies on triple osteotomy have reported good improvement of the radiological indices (Figure 1). Janssen *et al.*<sup>[37]</sup> reported an increase of the CE angle<sup>[10]</sup> of 24.4° (10.2° → 34.6°)<sup>[37]</sup> and van Helmond *et al.*<sup>[38]</sup> revealed an increase of 19° in CE angle

( $9^{\circ} \rightarrow 28^{\circ}$ )<sup>[38]</sup>. de Kleuver *et al.*<sup>[39]</sup> reported a reduction of  $12^{\circ}$  in Sharp angle<sup>[12]</sup> ( $22^{\circ} \rightarrow 10^{\circ}$ )<sup>[39]</sup>. Peters *et al.*<sup>[11]</sup> revealed an increase of  $20^{\circ}$  in the CE angle ( $11^{\circ} \rightarrow 31^{\circ}$ ) and a reduction of  $11^{\circ}$  in Sharp ( $50^{\circ} \rightarrow 39^{\circ}$ ). Dora *et al.*<sup>[40]</sup> showed an increase of  $8.2^{\circ}$  in the CE angle ( $7.8^{\circ} \rightarrow 36^{\circ}$ ) and a decrease of  $15^{\circ}$  in the Sharp angle ( $46^{\circ} \rightarrow 31^{\circ}$ ). Tönnis *et al.*<sup>[15,16]</sup> reported an increase of  $27.8^{\circ}$  in the CE angle ( $-10^{\circ} \rightarrow 17.8^{\circ}$ ) and decrease of  $18^{\circ}$  in acetabular index angle<sup>[41]</sup> ( $36.7^{\circ} \rightarrow 18.5^{\circ}$ )<sup>[15,16]</sup>. In our case series, the degree of acetabular correction for CE angle, acetabular index angle, and Sharp angle was  $+19.8^{\circ}$ ,  $-15.4^{\circ}$ , and  $-17.3^{\circ}$ , respectively. In addition, Hailer *et al.*<sup>[42]</sup> reported that the median correction of lateralization in their study was approximately 0 mm. On the other hand, Dungal found 6 mm medialization in their young patients (average age 16.5 years)<sup>[6]</sup>. HLI in our series was 0.02; *i.e.*, no medialization of the femoral head was achieved.

Frick *et al.*<sup>[7]</sup> performed detailed analysis by 3-dimensional computed tomography and reported that the acetabular fragment moved in the directions of adduction, anterior rotation (extension), and external rotation, thus improving femoral head coverage. They also found that the surgical procedure increased external rotation of the acetabulum and an excessive external rotation was noted in 22% of all cases. Exaggerated external rotation of an osteotomized acetabulum increases the risk of non-union by producing gaps at the pubic and ischial osteotomy sites<sup>[28,43]</sup>. Wenger *et al.*<sup>[44]</sup> reported that a “figure-of-four” maneuver, often used to improve the mobility of osteotomized acetabulum, should not be employed to avoid excess external rotation of the acetabulum.

Tönnis *et al.*<sup>[45]</sup> reported a case of painful hip due to over-correction. Acetabular retroversion is a cause of hip pain<sup>[14,46]</sup> and Kim *et al.*<sup>[47]</sup> reported that retroversion of the acetabulum was likely to cause an early onset of coxarthrosis. Femoroacetabular impingement was first described as an anterior impingement after a Bernese periacetabular osteotomy by Myers *et al.*<sup>[48]</sup> in 1999. Dora *et al.*<sup>[40]</sup> also reported retroversion of the acetabulum after the Salter and triple osteotomy procedures, and found that a retroverted acetabulum was present in 27% of their cases, with an average angle of  $-15^{\circ}$ . A retroverted acetabulum was more frequent and pronounced after a triple osteotomy than after a Salter osteotomy, *i.e.*, 60% *vs* 24%, respectively. Acetabular retroversion may further predispose the patient to osteoarthritis<sup>[14,46]</sup>. de Kleuver *et al.*<sup>[49]</sup> reported that decreased coverage of the posterolateral quadrant of the femoral head would sacrifice walking ability and recommended not to overcorrect the acetabular rotation anteriorly only to improve anterior coverage.

## ELONGATION OF LOWER LIMBS

Vukasinovic *et al.*<sup>[5]</sup> reported that leg length may well influence patients' satisfaction. Hailer *et al.*<sup>[42]</sup> reported that the average gain of limb length was  $+0.5$  cm (0 to 4 cm). Dungal *et al.*<sup>[6]</sup> reported an average gain of  $+1.8$  cm, and speculated that the limb lengthening was due to a distal shift of the osteotomized acetabulum. In our cases, the

average gain of limb length was  $+1.2$  cm. In general, the length of the operated lower limb is increased following a triple osteotomy.

## RANGE OF MOTION

Dungal *et al.*<sup>[6]</sup> reported loss of hip flexion and internal rotation after a triple osteotomy. Hip flexion after the operation is restricted because of the anterolateral tilt of the acetabulum, and the internal rotation becomes restricted in a similar manner. Faciszewski *et al.*<sup>[50]</sup> studied 56 hips in their series, with an average age of 28 years and follow-up period of 7 years. They reported that patients had a slight decrease in hip internal rotation and abduction. A slight loss of ROM seems to be common in adults after a pelvic osteotomy because of lateral and external correction of the acetabulum. On the other hand, several authors have reported improvement in ROM. In a series of adult patients with mean age of 27.8 years, Kooijman *et al.*<sup>[51]</sup> found that a moderately restricted preoperative ROM improved to full ROM with 47/51 (92%) hips becoming pain free at 2 years after the operation. In adolescents with an average age of 13.9 years, Kumar *et al.*<sup>[8]</sup> reported that post-operative ROM in term of flexion and abduction recovered to the pre-operative ROM level with an average follow-up period of 6 years.

## REHABILITATION AFTER TRIPLE OSTEOTOMY

Steel described the detailed postoperative treatment of a series of patients aged 7-17 years<sup>[4]</sup>. A cast was maintained for a period of 8-10 wk, after which the K-wires were removed. Passive and active motion was started, and then weight bearing began with crutches at 12-14 wk. Tönnis *et al.*<sup>[15,16]</sup> reported that patients were immobilized in a long-leg spica cast for 6 wk and weight bearing was not allowed until sufficient consolidation of the osteotomy sites in the first series. The average age in their study was 19.8 years and 12-16 wk were needed before weight bearing began in adults. Weight bearing tended to be later, especially among those with osteoporosis or osteoarthritis.

Peters *et al.*<sup>[11]</sup> noted that patients (average age 26 years) were limited to toe touching for 8 wk, at which time partial weight bearing was allowed if AP radiographs showed adequate osseous healing. Hip ROM and muscle exercises were also begun at 8 wk and full weight bearing was achieved after 36 mo. Hailer *et al.*<sup>[42]</sup> reported that K-wires were routinely removed approximately 1 year after the operation, in patients whose average age was 23 years. Early mobilization on crutches without weight bearing was conducted for 6 wk and prophylaxis for deep venous thrombosis was performed until full weight bearing was achieved.

Janssen *et al.*<sup>[37]</sup> reported that weight bearing was not allowed for 12 wk in their patients (average 38.6 years). During the early postoperative rehabilitation, ROM exercises over the following limits was prohibited: (1) joint



movement only up to 30° for abduction and adduction; (2) no external rotation; and (3) maximum flexion of 60°. When radiographic evidence of consolidation appeared 6 wk after surgery, flexion up to 90° and abduction were permitted. Thrombosis prophylaxis with low-molecular weight heparin was administered for the entire period of limited weight bearing. Vukasinovic *et al.*<sup>[5]</sup> reported a young series (mean age 15.9 years), in which none of the patients were immobilized and post-operative skin traction was used in all for a mean period of 44.4 d. Rehabilitation began 8.8 d after surgery and weight bearing after 128.7 d. Eren *et al.*<sup>[35]</sup> described post-operative rehabilitation results after incomplete triple pelvic osteotomy procedures in patients with an average age of 21.4 years. They reported that partial weight bearing (10 kg) with crutches and active motion of the hip were started on post-operative day 3, and full weight bearing with crutches was allowed approximately 6-8 wk after surgery.

## FUNCTIONAL AND CLINICAL RATING

In Steel's original publication in 1973, the failure rate was 23% for 52 hips in 45 patients who were followed up from 2-10 years of age<sup>[4]</sup>. Furthermore, in 1977, Steel<sup>[21]</sup> reported the results of 175 hips in patients aged 6-35 years (70% aged 9-12 years) after a follow-up period of 3-13 years, which had an 86% success rate. de Kleuver *et al.*<sup>[39]</sup> and van Hellemond *et al.*<sup>[38]</sup> reported the long-term results (mean follow-up of 15 years) of the triple osteotomy procedure in patients (mean age of 28 years) with pre-operative osteoarthritis stage grade 0 or 1. They performed triple osteotomy procedures on 51 patients (5 males, 38 females), 88% of did not undergo total hip arthroplasty (THA) and 83% reported no pain. Furthermore, there was no progression of osteoarthritis in 65% of the patients, and 64% had either "excellent" or "good" clinical scores. They concluded that a significant negative factor for good long-term results was the presence of advanced osteoarthritis designated by a fair or poor pre-operative clinical score.

Peters *et al.*<sup>[11]</sup> found a significant relationship between osteotomy failure and pre-operative osteoarthritis. In their study (mean age: 26 years; mean follow-up duration: 9 years), 27% of the hips were classified as failures, out of which 20% needed to be converted to THA and 7% required THA. They concluded that a triple osteotomy is an alternative modality to THA, although the duration of the operation and postoperative treatment are much longer than that of THA. Dungal *et al.*<sup>[6]</sup> (mean age at operation 16.5 years, mean duration of follow-up 12.5 years) reported that the results of the osteotomy procedure were excellent in the majority of cases (76% of the cases). In 8 patients (5%) with unsatisfactory results after the operation, THA was performed, whereas another 8 patients (5%) were candidates for THA. Vukasinovic *et al.*<sup>[5]</sup> reported the occurrence of early osteoarthritis in 4 operated hips (5.3%), of which only 1 (1.3%) required an additional THA procedure 4.2 years later. von Bremen-Kühne *et al.*<sup>[52]</sup> reported a conversion rate to THA of 2.6%, whereas

van Hellemond *et al.*<sup>[38]</sup> had a conversion rate to THA of 11.7% after a mean follow-up period of 15 years. In general, long-term results of a triple osteotomy without osteoarthritis or with low-grade osteoarthritis are good<sup>[53]</sup>.

Janssen *et al.*<sup>[37]</sup> reported that a preoperative body mass index > 25 kg/m<sup>2</sup> and HHS < 70 resulted in a poor outcome or early conversion to a THA. They presented results of a triple osteotomy for only second-grade osteoarthritis (advanced stage) related to DDH (mean age at operation 38.6 years), with a long-term follow-up duration of 11.5 years. They concluded DDH even at an advanced stage can be treated with a triple osteotomy procedure.

## PATIENT SATISFACTION

Peters *et al.*<sup>[11]</sup> found that 98% of their patients would recommend the same procedure to other patients with similar symptoms. In contrast, Hailer *et al.*<sup>[42]</sup> reported that 65% were satisfied with the procedure, whereas 35% were not, and 2 patients underwent THA after 11 years. The incidence of complications such as non-union at the osteotomy site influenced patient satisfaction. Their analysis showed that the "not satisfied" group was significantly older ( $P = 0.005$ ) with significantly poorer clinical scores ( $P < 0.0005$ ). The incidence of non-union ( $P = 0.0017$ ) and that of other complications ( $P < 0.0005$ ) was also significantly higher in the same group. They concluded that the occurrence of complications had a grave impact on patient satisfaction.

## SURGICAL COMPLICATIONS

### Non-union

Steel<sup>[21]</sup> reported no incidence of non-union in their original article, whereas Tönnis reported that 1 patient developed pseudoarthrosis in the pubic ramus (3%, 1/32)<sup>[41]</sup> and Vukasinovic *et al.*<sup>[5]</sup> noted that 9.2% (7/76) experienced non-union. In the latter study, there was 1 (1.3%) case with triple non-unions of the ilium, pubis, and ischium, and 6 (7.9%) with double non-unions of pubis and ischium. However, all non-unions were asymptomatic and did not require an additional procedure. They also reported that non-union occurred more frequently when a saw was used (4/12) compared with when a chisel was used (2/64) ( $P = 0.003$ ), suggesting that non-union may occur because of soft tissue interposition secondary to extensive bone resections. There was no statistically significant difference either between cases with 2 and 3 K-wire fixation, or among the levels of the osteotomy. On the other hand, non-unions tended to occur significantly more often in older patients; the average age in the non-union group was  $20.2 \pm 27.12$  years, whereas that in the union group was  $15.5 \pm 4.67$  years old ( $P = 0.029$ )<sup>[5]</sup>.

Kirschner *et al.*<sup>[54]</sup> presented 7 cases of pubis and ischium non-union in a series of 48 patients (14.6%). In turn, Dungal *et al.*<sup>[6]</sup> reported non-union in 19 of 329 patients (5.4%), of whom 2 patients were triple non-union cases and 2 patients double non-union cases. All triple

non-union cases required osteosynthesis and bone grafting, whereas the double non-union cases also needed surgical intervention. Isolated non-union was seen in 15 patients (ischium 8, pubis 7). The most frequent site was the ischium, but isolated non-union was not considered to be indicative for re-operation. van Hellemond *et al.*<sup>[38]</sup> reported isolated non-union of the ischium in 3 patients out of 48 (6.25%) as well as an isolated non-union of the pubis in 1 patient out of 48 (2%). Their mean age at operation was 28 years. Their pre-operative grades for osteoarthritis were 0 and 1, and the non-union cases occurred in those with major acetabular correction. Peters *et al.*<sup>[1]</sup> reported double non-union of the ilium in 2 patients out of 60 (3.3%), with a mean age at operation was 26 years and mean duration of follow-up was 9 years.

In 2003, Tschanner *et al.*<sup>[55]</sup> reported cases of “painful non-union” after a triple osteotomy, and the mean age at operation of the patients was 25.7 years where as the mean duration of follow-up was 7.1 years. Their triple osteotomy utilized the Tönnis method with AO screw fixation. Partial weight bearing was permitted after 8 wk and full weight bearing after 16 wk. Isolated pseudoarthrosis of the pubis was seen in 8 patients (2%), though all were asymptomatic and no further surgical treatment was required. Five patients (1.2%) developed double pseudoarthrosis with non-union of the pubis and ischium, all of whom were symptomatic and required another operation including bone grafting, fixation, and excision at a mean duration of 19.4 mo after osteotomy. On the basis of their investigation of 409 triple osteotomies, they provided the following recommendation: (1) adequate bony contact should be ensured at all 3 osteotomy sites; (2) 2 or 3 screws should be used for the iliac osteotomy; (3) a long mediolateral screw should be used to stabilize the pubic osteotomy until union; (4) patients should not sit on the ipsilateral ischial tuberosity for 6 wk; and (5) patients should be informed that smoking is a risk factor for non-union. In general, the non-union rate seems to be approximately 7%.

### Acetabular osteonecrosis

Tönnis reported no acetabular osteonecrosis in the first series<sup>[21]</sup>, and van Hellemond *et al.*<sup>[38]</sup> later confirmed the absence of osteonecrosis. Few articles have provided details of acetabular osteonecrosis and, to the best of our knowledge, there are no reports of that complication in association with a triple osteotomy.

### Infection

Steel reported 1 case of infection (2.2%) in their initial article<sup>[14]</sup>, whereas Tönnis *et al.*<sup>[15]</sup> and Dungal *et al.*<sup>[6]</sup> reported none. Furthermore, Van Hellemond *et al.* reported superficial infections in 2 (4.2%) and deep infections in 1 (2.1%) out of 48 cases<sup>[11]</sup>. The prevalence of infection reported by Vukasinovic *et al.*<sup>[5]</sup>, Peters *et al.*<sup>[1]</sup>, and Hailer *et al.*<sup>[42]</sup> was 1.3% (1/76), 3.3% (2/61), and 3.3% (2/61), respectively. In general, the rate of infection seems to be approximately 2.7%.

### Nerve injury

Tönnis *et al.*<sup>[15]</sup> reported that 1 patient in their series developed transient peroneal nerve palsy<sup>[15]</sup>, whereas Vukasinovic *et al.*<sup>[5]</sup> reported 2 peroneal nerve palsy cases (2/76 patients, 2.6%). Dungal *et al.*<sup>[6]</sup> reported no serious neurovascular complications in their 329 patients. However, in 9% of those cases, loss of sensation in the region supplied by LFCN became permanent. Peters *et al.*<sup>[1]</sup> also reported temporary irritation of LFCN in 6 of 32 cases (19%), and van Hellemond *et al.*<sup>[38]</sup> noted LFCN dysfunction in 9 (19%) and transient palsy of the sciatic nerve in 1 (2%) of 48 cases. In addition, Hailer *et al.*<sup>[42]</sup> reported temporary sciatic nerve palsy in 2 of 61 patients (3.3%). In general, the nerve injury rate seems to be approximately 9.5%. Some authors found that a dorsal approach to the ischium has a higher level of safety as compared with an anterior approach<sup>[15,56,57]</sup>.

### Vascular injury

Few studies have investigated vascular injury in detail. Dungal *et al.*<sup>[6]</sup> reported no neurovascular complications in their 329 patients, whereas Hailer *et al.*<sup>[42]</sup> reported excessive bleeding from a branch of the internal iliac artery leading to discontinuation of a triple osteotomy in 1 case.

### Other complications

In their initial article, Steel<sup>[21]</sup> reported that paralytic ileus occurred in 2 of 45 patients (4.4%) as an immediate postoperative complication, whereas skin necrosis appeared in 2 patients (4.4%). Janssen *et al.*<sup>[37]</sup> reported 1 case of external snapping hip syndrome in their 32 patients (3%). Hailer *et al.*<sup>[42]</sup> noted 1 patient with a large hematoma (1.6%), 2 with heterotopic ossification (3.3%), 1 with complete insufficiency of the gluteal muscles (1.6%), and 1 with osteonecrosis of the femoral head (1.6%), though no other details were reported<sup>[39]</sup>.

It is also important to discuss the procedure in relation to childbirth. Winklemann in 1984 observed narrowing of the birth canal after a triple osteotomy performed according to the method of Steel and Tönnis in the middle part of the pelvic cavity. That study recommended a caesarian section in all cases after a triple osteotomy<sup>[58]</sup>. In those cases, 95 (32%) became pregnant and 40% of those gave birth naturally, with 60% undergoing a Caesarian section. Lord *et al.*<sup>[59]</sup> reported that Salter, Sutherland, and Steel osteotomies all narrowed both the inlet and outlet of the pelvis. Female patients should be informed of these alterations and the possibility of a caesarian section for future pregnancies.

## ADVANTAGES AND DEMERITS OF TRIPLE OSTEOTOMY

We summarized the advantages and demerits of triple osteotomy in Table 4. A biomechanical analysis performed by Hsin *et al.*<sup>[60]</sup> revealed significantly smaller stress on the hip after a triple osteotomy and at the time of the latest

follow-up examination than that estimated after surgery. The decrease in stress was a direct result of a significant increase in the area of the weight-bearing surface of the hip. On the other hand, Huang *et al*<sup>[9]</sup> reported that patients who underwent an RAO were characterized by a better acetabular index angle than patients who underwent a triple osteotomy. However, the functional outcome based on HHS was better after a triple osteotomy than after an RAO, and patients who had a triple osteotomy tended to express better subjective scores.

Aminian *et al*<sup>[61]</sup> reported the freedom of the acetabular fragment on flexion (anterior femoral head coverage), abduction (lateral femoral coverage), and external rotation (acetabular retroversion) in several osteotomies using fresh-frozen male cadavers. Freedom of the acetabular fragment was evaluated with a Ganz osteotomy, Tönnis triple osteotomy, and Carliz *et al*<sup>[62]</sup> triple osteotomy in the same article. The results revealed that maximum motion was achieved with the Ganz osteotomy, while “coupled motion” (external rotation during abduction) was most prominent with the Carliz technique, and no coupled motion was seen with a Tönnis osteotomy. They considered the Tönnis osteotomy to be the safest and optimal for moving the acetabular fragment to improve abduction and flexion, such as the 20-20 rule.

## CONCLUSION

In the present study, we present a detailed review of the relevant literature. We found that the clinical results of a triple osteotomy were satisfactory and it should be considered as an alternative candidate procedure for a pelvic osteotomy in older adults with DDH.

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## Anterior cruciate ligament reconstruction best practice: A review of graft choice

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**Core tip:** There is no "ideal" graft to be used in anterior cruciate ligament reconstruction surgery and each of the four major graft choices has its advantages and disadvantages. Success or failure of the procedure depends heavily on surgical technique. Surgeons should be aware of the evidence behind the use of each graft and thus be able to make an informed decision of its appropriateness.

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### Abstract

There is much literature about differing grafts used in anterior cruciate ligament (ACL) reconstruction. Much of this is of poor quality and of a low evidence base. We review and summarise the literature looking at the four main classes of grafts used in ACL reconstruction; bone-patella tendon-bone, hamstrings, allograft and synthetic grafts. Each graft has the evidence for its use reviewed and then compared, where possible, to the others. We conclude that although there is no clear "best" graft, there are clear differences between the differing graft choices. Surgeon's need to be aware of the evidence behind these differences, in order to have appropriate discussions with their patients, so as to come to an informed choice of graft type to best suit each individual patient and their requirements.

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### INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction is a common operation<sup>[1]</sup>. The aim of surgery is to restore functional stability to the ACL deficient knee. The functional stability provided by the normal ACL is both in resisting anteroposterior translation as well as rotational subluxation. ACL reconstruction can be performed using a variety of different surgical techniques as well as different graft materials.

The choice of whether to operate or not is multifactorial and is highly dependent on patient's degree of symptoms and requirements in terms of activity level and participation in pivoting sports<sup>[2]</sup>. Many patients can become asymptomatic following a course of proprioceptive rehabilitation<sup>[3]</sup>. Timing of any ACL reconstruction is also crucial, it is commonplace to allow the acutely injured knee to settle, giving time for resolution of effu-

sion, restoration of range of motion and recovery from of concomitant ligamentous injuries<sup>[4]</sup>. Furthermore a delayed reconstruction allows patients to trial conservative therapy to see if surgery is indicated.

The three categories of commonly used grafts are autograft, allograft and synthetic graft<sup>[5]</sup>. Autografts usually consist of either hamstrings tendons (HS) or Bone-patella tendon-bone (BPTB). Allografts are varied but can consist of tibialis posterior tendon, Achilles tendon, tibialis anterior tendon, BPTB and peroneus longus tendon<sup>[6,7]</sup>. Synthetic grafts have been developed over the years and are currently on their “third generation” but have encountered considerable problems in the past<sup>[8-11]</sup>. Currently the most widely accepted synthetics are the Ligament Augmentation Reconstruction System (LARS; Corin, Gloucestershire, England) and the Leeds Keio (Xiros plc, Neoligaments, Leeds, United Kingdom) however their use remains somewhat controversial<sup>[12-15]</sup>.

The surgical technique used during ACL reconstruction varies widely not only from country to country but even within departments of the same hospital. Different techniques include arthroscopic *vs* open surgery, intra *vs* extra-articular reconstruction, femoral tunnel placement, number of graft strands, single *vs* double bundle and fixation method<sup>[16-20]</sup>. This heterogeneity of techniques makes comparison of graft choice difficult.

The choice of which graft and which technique to use are often dictated to the surgeon by the patient's anatomy, previous surgical history, concomitant injuries as well as patient choice. Surgeon's choice is dictated by a combination of factors including perceived functional outcome, rehabilitation speed, graft incorporation, graft availability and donor site morbidity. Surgical familiarity also dictates which technique is used as well as the graft choice.

Much research has been done in trying to identify which particular graft or technique is best. Some of this research has been of good quality including meta-analyses, systematic reviews and randomised controlled trials (RCT). Yet, there continues to be wide variation in the choices made by surgeons. Long-term outcomes are not immediately available for newer techniques which fuels further debate.

Our aim is to bring together current literature in order to allow surgeons to make decisions based on current evidence.

## DISCUSSION

The question of how best to assess results has been recently addressed by a review from the Dutch Orthopaedic Association. They recommended the use of a combination of physical examination using Lachman, pivot shift and anterior drawer tests, level 1 evidence, together with the following outcome scores-International Knee Documentation Committee Subjective Knee Evaluation Form Score (IKDC), Knee Injury and Osteoarthritis Outcome Score (KOOS) or Tegner Score from level 2 evidence<sup>[21]</sup>.

## Graft choice

**Hamstring tendon grafts:** Hamstring tendons are one of the more commonly used grafts for ACL reconstruction since Lipscombe in 1982 and arthroscopically assisted four stranded grafts by Friedman in 1988. The semi-tendinosus tendon with or without the gracilis tendon is harvested, typically from the ipsilateral leg. The resultant tissue is fashioned into a four strand graft which is then used to reconstruct the ACL as per the surgeon's favoured technique. It is common for the tendons to be folded over each other in order to increase the thickness of the donor graft. In order for the folded tendons to act as one unit they are sutured together using a whipstitch technique. The donor graft is then fed through the tibial tunnel and into the femoral tunnel and secured using a variety of fixation methods including screws, suspensory apparatus and transfixion devices which may be metallic, polymer or bio-absorbable.

Morbidity specifically associated with HS grafts include decreased knee flexion strength and tibial rotation although these do not usually translate into noticeable deficits in patients<sup>[22]</sup>. Other complications include sciatic or saphenous nerve damage, although again this is rare and may resolve with time<sup>[23]</sup>.

The long term follow-up results of HS grafts are sparse and many studies use differing outcomes to report success and/or failure. Recently the 14 year results of 74 patients with HS graft reconstruction were reported by Leiter *et al*<sup>[24]</sup> looking at patient outcome scores as well as re-rupture rates. They used the IKDC Score and found that 75% of patients scored normal or nearly normal, however radiographic changes of Kellgren-Lawrence grade 3 were 19% in operated knees compared to 4% in the contralateral knee, this finding reached significance even after controlling for medial meniscal surgery. They found re-rupture rates of the reconstructed ligament at 9% compared to contralateral ACL ruptures at 5%. Other studies of HS tendons with similar follow-up are uncommon. Leys *et al*<sup>[25]</sup> reported results from a cohort study with 15 years follow-up comparing HS to BPTB. In the HS arm they had 15 year results on 51 patients. Re-rupture rates were 17% in the HS group and 12% in the contralateral knee. Re-ruptures were more common in men, patients with non-ideal tunnel position. Mean IKDC Subjective symptom scores were 90 (out of 100) and mean functional scores 9.1 (out of 10). Shorter term studies but with larger study group sizes are available. Streich *et al*<sup>[26]</sup> reported a single blinded evaluation of 40 patients with 4 strand HS grafts at 10 year follow-up. They report 8% re-rupture rate and an IKDC score of 90.3 and all joints were either grade A or B (normal or nearly-normal). Asik *et al*<sup>[27]</sup> reported the results of 271 patients with 4 strand HS grafts fixed using a transfix pin. Their follow-up length was a mean of 6.8 years and 86% scored normal or nearly normal on IKDC score. Re-rupture occurred in 1.5% of patients in this shorter follow-up study. Maletis *et al*<sup>[6]</sup> reported retrospectively from the prospective Kaiser Permanente ACL Recon-



struction Registry revision rates after HS grafts in 3012 patients was 1.56% (1.1% revision rate per 100 years of observation), however follow-up was short at a mean of 1.5 years. No assessment of patient outcome/satisfaction was performed.

**BPTB grafts:** BPTB grafts for ACL reconstruction have been around since the pioneering work of Franke in 1969 and are still very popular in certain countries and in specific patients. BTPB has historically been considered the gold standard for ACL reconstruction. The method of harvest includes a horizontal or longitudinal skin incision followed by resection of the mid-portion of the patella (inferior pole) and tibial tuberosity with the intervening tendon as a complete unit. Thus the graft has bone block at both ends which allows potentially superior integration of the graft into the tibial and femoral tunnels. The graft is then detached and fed through the tibial tunnel into the femur in the same way as a hamstrings graft. Fixation can take place using a variety of different methods ranging from an interference fit with no fixation device to screw or suspensory fixation<sup>[28]</sup>.

There are many reports of the morbidity and complication associated with BTPB grafts. Complications include patella tendon rupture, patella/tibial fracture, quadriceps weakness, loss of full extension, anterior knee pain and difficulty kneeling<sup>[29,30]</sup>. Typically the cosmetic result is inferior to hamstrings harvest which may be of concern for some patient groups.

Long term results after BTPB graft reconstructions have been studied by many authors. Mihelic *et al*<sup>[31]</sup> retrospectively studied outcome of 33 operated BTPB grafts with 17 to 20 year follow-up with 83% of patients having stable knees with normal or near normal IKDC grades and an IKDC score of 83.15, they do not however report re-rupture rates. Gerhard *et al*<sup>[32]</sup> report 16 year mean follow-up of 63 patients after BTPB ACL reconstruction with 84% returning to previous sporting levels with 78% normal or near normal IKDC grades and a KOOS score of 84. Nineteen percent of patients had radiographic evidence of moderate to severe osteoarthritic changes, worse with meniscal injury at the time of ACL reconstruction. One point six percent of patients needed revision ACL reconstruction but a total of 33% needed further knee surgery during follow-up. Leys *et al*<sup>[25]</sup> who compared HS to BTPB showed in the BTPB arm of their study that there was no significant difference to HS in overall IKDC grade, whereas radiographic evidence of osteoarthritis was significantly more common in BPTB. Ahn *et al*<sup>[33]</sup> looked at 117 patients with mean 10.3 year follow-up after BTPB reconstruction and showed 90.6% normal or nearly normal IKDC subjective scores. Re-rupture rates were 5.1% and all were reported after additional injury. They did also report other complications including arthrofibrosis, limited range of motion, synovitis and patella fracture. Ninety-four point eight percent of patients complained of pain when kneeling on soft ground and 61.5% complained of knee pain on walking. Pernin *et al* reviewed 24.5 year data on 100 patients after

a combination of BTPB reconstruction with lateral extra-articular augmentation with iliotibial band. IKDC subjective scores at final follow-up were 74.7, however overall only 46% had IKDC grades A or B. They report 19.5% clinical failures of which 72.2% had a meniscal injury at the time of first operation. It is important to note that they acknowledge a drop-out rate of 75% from initial enrolment which may bring a large bias into the results. Maletis *et al*<sup>[6]</sup> reported from 2791 BTPB autograft patients a revision rate of 1.18% at 1.5 years (or 0.66% per 100 years observation) which was favourable in comparison to both HS and Allograft.

**Allografts:** Donor site morbidity particularly in BTPB grafts has led to the search for alternatives. Also in the case of revision surgery where autograft options have already been exhausted an alternative graft choice may be required. The use of allograft is appealing particularly to the complete lack of donor site morbidity, reasonably good availability and a range of graft sizes with the options of bone blocks attached to the graft. Allograft material does come with its own unique risks including risk of an immunogenic reaction or disease transmission and is an expensive option when compared to autograft which costs nothing in monetary terms.

The most commonly used allograft tendons are tibialis posterior/anterior and Achilles tendon allografts however patellar tendon and HS are also widely available in some countries. Sterilisation has been an issue for allografts and older studies often used high dose irradiation or ethylene glycol which led to structurally inferior grafts. Cost availability, variability in graft tissue and storage are all important issues with allograft.

Long term results are not readily available yet, however, Almqvist *et al*<sup>[34]</sup> report 10.5 year follow-up of 50 patients with a mean IKDC score of 97. Graft failure rate was quoted at 5.45% and all were due to new significant knee trauma. Edgar *et al*<sup>[35]</sup> compared 47 patients after allograft ACL reconstruction with autograft with 48 mo average follow-up. They reported IKDC grades A or B in 82.6% of patients with subjective scores of 86.8%, which were similar to autograft. They reported a revision rate of 4.3% for allograft reconstructions. Kleipool *et al*<sup>[36]</sup> again compared small numbers 26 autograft *vs* 36 BPTB with 46 mo follow-up and reported 85% IKDC grade A or B compared to 70% in the autograft group, however, these results were not statistically significant. Foster *et al*<sup>[37]</sup> performed a systematic review of allograft *vs* autograft and found little difference between the two and reported pooled results of 82.9% IKDC grades A or B (compared to 87.2% for autograft). They also pooled failures and showed a graft failure rate of 8.2 per 100 reconstructions which performed poorly compared to 4.7 per 100 reconstructions for autograft. However none of these trends reached statistical significance. Siebold *et al*<sup>[38]</sup> compared two different allografts in ACL reconstruction, fresh frozen patella tendon *vs* Achilles tendon. In total they evaluated 251 patients with a mean follow-up of 37.7 mo. IKDC grades were normal or nearly normal

in 75.3% and 76.2% of patients undergoing patella and Achilles allografts respectively. Whilst this was not significant there was a significant difference in re-rupture with 10.4% of patella grafts re-rupturing compared to 4.8% of Achilles grafts. They do further note that these rates were high in comparison to autograft studies with similar length follow-up. In the recent study by Maletis *et al*<sup>[6]</sup>, they included 4014 allograft patients and reported a re-rupture rate of 1.74% for allograft (1.23% per 100 observation years). A ready supply of allograft tissue requires a well co-ordinated and reliable human tissue bank with a consistent tissue cleaning and decontamination processes. The cost of providing this is typically high and is limited to the most developed healthcare systems.

**Synthetic grafts:** The concerns over both autograft and allograft have led to the development of synthetic alternatives which ideally have no risk of donor site morbidity but also lack the risks associated with allograft of possible disease transmission, can be widely available with a long shelf life and simple storage and inventory arrangements. Synthetic ligaments are now into their third generation. First generation ligaments were knitted, woven or braided. These early ligaments were subject to early breakage and tended to elongate. Second generation ligaments had additional longitudinal and transverse fibres woven into the braid or knit. The materials also advanced to use Polyethylene Terephthalate or Dacron to act as a permanent replacement and allow fibroblastic ingrowth. These ligaments also suffered with wear, fraying and low abrasion resistance. Both first and second-generation synthetics were plagued with problems related to wear debris and subsequent catastrophic synovitis. This led of large cohorts of patients with problematic knees and a general aversion to the use of synthetics for ACL reconstruction in the soft tissue knee surgery community. Third generation ligaments such as the LARS are similarly constructed of Polyethylene Terephthalate, however, they are now designed to specific indications. The ACL replacement has a knitted extra-articular portion with free longitudinal fibres which resist elongation but without any braids to cause intra-articular wear and the generation of biologically active wear debris.

The latest generation of synthetics have different indications from conventional graft choices. The design rationale is that the synthetic is used to augment the healing of a freshly injured ACL. Surgery should take place as soon as possible aft the acute injury and every effort must be made to preserve the native ACL stump and draw the stump up to its femoral attachment using the synthetic to then protect the graft whilst tissue ingrowth and healing occur. Thus the synthetic is used as an augmentation device alongside biological tissue, not as a substitute graft in isolation.

As well as availability, convenience, lack of disease transmission risk and cost, the other advantage of synthetic graft reconstruction is the potential for dramatically accelerated rehabilitation with return to sport significantly earlier than for autograft and allograft. This is because

biological grafts require prolonged period (probably at least one year) for incorporation of the graft tissue into the host bone.

The results of first and second generation ligaments are not applicable to third generation ligaments due to the substantial re-design. A large scale systematic review was performed by Newman *et al*<sup>[39]</sup> which led to only 9 out of 156 articles being included. This study looked at data from 675 LARS ACL reconstructions and found an overall failure rate of 2.5% of which many of these were reported to be associated with technical errors in tunnel placement. Synovitis, which had plagued earlier synthetic grafts only occurred in only one patient in the included studies. This data suggests the third generation of synthetics have largely solved the problems of synovitis that led to the disrepute of the first and second generation. Dericks<sup>[40]</sup> described his experience of 220 patients reported 3 infections (1.4%) and 9 ligament ruptures (4.1%) with 83% of patients returning to full sports by 6 mo (and 61% by as early as 4 mo). The largest published study of LARS ACL reconstructions is by Gao *et al*<sup>[41]</sup> who retrospectively report on 159 reconstructions. They describe 94% of patients achieving IKDC grade A or B at a mean of 50 mo follow-up. All patients achieved return to sports by 6 mo with a re-rupture rate of only 1.9%. Nau *et al*<sup>[42]</sup> report the 24 mo results of a randomised controlled trial comparing BTPB and LARS ACL reconstruction in 27 and 26 patients respectively. They found no significant differences at final follow-up in the results of either graft with respect to IKDC, KOOS or Tegner scores. They also did not report and ruptures but did list patients lost to follow-up and other complications, with no significant difference. The only difference that they reported is a trend to earlier return to sport in the LARS group possibly allowing a faster rehabilitation protocol. Pan *et al*<sup>[43]</sup> report retrospective follow-up of a minimum of 4 years in 32 LARS reconstructions and compare these to 30 BPTB reconstructions. IKDC grades and Tegner scores were similar in both groups, the LARS group had A or B grading in 87.5% and a score of 6.16 respectively. No ruptures were reported in either group.

## COMPARATIVE STUDIES

There are numerous studies that have compared BPTB grafts to HS grafts for ACL reconstruction. Many of these studies are well summarised by Li *et al*<sup>[44]</sup> in their recent systematic review of the available RCT. After using thorough methods of identifying and processing available data they identified 9 RCTs with useable outcome data. They performed meta-analysis of data where available and showed significant differences between the outcome of BPTB and HS grafts in respect to pivot shift (RR = 0.87 in favour of BPTB), anterior knee pain (RR = 0.66 in favour of HS), kneeling pain (RR = 0.49 in favour of HS) and extension loss (RR = 0.63 in favour of HS). Graft failure was slightly more common in the HS group, however this did not reach significance (RR = 1.37, *P* = 0.38). IKDC scores pooled from the available data

showed normal or nearly normal results in 206/266 HS reconstructions and 169/225 BPTB reconstructions ( $P = 0.41$ ). Interestingly they concluded from this data that HS grafts restore knee joint function in a similar fashion to BTPB, however they comment that they were inferior with respect to restoration of stability.

In the multicentre study of 9817 patients by Maletis *et al*<sup>[6]</sup> they compared revision rate only and found a tendency to increasing revision rates from BPTB to HS to Allograft (1.18%, 1.56% and 1.74% respectively) with 2.7 year survival rates of 98.0%, 96.9% and 96.0% respectively. The other significant findings were increasing revision rates of 3.02 comparing Allograft to BPTB, and 1.82 comparing HS to BPTB grafts. Interestingly there was a 2.26 increased risk of revision in females with HS grafts compared to BPTB which was not reproduced in men. They also reported a protective effect of age of 7% per year which may well be an activity related phenomenon. The data they used to analyse was only related to crude failure and revision rates and no information was given on functional outcome.

The largest comparative study of LARS *vs* HS grafts, Liu *et al*<sup>[45]</sup> retrospectively compared 28 LARS and 32 HS grafts and found no significant differences between the two except in KT-1000 examination results showing the LARS to be more stable (1.2 mm *vs* 2.4 mm). However there were no differences in IKDC or revision rates. Similarly when comparing LARS to BTPB Pan *et al*<sup>[43]</sup> found no significant differences in functional outcome or examination findings between the two groups (30 BPTB and 32 LARS). In a large RCT of HS *vs* fresh frozen allograft with 7.8 year follow-up Sun *et al*<sup>[46]</sup> showed that apart from a shorter operative time for allograft procedures they showed no significant differences between the groups and both had similar outcome scores (IKDC 90 Allograft *vs* 89 Autograft). Interestingly they reported no ruptures and no complications apart from two superficial wound infections in the allograft group.

Several studies have investigated the relationship between muscle strength and isokinetic measurements after ACL reconstruction. In a series of patients by Condouret *et al*<sup>[47]</sup>, the outcome of quadriceps and hamstring strength based on the type of graft used (BoB *vs* hamstrings), was evaluated. The review of 127 patients included isokinetic muscle tests, concentric and eccentric extensors/flexors but also internal rotators/external rotators with analysis of mean work and mean power. In their series, the average muscles deficit at two years was 10% for the flexors and extensors. The type of reconstruction (patellar tendon *vs* hamstrings) had an influence on the muscle deficit. For extensors, the recovery was the same in the two groups. For flexors, residual deficits were significantly higher in the hamstrings group on the three studied parameters whatever the speed and the type of contraction (concentric or eccentric) with an average deficit of 14% to 18%, while, in the patellar tendon group, there was a dominance over the opposite side of 2% to 3% in concentric contraction. For internal rotators, a significantly higher deficit is observed in eccentric contraction for the

hamstrings group. The residual hamstrings deficits were related to the number of tendons harvested: -7% when there was no harvest, 7% with one tendon harvested and 17% with two tendons harvested.

A systematic review by Dauty *et al*<sup>[48]</sup> reporting on isokinetic results following ACL reconstruction included 53 studies; 29 reported isokinetic results after ACL reconstruction with patellar tendon graft, 15 reported isokinetic results after ACL reconstruction with hamstring graft, and 9 studies compared the two surgical procedures. Comparing the two graft choices, they found that BOB *vs* hamstring resulted in a larger knee extensor deficit but less knee flexion weakness for up to two years. They found no difference in isokinetic parameters between the two groups. These findings are supported by another metaanalysis conducted by Xergia *et al*<sup>[49]</sup>.

## CONCLUSION

All the different types of grafts used in current everyday practice for the reconstruction of a ruptured ACL have a place in this complex field of surgery. There are good data to support all of them. There is no clear “best” graft to use. However there are some clear advantages with respect to the different grafts. Donor site morbidity has been a problem for the BTPB graft, however it appears to have consistently good results particularly with respect to graft stability and return to high level sports. HS grafts appear to be a good all-round graft choice with fewer donor site complications and good results, both sources of autograft are readily available in most patients and cost nothing, but do have some technical demands for safe and efficient harvest. Allograft generally has slightly poorer results in terms of re-rupture rates, however can be invaluable in certain patient groups, particularly those with multi-ligament deficiencies or in the revision scenario. Allografts are expensive, but save time and undoubtedly remove one of the more technically demanding stages of ACL reconstruction surgery. They remove the potential for donor site morbidity but do not permit faster return to sport. Synthetic grafts are slowly regaining popularity as these too show good general results with no donor site morbidity and the ability to perform multi-ligament reconstructions without compromising the patella or hamstrings. They offer an off the shelf solution which shortens operative time and renders the surgical procedure is somewhat less complex and no graft harvest is required however the surgery is technically different, and should ideally be performed on a different time scale from conventional ACL surgery. Graft choice, therefore, needs to be made after an educated discussion with the patient regarding their requirements and expectations with regards to donor morbidity and speed of rehabilitation as well as the surgeon's personal experience and the surgical units experience and access to graft options. Certainly there is no one-size-fits-all graft yet, however, surgeons should offer the differing graft options and inform their patients of the differences as well as their own personal results with each graft suggested.



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## Use of demineralized bone matrix in spinal fusion

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### Abstract

Spinal fusion remains the gold-standard treatment for several pathological spine conditions. Although, autologous Iliac Crest Bone Grafting is considered the gold-standard graft choice to promote spinal fusion; however, it is associated with significant donor site morbidity and a limited graft quantity. Therefore, several bone graft alternatives have been developed, to augment arthrodesis. The purpose of this review is to present the results of clinical studies concerning the use of demineralized bone matrix (DBM), alone or as a composite graft, in the spinal fusion. A critical review of the English-language literature was conducted on Pubmed, using key word "demineralized bone matrix", "DBM", "spinal fusion", and "scoliosis". Results had been restricted to clinical studies. The majority of clinical trials demonstrate satisfactory fusion rates when DBM is employed as a graft extender or a graft enhancer.

Limited number of prospective randomized controlled trials (4 studies), have been performed comparing DBM to autologous iliac crest bone graft in spine fusion. The majority of the clinical trials demonstrate comparable efficacy of DBM when it used as a graft extender in combination with autograft, but there is no clinical evidence to support its use as a standalone graft material. Additionally, high level of evidence studies are required, in order to optimize and clarify the indications of its use and the appropriate patient population that will benefit from DBM in spine arthrodesis.

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**Key words:** Bone grafts; Demineralized bone matrix; Spinal fusion; Scoliosis

**Core tip:** It is widely accepted that autologous iliac crest bone graft (ICBG) is considered the gold-standard for spinal fusion surgery, although it is associated with a series of complications and a morbidity rate. Demineralized bone matrix (DBM) could be successfully used as a potential graft extender, enhancer or substitute. Spinal surgeons can take advance of DBMs osteoinductivity and osteoconductivity and achieve good results in spinal fusion, with a significantly lower complication rate and results similar to these of ICBG. The most significant drawbacks to DBM may be the difference between and within products so, it is important the surgeon to remain updated of the product properties to optimize the successful use of DBM, and the fact that it is not useful as a structural graft material because of its amorphous consistency, so it has to be used in combination with other type of grafts or scaffolds increasing the cost.

Tilkeridis K, Touzopoulos P, Ververidis A, Christodoulou S, Kazakos K, Drosos GI. Use of demineralized bone matrix in spinal fusion. *World J Orthop* 2014; 5(1): 30-37 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v5/i1/30.htm> DOI: <http://dx.doi.org/10.5312/wjo.v5.i1.30>

## INTRODUCTION

Spinal fusion remains the gold-standard treatment for several pathological spine conditions, such as; spine trauma, tumors, degenerative disorders, and discogenic back pain. It is estimated that the number of spinal fusions performed in the United States, could be greater than 200000 per annum, with the majority of these being lumbar fusions<sup>[1,2]</sup>. Although spinal fusion is a widely accepted successful procedure, offering acceptable clinical results, pseudarthrosis following spine surgery remains a major clinical challenge. Rates of pseudarthrosis have been reported to be as high as 48% in posterolateral inter-transverse process lumbar fusions<sup>[3]</sup>, with an increasing risk in multi-level fusions.

The high rate of non-union necessitates the use of various bone graft materials and substitutes, ceramics, and augmentation with growth factors such as bone morphogenetic protein-2 (BMP-2). It is widely accepted that autologous iliac crest bone graft (ICBG) is considered the gold-standard for spinal fusion surgery<sup>[4-7]</sup>.

ICBG demonstrates a reliably high fusion rate, and additionally, being autologous, does not carry the risk of rejection or disease transmission<sup>[8]</sup>.

However, harvesting bone from the iliac crest is associated with a series of complications and a morbidity rate<sup>[9]</sup>, that have made spine surgeons to employ alternatives to ICBG such as bone graft substitutes or extenders<sup>[10-20]</sup>. Ideally these bone graft substitutes or extenders should have both osteoinductive and osteoconductive characteristics, in order to promote comparable fusion rates to autologous bone graft.

Demineralized bone matrix (DBM) is bone that has been acid treated to have the mineralized portion removed while maintaining the organic matrix and growth factors. Approximately 93% of DBM consists of collagen, whereas only 5% consists of other growth factors, a fraction of which are BMPs. It is weakly osteoconductive because the organic portions of bone, such as collagen, remain. The small quantity of BMPs provides osteoinductive capabilities<sup>[21-26]</sup> as well, but has no osteogenic capacity because of its processing. Osteoinductivity may be variable within a single manufacturer's product and between manufacturers, because the osteoinductive capacity of DBM can be affected by storage, demineralization process, washing procedure, sterilization method and the source of the bone, which depends on the individual donor and the site of harvest<sup>[27-33]</sup>. DBM has no immunological rejection as the antigenic surface structure of the bone is destroyed during demineralization by acid<sup>[34]</sup>, but, in the other hand, various studies have shown that any allograft bone can induce host immune responses<sup>[35-38]</sup> despite its processing. Unfortunately, there are no studies, referred whether available DBM products could differ in immunogenicity issues, or whether immunogenicity issues would influence the osteoconductive and osteoinductive potentials of DBM.

Since DBM was found to be effective and safe as an option of bone grafting, it has been used to induce bone

formation in various clinical applications.

The purpose of this review is to present the results of clinical studies concerning the use of DBM, alone or as a composite graft, in the spinal fusion, and the Grades of Recommendation<sup>[39]</sup> of use of DBM in different situations, like cervical fusion, lumbar fusion and at the treatment of scoliosis.

## LITERATURE RESEARCH

A critical review of the English-language literature was conducted on MEDLINE using Pubmed. Various combinations of search key and MeSH terms including “demineralized bone matrix”, “DBM”, “spinal fusion”, “scoliosis” and “cervical spine fusion” were employed to generate a broad literature base. The two senior authors K.T and D.G conducted the search independently, and there were not any discrepancies in their findings. Results had been restricted to clinical studies in English language. Abstracts, supplements, editorials, correspondence, book reviews, and articles on aspects of DBM unrelated to efficacy and outcome were excluded. Clinical studies of use of DBM in non-spinal surgery were excluded as well. Papers that were included were full-length original research articles in peer-reviewed journals that investigated fusion efficacy. The Grades of Recommendation and the levels of evidences (LOEs) are presented. The Oxford centre for evidence based medicine classification is used in order to classify LOEs of individual studies<sup>[40]</sup>. Clinical studies, authors, and their main outcomes presented in Table 1, and described by category of use.

Requirements of extensive bone grafting in spinal fusion and the subsequent morbidity of the donor site, are making iliac crest not the most accessible option for graft harvesting. This fact leads the spinal surgeons to employ different type of bone graft substitutes in order to cover their needs.

DBM has, performed successfully in long bones operative procedures requiring bone grafts, such as repairing segmental defects<sup>[41-44]</sup>. However, there are limited clinical data to support the efficacy of any DBMs in spinal arthrodesis.

The literature has supported the use of DBM as a potential graft extender, enhancer or substitute, but there was no clinical evidence to support its use as a stand-alone graft material. On top of that there are studies that demonstrate, that in younger and healthier patients, use of DBM may be unnecessary, since harvesting autograft from local sources, like laminae and spinous processes after destruction of facet joints and decortication, shows excellent results and a fusion rate of 94% without implant failure, infection or loss of correction<sup>[45]</sup>. It seems that spinal surgeons can take advance of DBMs osteoinductivity and osteoconductivity and achieve good results in spinal fusion but unfortunately, it is not useful as a structural graft material because of its amorphous consistency which is a draw back, since in has to be used in combination with other type of grafts or scaffolds which

**Table 1 Clinical studies of demineralized bone matrix used in spinal fusion**

Ref.	Study design	Diagnosis/procedures	Type of graft	Main outcomes	Level of evidence
<b>Cervical spine</b>					
An <i>et al</i> <sup>[48]</sup>	2-Center randomized prospective control trial	Patients undergone anterior cervical fusion for degenerative disc disease, <i>n</i> = 77	Freeze-dried allograft augmented with DBM (Grafton®), <i>n</i> = 39. Iliac Crest Autograft, <i>n</i> = 38	Pseudarthrosis rate was 46.2% in DBM-allograft Group <i>vs</i> 26.3% in autograft group, but with no significant differences. Graft collapse $\geq 2$ mm occurred in 39.7% in DBM-allograft group than 24.4% in autograft group ( <i>P</i> = 0.09)	II
Vaidya <i>et al</i> <sup>[49]</sup>	Retrospective comparative study	Patients treated with anterior cervical discectomy and fusion, <i>n</i> = 46	PEEK cages + morphogenetic protein-2 (rhBMP-2), <i>n</i> = 22 Allograft spacers + DBM, <i>n</i> = 24	No significant difference in pain scores between groups. Probable fusion at latest follow up in 23/24 of DBM group <i>vs</i> 22/22 in rhBMP-2 group. 85% of rhBMP-2 and 56% of DBM reported difficulty in swallowing. The cost of implants in patients treated with rhBMP-2 and PEEK spacers was more than three times the cost of the other group	III
Park <i>et al</i> <sup>[52]</sup>	Prospective, case series study	Patients undergoing anterior cervical discectomy and fusion	PEEK cages and DBM (Grafton®), <i>n</i> = 31	97% fusion rate (41/42 levels), neck and arm pain improved after surgery and significantly improved in 12/12 follow-up, <i>P</i> < 0.05	IV
Topuz <i>et al</i> <sup>[50]</sup>	Retrospective, case series study	Patients underwent 2-level contiguous anterior cervical discectomy and fusion	PEEK cages and DBM (Grafton®) and autologous blood, <i>n</i> = 79	87.3% "excellent" and "good" clinical outcomes, final fusion rate 91.7% (145/158 levels)	IV
Moon <i>et al</i> <sup>[51]</sup>	Retrospective case series	Patients undergone 2-level, non-instrumented cervical fusion for degenerative disk disease, <i>n</i> = 27 (54 levels)	PEEK cages and DBM	Fusion rate was 88.9% of levels. All patients showed improvements in clinical outcomes (VAS score, neurologic pain and JOA myelopathy score)	IV
Demircan <i>et al</i> <sup>[53]</sup>	Prospective case series	Patients undergone non-instrumented anterior cervical fusion for degenerative disk disease, <i>n</i> = 16 (42 levels)	Polyetheretherketone cages packed with autologous blood, curettage microchip material, and DBM (Grafton®)	Fusion rate was 90.5% of levels, at 18 mo after surgery with improved clinical outcomes using JOA score ( <i>P</i> = 0.004)	IV
<b>Lumbar spine</b>					
Kang <i>et al</i> <sup>[54]</sup>	Prospective multicenter randomized clinical trial	Patients undergoing single-level posterior lumbar fusion	DBM (Grafton®) + local bone, <i>n</i> = 30. Autologous iliac crest bone graft, <i>n</i> = 16	Fusion rates were 86% (Grafton®) <i>vs</i> 92% (autologous graft). Grafton showed consistently higher physical function scores at 24 mo. There was a greater mean intraoperative blood loss in the autologous group.	I
Cammisa <i>et al</i> <sup>[31]</sup>	Prospective multicenter control trial	Patients undergone posterolateral lumbar, instrumented fusion, <i>n</i> = 120	Iliac Crest Autograft on one side DBM (Grafton®) + Iliac crest autograft on contralateral side of same patient	Radiographic fusion rates at 24 mo after surgery in Grafton DBM side was 52% and in Iliac Crest Bone Autograft side was 54%	II
Vaccaro <i>et al</i> <sup>[55]</sup>	Prospective, comparative study	Patients undergone instrumented posterolateral lumbosacral spinal fusion	DBM (Grafton®) + Bone Marrow, <i>n</i> = 19, DBM + Iliac crest autograft, <i>n</i> = 27 Autograft, <i>n</i> = 27	Fusion rates were 63% with DBM + Bone Marrow, 70% DBM + autograft and 67% with autograft	III
Sassard <i>et al</i> <sup>[56]</sup>	Retrospective comparative study	Instrumented posterolateral lumbar spinal fusion with rigid pedicle screw fixation ( <i>n</i> = 108)	Iliac crest bone graft ( <i>n</i> = 52). Local autograft-Grafton® ( <i>n</i> = 56)	Fusion rates at 24 mo after surgery: In Iliac crest bone graft group: 56% and in local autograft-Grafton group: 60%	III



Schizas <i>et al</i> <sup>[57]</sup>	Retrospective case control study	Patients undergone posterolateral, one or two-level, instrumented, lumbar fusion, <i>n</i> = 59 (78 levels)	DBM (Accell Connexus <sup>®</sup> putty) with Iliac crest autograft or local decompression material, <i>n</i> = 33 Iliac crest autograft or local decompression material, <i>n</i> = 26	Fusion rate was 69.7% with DBM <i>vs</i> 76.9% without DBM. There were no differences in complication rates, ODI or VAS pain score	III
Epstein <i>et al</i> <sup>[58]</sup>	Prospective, clinical study	Patients undergone multilevel lumbar laminectomies, 1-level ( <i>n</i> = 95) and 2-levels ( <i>n</i> = 45)	Lamina autograft + DBM (Osteofil), <i>n</i> = 140	1-level fusion rates: 98%, 2-levels fusion rates: 96%. Revealed essentially comparable outcomes on 6 of 8 Health Scales of SF-36	IV
Thalgott <i>et al</i> <sup>[61]</sup>	Prospective case series study	Patients undergone lumbar interbody fusion ( <i>n</i> = 50)	Titanium mesh cages filled with coralline hydroxyapatite (ProOsteon <sup>™</sup> 500R) and DBM (Grafton <sup>®</sup> )	96% fusion rate, decrease in mean pain scores by 60% from baseline	IV
Girardi <i>et al</i> <sup>[60]</sup>	Retrospective case series study	Instrumented lumbar spinal fusion for various diagnoses ( <i>n</i> = 65)	Combination of autologous bone graft and allograft DBM (AlloMatrix <sup>®</sup> Injectable Putty)	Gradual and constant improvement based on radiographic measurements taken 1, 3, 6 and 12 mo after surgery	IV
Thalgott <i>et al</i> <sup>[62]</sup>	Retrospective case series	Patients undergone instrumented posterolateral lumbar fusion, <i>n</i> = 40	Coralline hydroxyapatite (Pro Osteon <sup>™</sup> 500) + DBM (Grafton <sup>®</sup> ), <i>n</i> = 28 Pro Osteon <sup>™</sup> 500 alone, <i>n</i> = 12.	Radiographic fusion rates was 100% with coralline hydroxyapatite alone, than 89.3% with Grafton added.	IV
Epstein <sup>[59]</sup>	Prospective case series	Geriatric patients undergone posterolateral non-instrumented lumbar fusion, <i>n</i> = 75	Lamina autograft mixed with DBM (Osteofil) in 1:1 ratio	Fusion rate was 82.7% of levels. Improved clinical outcomes using SF-36 score.	IV
Idiopathic scoliosis Weinzapfel <i>et al</i> <sup>[63]</sup>	Retrospective comparative study	Anterior thoracic discectomies with video Assisted thoracoscopic surgery in idiopathic scoliosis	Morselized allograft bone, <i>n</i> = 12. DBM (Grafton <sup>®</sup> ), <i>n</i> = 28	Curve correction was similar for both groups (68% <i>vs</i> 67%). Radiological fusion fusion: 82% in allograft group <i>vs</i> 92% in DBM group	III

DBM: Demineralized bone matrix; PEEK: Polyetheretherketone; JOA: Japanese-orthopaedic-association; BMP: Bone morphogenetic protein; ODI: Oswestry disability index; VAS: Visual analogue scale.

increases the cost.

The most significant drawback to DBM may be the difference between and within products. The osteo-inductive potential of DBM may be variable within a single manufacturer's product and among manufacturers, because the osteoinductive capacity of DBM can be affected by storage, demineralization process, washing procedure, sterilization method and the source of the bone, which depends on the individual donor and the site of harvest and affects the quantity and type of BMPs preserved. There are numerous DBM composites in many forms, from gels, pastes, putties, and sheets available currently for clinical use.

Bae *et al*<sup>[27]</sup> have pointed out that the variability of BMP concentrations among different lots of the same DBM formulation was higher than the inter-product variability or concentrations of BMP among different DBM formulations.

Another important factor that could influence efficacy of DBMs is the choice of the carrier. As opposed to the neutral pH of hyaluronic acid (DBX) carriers, negative effects have been observed in relation to the use of glycerol carriers (Grafton), which generate a highly

acidic environment for host tissues, especially when used in large quantities at the fusion site<sup>[46]</sup>. Moreover, the amount of DBM applied does not necessarily correlate with outcomes and efficacy as demineralization process, and sterilization method can also affect osteoinductivity, as mentioned before<sup>[21,47]</sup>. It is important the surgeon to remain updated of the product properties to optimize the successful use of DBM.

## DBM USED IN CERVICAL FUSION

There are a few clinical trials in literature, which evaluated the use of DBM in fusion in cervical spine. In one of the first reports, An *et al*<sup>[48]</sup> in a two-center prospective randomized controlled clinical trial (Level 2), found that freeze-dried allograft with DBM (Grafton<sup>®</sup>) mixed, shown higher nonunion and graft collapse rates than iliac crest autograft. Thirty-nine patients undergoing anterior cervical fusion for degenerative disc disease had randomly selected to take freeze-dried allograft augmented with DBM (Grafton<sup>®</sup>), while 38 patients took autologous ICBG. Pseudarthrosis developed in 33.3% of levels (46.2% of patients) in the allograft-DBM group, than

22% of levels (26.3% of patients) in autograft group, but with no significant difference between groups ( $P = 0.23$ ). In addition, graft collapse  $> 2$  mm occurred in 39.7% of the allograft-DBM group compared with 24.4% of the autograft group ( $P = 0.09$ ). Authors suggested the use of autograft in cervical fusion for better outcomes.

In a level 3 study, Vaidya *et al.*<sup>[49]</sup>, evaluated the use of polyetheretherketone (PEEK) cages and morphogenetic protein-2 (rhBMP-2) against allograft spacers and DBM, in patients treated with anterior cervical discectomy and fusion. There were no significant differences in pain scores between groups. Probable fusion occurred in 23 of 24 patients of DBM group *vs* 22 of 22 patients in rhBMP-2 group. 85% of patients in rhBMP-2 group and 56% of patients in DBM group reported difficulty in swallowing. The cost of implants in patients treated with rhBMP-2 and PEEK spacers was more than three times the cost of the other group. Authors concluded that despite providing good fusion rates, they have abandoned using rhBMP-2 and PEEK cages for anterior cervical fusion, due to the side effects, high cost, and the availability of a suitable alternative.

There are also 4 series of patients in literature, which studied the use of PEEK cages and DBM (Grafton®) in patients treated with cervical discectomy and fusion. Topuz *et al.*<sup>[50]</sup> used PEEK cages packed with Grafton® DBM and autologous blood in 79 patients, who underwent 2-levels contiguous anterior cervical discectomy and fusion. Authors found “excellent” and “good” clinical results in 87.3% of patients, while final fusion had occurred in 145 of 158 levels (91.7%). In a same case series study, Moon *et al.*<sup>[51]</sup> used PEEK cages packed with DBM, and found that fusion rate was 88.9% of levels. All patients had clinical improvement using visual analogue scale (VAS) score, neurological pain and Japanese-orthopaedic-association (JOA) myelopathy score. Park *et al.*<sup>[52]</sup> also found high fusion rate, up to 97% using same methods in a prospective case series study. Similar main outcomes, found Demircan *et al.*<sup>[53]</sup> in a case series of patients undergone non-instrumented anterior cervical fusion for degenerative disc disease. Authors used PEEK cages packed with Grafton®, autologous blood and curettage microchip material. Fusion rate was 90.5% with patients had improved clinical outcomes using JOA score ( $P = 0.004$ ).

## USE OF DBM IN LUMBAR FUSION

Despite the few published clinical trials about the use of DBM in cervical fusion, there are a few more about lumbar fusion. There are two level 1 and 2, three level 3 and five level 4 available clinical trials, since the preparation of this manuscript.

In a prospective multicenter randomized controlled clinical trial, Kang *et al.*<sup>[54]</sup> reported the efficacy of a commercial DBM graft (Grafton®) compared with iliac crest autograft in patients undergone single-level posterior lumbar fusion. In this study 46 patients were randomly assigned to receive Grafton DBM Matrix with local bone

(30 patients) or autologous ICBG (16 patients). Fifty-one patients completed the 2-year follow-up. Fusion rates were 86% for Grafton group than 92% for autologous group. Grafton showed consistently higher physical function scores at 24 mo, but this was not significant. There was a significant greater mean intraoperative blood loss in the autologous group ( $P = 0.0031$ ). Authors concluded that fusion rate and improvement in clinical outcomes of use of Grafton in lumbar fusion were comparable with those in iliac crest autograft group.

Cammisa *et al.*<sup>[3]</sup> investigated whether Grafton® might be able to serve the function of an autograft extender, in 120 patients undergone posterolateral instrumented lumbar fusion. In this level 2 study, Iliac crest autograft was implanted on one side of the spine and a Grafton® DBM and autograft composite was implanted on the contralateral side in the same patient. After 24-mo follow-up, Radiographic fusion rates in Grafton DBM side was 52% and in Iliac Crest Bone Autograft side was 54%, while overall percentage agreement for fusion status between sides was approximately 75% ( $P < 0.001$ ). These results suggested that Grafton DBM gel in combination with autologous bone can provide a similar rate of successful fusion as autograft alone.

In a prospective series, Vaccaro *et al.*<sup>[55]</sup> evaluated patients undergone instrumented posterolateral lumbosacral spinal fusion. Nineteen patients had supplemental bone grafting with DBM putty (Grafton®; Osteotech, Eatontown, NJ) enriched with aspirated bone marrow, 27 patients DBM putty combined with iliac crest autograft, and 27 patients had autograft. Fusion rate at 24 mo after surgery were 63% of levels in DBM and bone marrow group, 70% of levels in DBM and iliac crest group and 67% in ICBG group. Findings suggest that both DBM composites offer similar performance to autograft in posterolateral spinal fusion.

Sassard *et al.*<sup>[56]</sup>, in a level 3 clinical trial, examined the fusion rates of a local autograft-Grafton® construct against that of iliac crest autograft alone in one hundred and eight patients undergone instrumented posterolateral lumbar spinal fusion. Fusion rates were found not to vary between the two groups, with 60% in local autograft-DBM group and 56% in iliac crest autograft group. These findings prompted further evaluation of whether Grafton® might be able to serve as graft extender.

Schizas *et al.*<sup>[57]</sup> found that DBM was useful as a graft extender for both local bone and ICBG. They compared 33 patients who had local bone or ICBG augmented with DBM with 26 patients who received ICBG or local bone alone, for posterolateral, one or two-level, instrumented, lumbar fusion. The groups were equivalent in radiographic fusion and clinical outcomes. Fusion rates were 69.7% with DBM augmented *vs* 76.9% without DBM. There were no differences in complication rates, Oswestry disability index or VAS pain score.

There are also case series available in literature, which concluded that DBM is a useful graft extender for spinal fusions, when mixed with lamina autograft, or iliac crest autograft. Epstein *et al.*<sup>[58]</sup> reported high fusion rates

(1-level fusion rate: 98%, 2-levels fusion rate: 96%) in 140 patients undergone multilevel lumbar laminectomies and had lamina autograft augmented with DBM (Osteofil) as a graft for fusion. Radiographic followed by clinical outcomes. Same authors, reported similar results in geriatric patients undergone posterolateral non-instrumented lumbar fusion, with fusion rate up to 82.7% of levels and improved clinical outcomes, using SF-36 surveys<sup>[59]</sup>. Girardi *et al*<sup>[60]</sup>, in a series of 65 patients who undergone instrumented spinal fusion for various diagnoses, reported a gradual and constant improvement based on radiographic measurements taken 1, 3, 6, and 12 mo after surgery. Patients had combination of autologous bone graft and DBM (AlloMatrix® Injectable Putty).

Thalgott *et al*<sup>[61]</sup> retrospectively reviewed the radiographic and clinical results of 50 patients who had received titanium mesh cages filled with coralline hydroxyapatite (ProOsteon™ 500R) and DBM Grafton® preparation for anterior lumbar interbody fusion. The authors reported a 96% fusion rate, alongside with a decrease in mean pain scores by 60% from baseline. In the other hand, there are conflicting results on the efficacy of DBM as a graft extender by the same authors, who found a higher rate of pseudarthrosis (10.7% *vs* 0%) with the use of Grafton® gel and coralline hydroxyapatite (Pro Osteon™ 500R) as compared with coralline hydroxyapatite alone in a retrospective study of 40 patients who underwent instrumented posterolateral lumbar spinal fusion<sup>[62]</sup>.

## DBM USED FOR TREATMENT OF SCOLIOSIS

Because of the extensive fusion requirements for correction of scoliosis, DBM can be an available alternative to iliac crest. Weinzapfel *et al*<sup>[63]</sup> compared retrospectively the fusion rates between allograft bone and Grafton DBM Flex in video-assisted thoracoscopic surgery for idiopathic scoliosis. Forty patients with 1 year or more follow-up were evaluated-12 with morselized allograft bone and 28 with folded Grafton DBM Flex. Percent curve correction from before surgery to the most recent follow-up was very similar in both groups (68% in Allograft and 67% in DBM group). Sixty of 73 disc spaces (82%) in the Allograft group and 100 of 109 disc spaces (92%) in the DBM group were rated as radiographically fused.

## CONCLUSION

This review demonstrates that DBM shows similar fusion rates with autologous bone graft in lumbar spine fusion, when used as a graft extender either with local autologous bone of ICBG. In addition in the only one level I study that was included in this review DBM group showed consistently higher physical function scores at 24 mo and there was a greater mean intraoperative blood loss in the autologous group.

Regarding use of DBM in cervical spine fusion, it is clear that when used as an extender with autologous bone

graft in PEEK cages, shows good results, although in a level two study where Freeze-dried allograft augmented with DBM compared with ICBG, the autograft group showed superior non-union rates (Pseudarthrosis rate was 46.2% in DBM-allograft Group *vs* 26.3% in autograft group).

For correction of scoliosis due to the extensive fusion requirements DBM shows to be a reliable alternative to autograft, especially comparing with the use of other types of allografts.

Concluding, the majority of the clinical trials demonstrate comparable efficacy of DBM when it used as a graft extender in combination with autograft, but there is no clinical evidence to support its use as a standalone graft material. Additionally, studies of high methodological quality are required, in order to optimize and clarify the indications of its use and the appropriate patient population that will benefit from DBM in spine arthrodesis.

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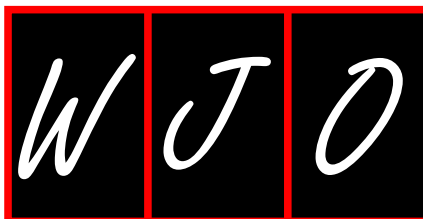
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## Orthopedic surgery and its complication in systemic lupus erythematosus

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### Abstract

Systemic lupus erythematosus (SLE) is a multi-systemic immune-complex mediated autoimmune condition which chiefly affects women during their prime year. While the management of the condition falls into the specialty of internal medicine, patients with SLE often present with signs and symptoms pertaining to the territory of orthopedic surgery such as tendon rupture, carpal tunnel syndrome, osteonecrosis, osteoporotic fracture and infection including septic arthritis, osteomyelitis and spondylodiscitis. While these orthopedic-related conditions are often debilitating in patients with SLE which necessitate management by orthopedic specialists, a high index of suspicion is necessary in diagnosing these conditions early because lupus patients with potentially severe orthopedic conditions such as osteomyelitis frequently present with mild symptoms and subtle signs such as low grade fever, mild hip pain and back tenderness. Additionally, even if these orthopedic conditions can be recognized, complications as a result of surgical procedures are indeed not uncommon. SLE *per se* and its various associated pharmacological treatments may pose lupus patients to certain surgical risks if they are not properly attended to and

managed prior to, during and after surgery. Concerted effort of management and effective communication among orthopedic specialists and rheumatologists play an integral part in enhancing favorable outcome and reduction in postoperative complications for patients with SLE through thorough pre-operative evaluation, careful peri-operative monitoring and treatment, as well as judicious postoperative care.

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**Key words:** Orthopedics; Complications; Surgery; Systemic lupus erythematosus; Operation

**Core tip:** Systemic lupus erythematosus (SLE) is a complex autoimmune condition. Orthopedic specialists often encounter patients with SLE presenting with various orthopedic conditions which require surgical intervention but due to the complexity of SLE and its associated treatment, pre-operative preparation and post-operative care for these patients are often challenging. Concerted effort of management and effective communication between orthopedic specialists and rheumatologists play an integral part in enhancing favorable outcome and reduction in postoperative complications for patients with SLE through thorough pre-operative evaluation, careful peri-operative monitoring and treatment, as well as judicious postoperative care.

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### INTRODUCTION

Systemic lupus erythematosus (SLE) is an immune-complex mediated autoimmune disease characterized

by protean clinical manifestation and fluctuating disease course<sup>[1]</sup>. The exact patho-aetiology of SLE is not fully understood but is believed to be multi-factorial, with environmental, neuroendocrine, genetic, hormonal and infectious factors participating in playing a role<sup>[2]</sup>. On the molecular level, failure in clearance of apoptotic bodies which contain a wide array of genetic materials exposes lupus-susceptible individuals to the formation of autoantibodies against these genetic materials. The pathogenic autoantibodies induce inflammatory reactions through complement deposition, leucocyte ingress and tissue damage due to the consequent formation of immune complexes<sup>[3]</sup>. The reason why SLE preferentially affects young females is not fully understood although high estrogen levels and increase in CD40L expression in lymphocytes have been postulated<sup>[4]</sup>. Thus far, SLE is an incurable and unpreventable disease. Treatment largely aims at suppressing inflammation and reducing the occurrence of chronic tissue and organ damage<sup>[5]</sup>. In general, patients with major organ involvement such as diffuse proliferative glomerulonephritis, severe systemic vasculitis and neuropsychiatric involvement including myelitis will require heavier immunosuppression such as high dose glucocorticoids and cytotoxic agents. In contrast, symptomatic therapy may be the sole treatment in those who present with mild symptoms such as arthralgia, photosensitive rash and mild depression.

While rheumatologists are amongst the chief health-care providers for patients with SLE, these patients often present with common and potentially debilitating conditions which require attention by orthopedic specialists. These conditions include tendon rupture, carpal tunnel syndrome (CTS), osteonecrosis or avascular necrosis (AVN), osteoporotic fracture and infections such as osteomyelitis, septic arthritis and spondylodiscitis. While many of these conditions require surgical treatment, SLE *per se* and its medications may predispose patients to surgical risks<sup>[6]</sup>. Currently, strong literature and guideline with respect to pre-operative evaluation and post-operative care for patients with SLE are scarce. In this short review, individual diseases which are more commonly associated with the area of orthopedic surgery will be briefly discussed, followed by discussing how patients should be assessed pre-operatively and monitored peri-operatively and managed post-operatively with an aim to reduce the chance of post-operative complications.

## COMMON ORTHOPEDIC CONDITIONS IN PATIENTS WITH SLE

### CTS

CTS (or median entrapment neuropathy) is common, especially amongst middle-aged women. If severe, CTS can cause disturbing symptoms such as paresthesia, pain and numbness which can lead to sleep disturbance and poor quality of life especially if they occur nocturnally<sup>[7]</sup>. In a study of 436 patients reported in the 1990s, the prevalence of CTS was found to be around 11%<sup>[8]</sup>. In severe and prolonged cases, wasting of the thenar muscles

and weakness of palmar adduction would be observed and hand function may be impaired. Since most patients experience satisfactory outcome with night splints and carpal tunnel release as day surgical procedures, most patients will not require specific pre-operative assessment unless patients have bleeding tendency which may need to be corrected before the procedure.

### Fragility fracture

Observational studies have unanimously demonstrated a higher risk of osteoporotic fracture in patients with SLE<sup>[9]</sup>. One of the largest observational studies found that there was a five-fold increase in fragility fracture occurrence in women with SLE when compared with the general population<sup>[10]</sup>. Bone loss in patients with SLE is a result of a number of well-established factors such as glucocorticoid use, renal dysfunction, vitamin D deficiency, immobility, inflammation and premature menopause<sup>[11]</sup>. A recent case-control study has found that by using the FRAX<sup>®</sup> risk calculation model, the 10-year major fracture risk was estimated to be increased as a result of post-menopausal state and the use of glucocorticoids<sup>[11]</sup>. In fact, other medications which patients with SLE are taking may induce bone loss, such as anti-coagulants and cyclosporin. Apart from treatment, it appears that high SLE disease activity may predispose lupus patients to fracture<sup>[11]</sup>. Hip fractures are the most serious consequences of osteoporosis due to the associated disability and high mortality. It has been estimated that the mortality rate in the first year after fracture is up to 20%-30%<sup>[12]</sup>. Osteoporotic vertebral fractures, which are clinically silent in two thirds of cases, are also common, with reported prevalence between 9% and 20%<sup>[13,14]</sup>. An important point of note is, back pain *per se* is not a manifestation of lupus and uncomplicated osteoporosis. Lupus patients with back pain must be thoroughly investigated for pathological processes such as nerve entrapment, fragility fracture, infection and metastases in the vertebra and their associated structures. To date, the gold standard to diagnose osteoporosis is dual energy X-ray absorptiometry (DXA) of the hips and spine. According to the definition by the World Health Organization, a T-score (the number of standard deviation above or below the peak bone mass of young adult of the general population) of or below -2.5 is considered to be osteoporosis<sup>[15]</sup>. However, those who have history of fragility fracture are considered to have established osteoporosis even though their T-scores do not fall into the osteoporotic range. Indeed, many patients do fracture above the osteoporotic range of T-score, suggesting that DXA and the T-score are not perfect predictors for fractures<sup>[11]</sup>. Inferior bone quality due to damage of bone micro-architecture is detrimental to bone strength and cannot be assessed by routine DXA<sup>[16]</sup>. As for the treatment of osteoporotic fracture, hip fractures are largely managed by hip replacement or arthroplasty, while vertebral fractures are chiefly conservatively managed unless the fractures lead to neurological involvement, which is rare. Medical treatment of osteoporosis includes the use of anti-resorptive agents such as

bisphosphonates and RANKL inhibitor (Denosumab)<sup>[17]</sup>, or anabolic agents including strontium ranelate and intermittent subcutaneous parathyroid hormone injection (Teriparatide)<sup>[18,19]</sup>. While the risks and benefits regarding the use of these agents are beyond the scope of discussion of this review, the benefits of regular weight-bearing exercise and adequate intake of elementary calcium and vitamin D are paramount, in terms of prevention and reduction of the severity of osteoporosis<sup>[20]</sup>.

## AVN

AVN or osteonecrosis is not an uncommon phenomenon in SLE patients. Amongst all rheumatic diseases, the prevalence of AVN is the highest in patients with SLE, as compared with patients with other rheumatological conditions such as autoimmune myositis, vasculitides, rheumatoid arthritis (RA) and systemic sclerosis<sup>[21]</sup>. In one of the oldest studies, 4.6% of patients with SLE were found to develop AVN<sup>[22]</sup>. One of the main factors of predisposition to AVN is the presence of anti-phospholipid antibodies (APA) and/or anti-phospholipid syndrome. In a one-year prospective magnetic resonance imaging (MRI) study of 687 joints in patients with SLE, the risk factors for the increase in the incidence of AVN in comparison to patients with other autoimmune diseases such as myositis, medium- and large-vessel vasculitides, pemphigoid, RA, scleroderma and Behcet's disease were adult and adolescent patients (OR = 13.2), high glucocorticoid dose of more than 40 mg/d of prednisolone equivalent (OR = 4.2), patients with SLE (OR = 2.6) and the male sex (OR = 1.6)<sup>[21]</sup>. Treatment of AVN depends on the stage of the disease, the severity of the involvement of AVN, pain severity and the presence of co-morbidities which may pose patients to higher risks for major operation and anesthesia<sup>[23]</sup>. Patients with stage 0 and stage 1 AVN associated with mild symptoms warrant conservative treatment with rest and reduction in weight bearing. However, a randomized controlled trial of 36 patients demonstrated superiority of treatment success with surgical approach compared with conservative therapy (70% *vs* 20%)<sup>[24]</sup>. Free vascularized grafting for AVN of the femoral head appears to be promising in lupus patients although the concern of the health of the graft which might be compromised by SLE-related vasculitis will need to be addressed by further investigation<sup>[25]</sup>. Nevertheless, the best approach to manage AVN is prevention and early recognition so as to slow down disease progression and delay the need for hip replacement<sup>[26]</sup>. Judicious use of glucocorticoids, especially in patients who are positive for APA, is an important strategy to reduce the incidence of AVN.

## Infection

**Osteomyelitis and spondylodiscitis:** Besides osteoporotic fracture, clinicians taking care of lupus patients with back pain should always carry a high index of suspicion of osteomyelitis of the vertebra and their associated structures. Patients with SLE are more prone to bacterial infection due to a number of reasons, for example,

quantitative and qualitative deficiencies of complement proteins and immunoglobulins, renal dysfunction, impaired phagocytosis and chemotaxis, and obviously, the use of immunosuppressants<sup>[27]</sup>. Threshold of suspicion of infection should even be lower if these patients experience fever, night sweating, night pain without promising relieving factors and suboptimal response to painkillers. Apart from appropriate imaging studies such as computed tomography or MRI of the spine, patients suspicious of osteomyelitis should always have complete sepsis workup including blood, urine and stool cultures because aside from common bacterial infections such as those caused by *Staphylococcus aureus*, opportunistic infections such as those due to *Salmonella* should not be overlooked. In regions where tuberculosis (TB) is prevalent, a chest radiograph and sputum smear and culture, as well as TB molecular tests should be performed.

**Septic arthritis and tenosynovitis:** Only 1% to 2% of patients with SLE satisfy the American College of Rheumatology criteria for classical RA and have erosive arthropathy<sup>[28]</sup>. Most patients with SLE do not present with inflammatory arthritis with effusion although up to 90% of lupus patients experience arthralgia during the course of the disease. The "swan-neck" deformities and ulnar deviation observed in lupus patients are more likely due to tenosynovitis, or Jaccoud's deformities. Thus, a high index of suspicion of septic arthritis should always be exercised in lupus patients with joint inflammation and effusion. In sexually-active patients who present with polyarthritis, tenosynovitis and dermatitis, disseminated gonococcal infection (DGI) must be considered. In these patients, blood and extra-articular cultures of urethral, cervical, rectal and pharyngeal sites for *Neisseria gonorrhoeae* with a special medium (chocolate or Thayer-Martin medium) will be helpful. Similar to vertebral infections, TB needs to be excluded in patients with tenosynovitis which is highly suspicious of an infective process<sup>[29]</sup>. For the management of non-gonococcal septic arthritis, the prompt use of intravenous antibiotics should be accompanied by drainage of the affected joint, with continuation of antibiotics for at least 6 wk. DGI responds very well to intravenous or intramuscular third-generation cephalosporin, or intramuscular spectinomycin. Open drainage for joints affected by DGI is often unnecessary<sup>[30]</sup>. Importantly, patients who are confirmed to have DGI should undergo comprehensive screening for other potentially concomitant sexually transmitted diseases such as hepatitis B, hepatitis C, chlamydial infection and HIV.

## Tendon rupture

Spontaneous rupture of tendons which has been reported in patients with chronic renal failure, RA, local glucocorticoid injection and hyperparathyroidism<sup>[31]</sup>, occurs rarely in patients with SLE but it can be disabling<sup>[32,33]</sup>. While no large-scale study has been performed, high dose, prolonged and pulse glucocorticoid therapies, hypercoagulability state and APA positivity tend to be



reported more frequently in lupus patients who experienced tendon rupture<sup>[34]</sup>. Most reported sites of tendon rupture are weight-bearing areas such as Achilles' tendon, patellar tendon and extensor tendons of the hands<sup>[33,34]</sup>. While tendon rupture can be diagnosed based on physical examination, a definite diagnosis can be made with MRI. Tendon biopsy is not required in most cases unless infection is suspected, since biopsy specimens may yield non-specific findings such as mononuclear infiltration and neovascularization<sup>[35]</sup>. Most of the patients require tendon transfer and full recovery is often achieved.

## IMPORTANT PRE-OPERATIVE ASSESSMENT FOR PATIENTS WITH SLE

### **Cardiovascular condition**

Data from a number of observational studies of large cohorts invariably revealed a higher prevalence of cardiovascular disease in patients with SLE when compared with the age- and gender-matched general population<sup>[36]</sup>. While traditional cardiovascular risk factors such as hypertension, hyperlipidaemia and the use of glucocorticoids are more prevalent in patients with SLE, non-traditional risk factors such as inflammation are also operant in these patients. In fact, a recent study has found that inflammation exerts its impact very early on atherosclerosis by inducing endothelial dysfunction, which is the very first step of the atherogenic process<sup>[37]</sup>. Thus, based on the higher cardiovascular risk amongst patients with lupus, pre-operative assessment of the cardiovascular system is essential. Detailed personal and family history of cardiovascular disease and its risk factors should be obtained. A thorough cardiovascular examination including blood pressure, peripheral pulses, carotid bruit, position and character of the apex beat, added heart sounds and cardiac murmur, as well as signs of cardiac failure should be noted. Investigation should include a 12-lead electrocardiogram and chest radiograph at baseline. If possible, a cardiologist should always be consulted for further investigation such as an echocardiogram, Treadmill test or even coroangiogram in any suspected cases of heart disease before surgery.

### **Thrombophilia and thrombocytopenia**

Patients with SLE are prone to thrombosis especially if they have history of vascular thrombosis, heart failure, pulmonary hypertension, or if they are positive for APA and/or lupus anticoagulant (LAC). On the other hand, lupus patients with positive APA and/or LAC, hypersplenism, anti-platelet antibodies and blood marrow suppression due to SLE *per se* or immunosuppressant may present with severe thrombocytopenia which may complicate invasive procedures due to an excessive bleeding risk. Management of patients with thrombotic risk will be discussed in subsequent section. Patients with thrombocytopenia may need to have their platelet count corrected before emergency surgery, an exception is thrombotic thrombocytopenic purpura (TTP) or microangiopathic

hemolytic anemia (MAHA) which is associated with active SLE in some cases. In these cases, thrombocytopenia is often associated with hemolytic anemia with fragmentation of red cells in combination with any of the following including fever, acute renal impairment and altered conscious level. Surgery will need to be postponed in case of TTP or MAHA unless the procedure is an important option to remove the cause of TTP or MAHA, such as severe infection or disseminated malignancy. In elective surgery, thrombocytopenia is preferred to be corrected prior to the procedures, such as the use of intravenous immunoglobulins (IVIg) in patients with autoimmune thrombocytopenia. Prior exclusion of immunoglobulin A (IgA) deficiency which is present in between 2.6% and 5.2% of patients with SLE<sup>[38,39]</sup>, is beneficial before IVIg infusion in order to avoid anaphylactic transfusion reaction upon subsequent encounter of IgA protein, although no guidance has been established at the time of writing. While there is no universal cut-off value for a safe level of platelet count, a platelet count of at least  $80 \times 10^9/L$  is usually advised in major operation such as hip replacement and vertebral instrumentation. Table 1 summarizes the major tests that patients may require before operation, appended with associated main points.

## POSTOPERATIVE CARE IN PATIENTS WITH SLE

### **Deep vein thrombosis and pulmonary embolism**

Due to immobilization after operation, screening for deep vein thrombosis (DVT) between day 3 and 5 after operation are routinely carried out in patients with hip and knee surgery in our centre, even in lupus patients without obvious thrombotic risk and whose APA and LAC are negative. Prophylactic low molecular weight heparin and early mobilization are beneficial in preventing DVT until sonographic absence of DVT is proven<sup>[40]</sup>.

## SPECIAL ISSUES ON MEDICATIONS IN PATIENTS WITH SLE

### **Glucocorticoids**

Glucocorticoids are the main immunosuppressants in patients with SLE. However, chronic glucocorticoid administration (*e.g.*, prednisolone 5 mg or equivalent and above for more than 2 wk) suppresses adrenal function. Adrenal suppression is detrimental in patients who are exposed to surgical stress, especially during the first 48 h peri-operatively when patients would develop circulatory shock and renal shutdown if adrenal suppression is not corrected before operation. To assess adrenal function, a physician should be consulted for performing a simple short synacthan test whereby 250 µg of intravenous synthetic adrenocorticotrophic hormone is injected and after 60 min a plasma level of cortisol of at least 550 nmol/L or a rise of 200 nmol/L is expected in individuals with normal adrenal response. However, since chronic glucocorticoid administration would affect the central component of

**Table 1 Pre-operative workup for patients with systemic lupus erythematosus planned for orthopaedic surgery**

Workup and test	Description
Baseline kidney and liver function tests, fasting glucose and lipid profile	Anaesthetists should be alerted to abnormalities of the renal and liver functions as they may have implications on anaesthetics use. Patients need to fast for at least 8 h for fasting glucose and lipid tests. Endocrinologists should ideally be referred to assess diabetic patients in order to maintain stable glucose levels before and after operation by adjusting existing or starting new hypoglycaemic agents and/or insulin.
Full blood count, peripheral blood smear (if hemolysis is suspected or proven) and clotting profile. Type and match if transfusion is contemplated or expected. Thrombophilic screen if there is history or suspicion of vascular thrombosis: Blood protein C and protein S levels, lupus anticoagulant, serum anti-cardiolipin antibodies and serum IgA level if IVIg infusion is required	Poor glycaemic control is associated with poor wound healing Haematology or rheumatology consultation is necessary in case of anaemia, hemolysis, thrombocytopenia and evidence of thrombophilia, especially if patients have history of severe bleeding and/or vascular thrombosis, and if patients are on anti-platelet agents and/or anticoagulants
Resting 12-lead ECG	Patient should be referred for formal CVS assessment if ECG abnormalities such as ST segment changes, heart block or arrhythmia is evident
Chest radiograph	A plain chest radiograph is considered baseline pre-operative assessment in case general anaesthesia is required. In patients with SLE, a chest radiograph allows a crude assessment for pulmonary lesions such as interstitial lung disease and serositis. Assessment by pulmonologists may be required if lung pathology is suspected
Radiograph of the cervical spine (flexion and extension views)	Rarely required unless lupus patients have features of bone erosion in the peripheral joints which might heighten the chance C1-C2 disease
Treadmill test and coroangiogram	Patients with suspected or confirmed ischaemic heart disease may require these tests after assessment by cardiologists on a case-by-case basis. These tests allow diagnosis of coronary artery disease and risk stratification

CVS: Cardiovascular; ECG: Electrocardiogram; SLE: Systemic lupus erythematosus; IgA: Immunoglobulin A; IVIg: Intravenous immunoglobulins.

the hypothalamic-pituitary-adrenal axis and tests for these central components are complex, most authorities recommend empirical glucocorticoid cover pre-operatively. While no strong data are available, in our centre, patients preparing for surgery who are on chronic glucocorticoid administration will be given hydrocortisone 100 mg intravenously on call to operation theatre. Then, hydrocortisone will be given 100 mg intravenously every 8 h on the first day after operation, followed by every 12 hourly and daily on the second and third day after operation. If patient is awake and stable, oral glucocorticoids of the usual dose will be re-commenced.

### **Methotrexate**

A few lupus patients are on methotrexate (MTX) to control lupus arthritis. While traditionally MTX would be held off several weeks before surgery, there is indeed no evidence suggesting that stopping MTX is beneficial unless patients have clinically overt postoperative wound infection<sup>[41]</sup>. While wound healing might be affected by MTX, the risk of arthritis flare which may delay postoperative rehabilitation progress outweighs the benefit of continuation of the medication.

### **Aspirin and warfarin**

Aspirin is mainly used in patients with ischaemic heart disease and history of cerebrovascular disease. However, aspirin inhibits cyclooxygenase-1 (COX-1) and impairs platelet aggregation, rendering an excessive risk of peri-operative bleeding. If there is no major contraindication, aspirin can be stopped for 5 to 7 d prior to surgery, and

should be restarted 3 to 4 d postoperatively. For patients who are on warfarin due to conditions such as anti-phospholipid antibody syndrome, the medication should be held off at least 5 d prior to surgery, and replaced by low molecular weight heparin, which should be held off in the morning of surgical procedure<sup>[42]</sup>. Anticoagulation should be re-commenced as soon as patients are haemodynamically stable with minimal bleeding risk.

### **Non-steroidal anti-inflammatory drugs**

Non-steroidal anti-inflammatory drugs (NSAIDs) are commonly used in patients with SLE who present with joint pain, muscle aches and pleuritis. NSAIDs also inhibit COX-1 and they have been shown to be associated with a higher risk of gastrointestinal bleeding when given peri-operatively. Thus, it is encouraged to withhold NSAIDs preoperatively for a period equivalent to five half-lives of the drugs in order to restore normal platelet function while they can be re-started 2-3 d postoperatively. COX-2 NSAIDs do not affect platelet function and hence they are safe to be given peri-operatively. However, an important point of note is, COX-2 may be associated with cardiovascular disease and shall be discouraged in lupus patients who have high cardiovascular risk such as hypertension, diabetes and hyperlipidaemia, and in those patients who are thrombophilic, or those who have a history of vascular thrombosis<sup>[43]</sup>.

## **CONCLUSION**

The link between SLE and orthopedic surgery is increas-

ingly recognized. Based on the literature, the link is largely facilitated by the use of glucocorticoids and immunosuppressants, infection, bleeding and hypercoagulability states, leading to a number of conditions such as AVN, tendon rupture, vascular thrombosis and postoperative bleeding. Heightened awareness, meticulous pre-operative assessment and judicious monitoring peri-operatively and post-operatively will likely increase the successful outcome of surgery and reduce the post-operative risk in patients with SLE.

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## Communication after cancellations in orthopaedics: The patient perspective

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### Abstract

**AIM:** To examine patients' perceptions on communication surrounding the cancellation of orthopaedic operations and to identify areas for improvement in communication.

**METHODS:** A prospective survey was undertaken at a university teaching hospital within the department of Trauma and Orthopaedics. Patients admitted to an acute orthopaedic unit, whose operations were cancelled, were surveyed to assess patient satisfaction and preferences for notification of cancellation of their operations. Patients with an abbreviated mental test score of < 9, patients unable to complete the survey independently, those under 16 years of age, and any patient notified of the cancellation by any of the authors were excluded from this study. Patients were surveyed the

morning after their operation had been cancelled thus ensuring that every opportunity was given for the medical staff to discuss the cancellation with the patient. The survey included questions on whether or not patients were notified of the cancellation of their surgery, the qualifications of the person discussing the cancellation, and patient preferences on the process. Satisfaction was assessed *via* 5-point Likert scale questions.

**RESULTS:** Sixty-five consecutive patients had their operations cancelled on 75 occasions. Fifty-four point seven percent of the patients who had cancellations were notified by a nurse and 32% by a doctor. No formal communication occurred for 13.3% cancellations and no explanation was provided for a further 16%. Patients reported that they were dissatisfied with the explanation provided for 36 of the 75 (48%) cancellations. Of those patients who were dissatisfied, 25 (69.4%) were notified by a nurse. Twenty-three of the 24 (96%) patients notified by a doctor were satisfied with the explanation and that communication. Of those patients who were notified by a nurse 83% patients reported that they would have preferred it if a doctor had discussed the cancellation with them. There was a significant difference in satisfaction between those counselled by a nurse and those notified by a doctor ( $P < 0.0001$ ).

**CONCLUSION:** Communication surrounding cancellations does not meet patient expectations. Patients prefer to be notified by a doctor, illustrating the importance of communication in the doctor-patient relationship.

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**Key words:** Communication; Patient satisfaction; Orthopaedic surgery; Cancellation

**Core tip:** Communication is a fundamental component of medical practice. This study highlights communication issues surrounding cancellation of orthopaedic

operations. It reflects patients' preferences and expectations in these situations. Failure to meet these preferences and expectations predisposes to dissatisfaction and can negatively impact patient experiences and health outcomes. In the current climate, it may fall to individual practitioners to change their approach to communication and patient interaction. Patients appear to place great value on communication delivered by doctors, and a few extra moments spent conversing with a patient may have profound and lasting effects.

Mehta SS, Bryson DJ, Mangwani J, Cutler L. Communication after cancellations in orthopaedics: The patient perspective. *World J Orthop* 2014; 5(1): 45-50 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v5/i1/45.htm> DOI: <http://dx.doi.org/10.5312/wjo.v5.i1.45>

## INTRODUCTION

Communication is a fundamental component of medical practice. Despite widespread introduction of communication skills in medical curricula, and post-graduate courses espousing such skills, poor communication remains a leading cause of patient dissatisfaction and complaints within the National Health Service (NHS)<sup>[1]</sup>. Operations that are cancelled for non-clinical reasons can cause psychosocial distress, disruption of daily life and have wider socioeconomic implications<sup>[2]</sup>. The 2002 NHS Modernisation Agency's Theatre Project, and Association of Anaesthetists of Great Britain and Ireland, have published recommendations for dealing with patients whose operation have been cancelled. This includes guidance to reschedule the operation within 28 d<sup>[3]</sup> and provision of an apology and an explanation for the cancellation by a senior member of the team<sup>[4]</sup>. Cancellations occur frequently in busy trauma and orthopaedic departments.

To the best of our knowledge there has not been a study examining patients' perceptions on the communication issues surrounding cancellations in trauma and orthopaedics in the NHS. This prospective study sought to examine current practice in our own department in an attempt to identify areas for improvement in our communication skills and the provision of care.

## MATERIALS AND METHODS

We created a survey requesting responses on the methods of informing patients of cancellations of their operation in orthopaedic surgery. This study was conducted in a university teaching hospital, in a dedicated trauma unit, that accepts only acute orthopaedic admissions. Since 2005 our hospital has employed specialist-trained nurses as Trauma Coordinators. Working closely with orthopaedic, anaesthetic and theatre teams, the Trauma Coordinators work seven days a week to plan and coordinate theatre lists. This necessarily involves

close communication with nursing and medical staff, junior doctors, and patients. Following the morning trauma meeting, attended by the on-call, operating and anaesthetic team, along with the Orthogeriatric consultant and the trauma coordinators, the order of the operative list is determined. Patients are then reviewed by the anaesthetist to assess their fitness for surgery and an anaesthetic plan formulated. If a patient was cancelled at that stage, because underlying medical factors prohibited surgery, then the patient was excluded from this study. Conversely, all patients who potentially remained on the planned trauma list remained eligible for participation in the study. Some patients were kept potentially on the list for either pending medical treatment or blood results for example International Normalised Ratio to be normal or review by Orthogeriatrician.

At our institution, two trauma theatre lists run in parallel each weekday with a single trauma theatre operating over the weekends. One theatre is ring-fenced for hip fracture patients and the other for general trauma. The hip fracture theatre is operational from 09:00-17:00 while the general trauma theatre runs from 09:00 until 20:00. We identified patients who were cancelled from either list. The decision to cancel a patient on the hip fracture list occurred late in the afternoon and cancellations from the trauma list were made in the evening.

All patients who were cancelled were invited to participate in this study. We surveyed patients the morning after their operation had been cancelled. This ensured that every opportunity was given for the medical staff to discuss the cancellation with the patient.

The survey included questions on whether or not patients were notified of the cancellation of their surgery, the qualifications of the person discussing the cancellation, and patient preferences on the process. Satisfaction was assessed *via* 5-point Likert scale questions. We assessed patients' satisfaction to overall communication of their entire stay in hospital and not just the episode of cancellation and also overall satisfaction with care provided. This information was collated to assess if communication surrounding cancellation affects these issues as well. A Fisher exact test was used evaluate differences in patient satisfaction and significance was assumed at  $P < 0.05$ .

All patients were surveyed after notification of the cancellation and before the re-scheduled operation was performed. The patients were encouraged to reply in their own time without any involvement from any of the staff. Inclusion criteria included any patient whose operation was cancelled for clinical or non-clinical reasons. Examples of the former included cases of blood results or soft tissue swelling which were not normal after the morning review but were kept on the operating list as potential cases pending correction of their issues. Non-clinical reasons mainly incorporated of lack of theatre time. Patients with an abbreviated mental test score of  $< 9$ , patients unable to complete the survey independently, those under 16 years of age, and any patient notified of

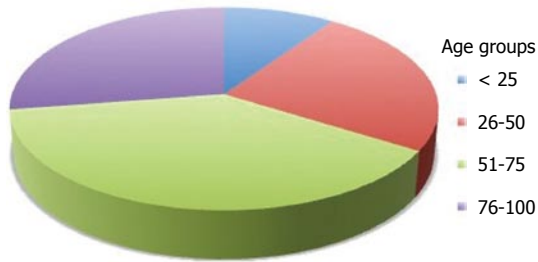


Figure 1 Age stratification of patients.

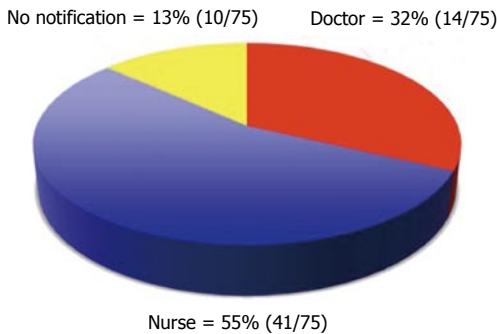


Figure 2 Breakdown (in percentage) of the qualification of the person notifying patients of the cancellation.

the cancellation by any of the authors were excluded from this study. Those doctors who were involved in the cancellation process did not participate in this study and were not aware that patients were being surveyed. Ethical approval was not required for this study; this was an audit of our current practice against accepted guidelines and it did not involve institution of any form of intervention.

## RESULTS

Sixty-five consecutive patients had their operation cancelled on 75 occasions. Individual cause for cancellation was not collated or correlated with satisfaction, as lack of theatre time was the leading cause of cancellations. Thirty-four of those cancelled were male and 31 females. The average age of patients was 59 years (range 17-91) (Figure 1). Ten patients had their operation cancelled on two occasions. A nurse notified patients for 41 (54.7%) of the cancellations and a doctor for 24 (32%) cancellations (Figure 2). Patients reported that they were dissatisfied with the explanation provided for 36 of the 75 (48%) cancellations. Of those patients who were dissatisfied, 25 (69.4%) were notified by a nurse. Overall, there was a significant difference in satisfaction between those counselled by a nurse and those notified by a doctor ( $P < 0.0001$ ). Twenty-three of the 24 (96%) patients notified by a doctor were satisfied with the explanation and that communication. Thirty-four (83%) patients notified by a nurse reported that they would have preferred it if a doctor had discussed the cancellation with them.

No formal communication occurred for 10 cancellations (13.3%) and no explanation was provided for a further 12 (16%) cancellations. When the results were

Table 1 Patient responses per age group

Age group (yr)	< 25	26-50	51-75	76-100
Satisfied	3	8	15	8
Not satisfied	3	7	8	9
Doctor:Nurse notification	2:3 (1 NN)	4:8 (3 NN)	8:15 (1 NN)	7:6 (4 NN)
<i>P</i> value	$P > 0.05$	$P > 0.05$	$P = 0.0194$	$P > 0.05$
Fisher Exact Test			Significant	

NN: No notification.

Table 2 Male:female responses and frequency of satisfaction

Sex	Male	Female
Number of patients	34	31
Satisfied	18	17
Not satisfied	16	14
<i>P</i> value	$P > 0.05$	
Fisher Exact Test		

stratified according to age group (Table 1) it revealed that significant differences between counselling by nurse or doctor were in age group 51-75 years. There was no difference in levels of satisfaction between male and female participants (Table 2). We also looked at 5 point likert scale for overall satisfaction with communication during the stay of the patient in the hospital as oppose to just the cancellation episode. Results revealed that 5 patients were completely satisfied, 30 very satisfied, 19 somewhat satisfied, 17 somewhat dissatisfied and 4 very dissatisfied.

There was significant association between patients who were not informed of their cancellation episode ( $n = 10$ ) and those that were ( $n = 65$ ) with their satisfaction with overall communication which was 1:52 respectively (Fisher exact test: two-tailed  $P$  value  $< 0.0001$ ).

## DISCUSSION

A good bedside manner, or the ability to take a medical history, is no longer the benchmark of good communication<sup>[5]</sup>. Communication skills are a core component of undergraduate and post-graduate medical curricula and communication has evolved into a measurable and assessable clinical skill<sup>[5,6]</sup>. In spite of this, poor communication remains pervasive-and in some cases can have very grave consequences. The Institute of Medicine in the United States has reported that an estimated 44000 to 98000 Americans die each year because of medical error with poor communication strongly implicated as cause of these errors<sup>[7,8]</sup>. More commonly, a failure of communication can lead to criticism, complaints and litigation<sup>[9-11]</sup>.

The results of this study suggest that patients have definitive preferences and expectations about the manner in which information is imparted regarding their operations. Members of the nursing team notified patients of their cancellation on 54.7% of cancellations but on the basis of these data patients appear to find this unsatisfactory.

Eighty-three percent patients who were notified by a nurse reported that they would have preferred it if a doctor had discussed the cancellation with them. These findings are in keeping with other studies suggesting that physicians are the preferred source of information provision<sup>[12,13]</sup> and serve to illustrate the importance of the doctor-patient relationship. Of the 34 patients notified by a nurse, nine reported that although they were satisfied with the explanation provided they would have been happier had a doctor discussed the cancellation with them. More worryingly, 10 patients (13% of cancellations) were not informed of their cancellations at all. A lack of theatre time availability was the leading cause for the cancellations. On those occasions when a doctor discussed the cancellation with the patient, 96% were satisfied with the explanation and the communication. Patients who were cancelled for medical reasons in the morning by the anaesthetic team were excluded from participation in this study.

The importance of effective communication and interpersonal skills, and the value ascribed to them by patients, encompasses several domains. According to Simpson *et al.*<sup>[14]</sup>, effective doctor-patient communication represents a central clinical function that cannot be delegated. Good communication can have a positive influence on psychosocial health, functional and physiological status, and pain control<sup>[15]</sup>, with patient satisfaction positively influenced by information provision by doctors<sup>[16]</sup>. Effective communication can also reduce the incidence of complaints and the incidence of clinical error<sup>[17]</sup>. In 2011, the Dr Foster Good Hospital Guide reported that disrespect and not being kept informed were two leading reasons why patients would not recommend their hospitals and that they valued this more than same-sex wards or cleanliness<sup>[18]</sup>.

The 2002 NHS Modernisation Agency's Step Guide to Improving Theatre Performance<sup>[3]</sup>, and the Association of Anaesthetists of Great Britain and Ireland<sup>[4]</sup>, have acknowledged the psychological impact of cancellations and advised that, in cases of cancellation for clinical reasons and system failings, a senior member of the medical team should visit the patient as soon as possible and offer an apology and explanation for the cancellation. Simpson *et al.*<sup>[14]</sup> have reported that uncertainty, a lack of information or explanation from doctors is associated with heightened anxiety and dissatisfaction. This was demonstrated in our data where a failure to communicate or provide adequate explanation correlated with overall patient dissatisfaction with communication.

The cause of these shortcomings is multifactorial. In the busy environment of an acute trauma and orthopaedic department it is not always feasible for the operating surgeon or a senior member of the medical team to meet with a patient to break the news immediately that their operation has been cancelled. In our own department, over 3500 trauma procedures are performed each year including more than 800 operations for hip fractures. Any theatre slot vacated by a cancellation may be quickly filled by another patient waiting for surgery. As a consequence,

the surgeon will seldom have an opportunity to leave theatre and visit the cancelled patient. It necessarily falls to a member of the nursing team or a ward based junior doctor to perform this role. This deficiency is further compounded by changes instituted as a result of the European Working Time Directive (EWTD) and the transition to shift-based rotas. The reduction in working hours to 48 h/wk has reduced the availability of junior doctors and, according to some authors, adversely affected the quality and continuity of patient care in some NHS services<sup>[19]</sup>. If the cancellation occurs outside normal working hours, the only doctor available to break the news may have no prior knowledge of the history and details for the cancelled patient.

Cancellations occur for a variety of reasons. Many of the factors that conspire to precipitate a cancellation will be outside the control and influence of the orthopaedic surgeon. It is a cause of concern that patients are cancelled because of a lack of theatre time. The purpose of this study was to evaluate the issues of communication irrespective of the reason for cancellation and not to examine the underlying factors for this lack of time. It can be challenging to identify those specific factors that conspire to precipitate the cancellation, but issues such as over-enthusiastic booking, delays in patient transfer, anaesthetics or surgical delays because of challenging patients or cases are regularly implicated. Despite the multifactorial nature of the cancellation, the cause is often attributed to lack of time. While this is invariably the case, citing a lack of time is not entirely reflective of the underlying reason.

This study suggests that one area in which surgeons can exert a positive influence is in the communication of cancellations. Communication skills are an integral component of medical education but this teaching is of little value if these skills are not employed in daily practice. The EWTD, a target-driven NHS, surgical departments operating at, or beyond, capacity may be regarded as barriers to communication. Irrespective of the cause, current practice does not appear to meet patient expectations or preferences and cultural and professional changes may be required to reverse this trend and improve performance.

We recognise that this study has limitations, including the fact that our questionnaire has not been validated. However, as no preceding study has examined this specific area of communication, there is no validated outcome measure available. Secondly, this study took place in a busy trauma unit and may not necessarily reflect the opportunities for communication seen in the elective realm. Lastly, the numbers involved in this study are comparatively small. However, we feel that the issues raised by this project will be applicable and transferable across all surgical disciplines.

The results of this study reveal that patients expect to be notified of cancellations and would prefer to be notified by a doctor rather than a member of the nursing team. While it is not always possible for a senior



doctor to break the news of the cancellation, a failure to notify the patient, either by a member of the medical or nursing team, is inexcusable. Moreover, it would not seem unreasonable for a doctor to spend a few minutes with a cancelled patient, even after notification by a nurse, to provide an explanation and address questions or concerns that were not answered or allayed at the initial notification. These findings illustrate the importance of the doctor-patient communication and the value that patients place on this relationship. In the current working environment there may be little scope or latitude for instituting widespread didactic changes in policy and practice. If changes are to be made, they may have to occur at the individual level-it must fall to members of the medical team to change their own practice. This may incur a few additional minutes of work but the impact of a few words of encouragement or a gentle hand of reassurance can have profound and lasting effects.

## COMMENTS

### Background

Communication is a fundamental component of medical practice. Poor communication predisposes to patient dissatisfaction. Good communication is of particular significance when breaking bad news, including notifying a patient of a cancelled operation. They wished to determine patient expectations and preferences regarding communication with a view to identify shortcomings in practice and improve provision of care.

### Research frontiers

Research has focused on the delivery and execution of communication skills in undergraduate curricula and post-graduate courses. In the area of communication research hotspot is to examine patients' preferences and expectations on day-to-day provision of care.

### Innovations and breakthroughs

This study has identified areas of weakness in communication in a busy orthopaedic trauma unit. Research has shown that good communication can positively influence patient experience and outcomes. To the best of person knowledge no previous study has examined the impact of communication on the notification of cancellation of operation in orthopaedics.

### Applications

These findings illustrate the importance of the doctor-patient communication and the value that patients place on this relationship. While it is not always possible for a senior doctor to break the news of the cancellation, a failure to notify the patient, either by a member of the medical or nursing team, is inexcusable. Moreover, it would not seem unreasonable for a doctor to spend a few minutes with a cancelled patient, even after notification by a nurse, to provide an explanation and address questions or concerns that were not answered or allayed at the initial notification. Furthermore, this study has highlighted shortcomings in practice, which may be transferred across other surgical disciplines. If changes are to be made, they may have to occur at the individual level. This may incur a few additional minutes of work but the impact of a few words of encouragement or a gentle hand of reassurance can have profound and lasting effects.

### Terminology

Communication- in context of this paper, this term relates to exchange of views between healthcare professional and patient and effectively imparting the information to the patient in a manner that they understand it in context of this paper. Cancellation- in context of this paper, this term stands for cancellation of operation of the patient.

### Peer review

This is an interesting manuscript about doctor-patient communication. The doctor-patient's relationship is core problem in the medicine surrounding. The goal of this paper was to examine the patients' perceptions on the communications surrounding cancellation of operations in orthopaedics and to identify ar-

eas for improvement in our communication skills. This prospective study was a new method to explore patients' satisfaction and preferences for notification of cancellation of their operations, by doctor and nurse respectively. The rationale is well presented and the manuscript is clearly written.

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## Comparative induction of controlled circulation by magnesium and remifentanyl in spine surgery

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of blood loss, urine output, fluid intake and surgeon's satisfaction were recorded. Data was analyzed with SPSS version 13.0 and *P* values less than 0.05 were considered significant.

**RESULTS:** Twenty patients in the MGS group and 19 patients in the REM group were studied. There was no difference between the two groups in the hemodynamic variables, blood loss, urine output, fluid requirement and surgeon's satisfaction for exposure. The target MAP was achieved in 75% of Mg and 58% of remifentanyl groups. Although a higher number of patients in the REM group required nitroglycerin (42.1%) to reach the target MAP than those in the MGS group (25%), this difference was not statistically significant (*P* = 0.32).

**CONCLUSION:** Our findings showed that in patients undergoing lumbar PSF surgery, remifentanyl and MGS have a similar hypotensive effect and comparable amount of blood loss without any significant adverse effects.

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**Key words:** Controlled hypotension; Magnesium sulfate; Remifentanyl; Spine surgery; Blood loss

**Core tip:** We conducted a relatively small sized prospective randomized clinical trial comparing intravenous infusion of remifentanyl with magnesium in controlling blood pressure during posterior spine fusion in order to decrease the intraoperative blood loss. Our experiments showed no difference between the two administered regimens in reducing mean arterial blood pressure and intraoperative blood loss, and satisfaction of the operating surgeons.

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### Abstract

**AIM:** To evaluate the efficacy of magnesium sulfate (MGS) in comparison with remifentanyl for induction of relative hypotension in posterior fusion of spine (PSF).

**METHODS:** In this randomized clinical trial, 40 patients with the American Society of Anesthesiologists I and II physical status undergoing lumbar PSF were randomized to receive remifentanyl (REM) 0.15 µg/kg or MGS 50 mg/kg for controlled hypotension. The administering anesthesiologist was blinded to the medication. Continuous infusion was maintained at a fixed volume rate to deliver precalculated doses of either study drugs. All other aspects of anesthesia and surgery were similar in the two groups. The target mean arterial pressure (MAP) range used in this study was 60-70 mmHg. In the course of surgery, the hemodynamic variables, volume

parative induction of controlled circulation by magnesium and remifentanyl in spine surgery. *World J Orthop* 2014; 5(1): 51-56 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v5/i1/51.htm> DOI: <http://dx.doi.org/10.5312/wjo.v5.i1.51>

## INTRODUCTION

In lumbar spine surgery, especially in posterior spinal fusion, a dry surgical field not only results in convenience for the surgeon, but also better hemostasis, reducing the likelihood of transfusion and its complications. Also, it decreases operation time and thereby avoids complications of prolonged surgery, particularly in the prone position, such as eyes injuries and nerve damage due to pressure, tongue edema and airway inflammation<sup>[1,2]</sup>.

Induced hypotension is one of the most effective methods for reduction of bleeding during surgery, known as controlled hypotension. Using this method during anesthesia for major spinal surgeries results in less bleeding and less need for blood transfusion<sup>[3]</sup>. Different methods for controlled hypotension have been described that can be divided into two main groups. First, the traditional style that keeps the patient in a light anesthesia with a secure airway and complete monitoring under a ganglion blocker or a vasodilator with a direct effect and, using this way, a beta blocker being used simultaneously is preferred<sup>[4]</sup>. The second method tries to control blood pressure without hypotensive drugs by increasing the depth of anesthesia, adequate ventilation and optimal position<sup>[5]</sup>.

Reduction in bleeding is not only important to maintain the hemodynamic balance, but also creates better visibility for the surgeon during surgery; this issue is especially important (significant) in spinal cord surgery because important neuronal structures are located in the field. In major surgical procedures such as scoliosis correction or posterior fusion, excessive bleeding occurs during or after surgery, so controlled hypotension is considered a way to reduce bleeding and improve surgical conditions<sup>[2,3]</sup>.

Various drugs have been used to reduce blood pressure, including vasodilators (nitroprusside, nicardipine), alpha-2 receptor agonists (clonidine, dexmedetomidine), beta-adrenergic antagonists (propranolol, esmolol) and alpha and beta antagonists (labetalol)<sup>[6-10]</sup>. However, hypotensive agents have several disadvantages, such as reflex tachycardia and tachyphylaxis<sup>[9]</sup>. Therefore, it is necessary to use compounds with dose-response effects that are predictable<sup>[11]</sup>. In recent years, remifentanyl as a short acting opioid receptor agonist has been used for this purpose in order for a mild to moderate reduction of blood pressure and as an effective agent for controlled hypotension<sup>[12]</sup>. Nevertheless, high doses of remifentanyl during surgery have its limits, with pain management after surgery and hyperalgesia in these patients<sup>[13]</sup>. Currently, remifentanyl with propofol is used for total intravenous anesthesia. Compared with other opioid drugs such as fentanyl and alfentanil, remifentanyl can provide better hemodynamic stability in the stressful events of surgery

and can minimize changes in cerebral blood flow<sup>[14-17]</sup>.

Magnesium sulfate (MGS) is a noncompetitive antagonist of N-methyl, D-aspartate (NMDA) receptors with an analgesic effect and is essential for release of acetylcholine from the presynaptic terminals<sup>[18,19]</sup> and, similar to calcium channel blockers (CCB), can prevent the entry of calcium into the cell. According to previous studies, magnesium can cause hypotension with a vasodilatory effect. The vasodilatory effects of this ion are due to increased construction of prostacyclins and inhibition of angiotensin converting enzyme. So it seems that this product could be applied for lowering blood pressure during various surgical procedures<sup>[20,21]</sup>.

To the best of our knowledge, there have been no studies comparing controlled hypotension by magnesium and remifentanyl in lumbar spine fusion surgery. So, we decided to compare their efficacy, blood loss and likely hemodynamic complications in a prospective study in candidates for lumbar spine fusion surgery. We hypothesized that magnesium is as effective as remifentanyl in deliberate induction of hypotension used to reduce surgical blood loss.

## MATERIALS AND METHODS

The study was designed as a prospective double-blind randomized trial. The experimental design and complete study protocol were reviewed and approved by the Medical Research Ethics Committee at Tehran University of Medical Sciences. The study was also registered with the national Iranian Registry of Clinical Trials (<http://www.irct.ir>), IRCT201111138091N1 in accordance with World Health Organization's requirements and the International Committee of Medical Journal Editors' initiative.

The study population included orthopedic and neurological patients admitted to Tehran's University Hospital (Firoozgar center) from 2010 to 2011. Patients between 20 and 60 years old undergoing posterior lumbar spine fusion were surveyed based on inclusion and exclusion criteria. Eligible patients [American Society of Anesthesiologists (ASA) physical status 1 or 2, operation time of 3 to 5 h and mentally competent] were approached and signed informed consent after complete explanation of the details of the research project and its potential risks.

Exclusion criteria were as follows: operation time more than 5 h, allergic reaction to drugs, and patients with a history of liver, renal, heart and vascular failure, cardiac conduction disturbance, opium addiction, any drug or substance abuse and chronic treatment with opium, non-steroidal anti-inflammatory drugs and CCB.

Patients were randomized with block randomization (four piece blocks) into two groups: MGS and receive remifentanyl (REM). Someone who was uninformed of the study developed a list of replacement and then according to the entry of each sample to study, treatment groups of patients were determined. Upon arrival to the operating room, standard monitoring, including end-tidal carbon dioxide, pulse oximetry, non-invasive blood pressure and 5-lead electrocardiography, was started and



baseline hemodynamic variables were recorded. After establishing an IV line and administration of 500 cc normal saline before induction of anesthesia, patients were preoxygenated with 100% oxygen for 5 min. All patients in both groups received midazolam 0.03 mg/kg and fentanyl 3 µg/kg upon arrival in the operating room. For induction of anesthesia, patients received 1.5-2.0 mg/kg propofol and atracurium 0.5 mg/kg was used for muscle relaxation and intubation. After induction of anesthesia, a radial arterial line from the non-dominant hand for continuous monitoring of mean arterial pressure (MAP) was obtained. All patients were mechanically ventilated with a mixture of oxygen and nitrous oxide (fraction of inspired oxygen was 50%) at a tidal volume of 8 mL/kg (ideal body weight), I/E ratio of 1/3 and the respiratory rates were adjusted in the 9-14 breaths/min range to maintain end-tidal concentration of carbon dioxide between 30 and 40 mmHg. Continuous infusion of propofol with a dose of 100-120 µg/kg per minute and bolus doses of atracurium every 20 to 30 min were used for maintenance of anesthesia, similar in both groups. Also, in the first 30 min after the position, morphine sulfate was infused 0.1 mg/kg within 20 min.

After establishing a prone position and ensuring hemodynamic stability, for the MGS group, a loading dose of 50 mg/kg magnesium diluted in 100 cc saline infused within 10 min and then the magnesium infusion continued with dose of 15 mg/kg per hour throughout surgery. In the REM group, remifentanyl (loading dose 1 µg/kg; maintenance infusion, 0.25 µg/kg per minute) was administered during anesthesia. A research pharmacist prepared both magnesium and remifentanyl solutions to make sure the volumes of infusion were the same for each group in order to maintain the blinding process for the administering anesthesiology team.

Our goal was to maintain MAP between 60 to 70 mmHg. Using the above method, if the optimum MAP was not reached in 10 min after skin incision, nitroglycerin (NTG) 10 to 20 µg/min was applied and increased if needed. Duration and frequency of NTG use was recorded as a measurement of failure in the primary goal for comparison between groups. If the blood pressure dropped below the target range, the infusion rate of propofol was reduced to half and in cases where hypotension continued, ephedrine was injected in bolus doses of 5 mg. Possible complications such as arrhythmia, hypotension, hypertension and bradycardia and measures necessary to treat these complications were recorded in both groups. Operation time, approximate amount of bleeding, urine output, volume of fluids and the need for transfusion were recorded on special forms. Blood transfusion was determined based on primary hemoglobin and calculation of maximum allowable blood loss (target hemoglobin = 10 g/dL).

For reducing the chance of prolonged muscle relaxation by magnesium, the study drug infusion was stopped about half an hour before the end of surgery (after fixation of rods and starting repair of wounds) and propofol and remifentanyl infusion was reduced to half.

Finally, after surgery and changing the patient's position from a prone to supine position, muscle relaxant effects was reversed and, in order to ensure adequate reversal of muscle relaxation, nerve stimulator and double burst stimulation (DBS) were applied (DBS > 90%).

After removing the endotracheal tube, patients were transferred to the post-anesthesia care unit where they were monitored for signs of hypermagnesemia (respiratory depression, decreased deep tendon reflexes, electrocardiographic changes) every 15 min in addition to routine cardiorespiratory monitoring. Serum magnesium concentrations were obtained if there was any clinical sign of hypermagnesemia.

Surgeries were performed in two centers with the two almost constant teams. Surgeon's satisfaction was recorded using the Likert technique or scale at the end of surgery (1 = very dissatisfied to 5 = completely satisfied). The research team member who recorded data during surgery, the person administering the infusion and the surgeon were blinded to the type of intervention.

### Statistical analysis

The data was analyzed with SPSS 18.0 software. Quantitative data was given as the mean and standard deviation and qualitative data presented as frequency. Categorical data were analyzed using the  $\chi^2$  test and Fisher's exact test; continuous variables were analyzed by the Student *t* test when data complied with a normal distribution and were expressed as mean  $\pm$  SD. Otherwise, non-parametric tests were used (Wilcoxon Rank test) and data were expressed as median and interquartile range. analysis of variance with repeated measures was used to analyze hemodynamic variables at different time points. Null hypotheses were rejected if *P* values were less than 0.05.

## RESULTS

The study was completed with 39 patients. One patient from the REM group was excluded from the study because of an unusual type of surgery and prolonged duration of operation. The average age was  $41.2 \pm 14.4$  years old and body mass index was  $30.8 \pm 9.2$  kg/m<sup>2</sup>. Demographic variables (age, gender, ASA physical status and body habitus) were comparable in the MGS and REM groups (Table 1).

Total intra-operative fluid administration was  $3.6 \pm 0.9$  L in the MGS group and  $3.3 \pm 1.0$  L in the REM group (*P* = 0.39) (Table 2). Average bleeding in the MGS and REM groups was  $650 \pm 335.9$  mL and  $681 \pm 312.8$  mL, respectively (*P* = 0.77). Three patients in the MGS group (15%) and 5 patients in the REM group (25%) required blood transfusion but it was not significant statistically (*P* = 0.21). Maximum blood transfusion in patients was 2 bags of packed cells. There was no difference in urine output between the two study arms (*P* = 0.56). The satisfaction scores from the surgeons regarding exposure of the surgical field between the groups were similar. In both groups, these values were higher than 3 (good satisfaction).

Table 1 Demographic data

	REM <i>n</i> = 19	MGS <i>n</i> = 20	<i>P</i> value
Age (yr)	43.1 ± 15.6	39.3 ± 13.2	0.42
Gender; male (%)	10 (52%)	11 (55%)	0.98
Body mass index (kg/m <sup>2</sup> )	31.3 ± 12.4	30.2 ± 4.6	0.72
ASA PS-1	5 (27%)	5 (25%)	0.86
ASA PS-2	14 (73%)	15 (75%)	
Satisfaction score	4.2 ± 0.6	4.3 ± 1.1	0.89

MGS: Magnesium sulfate; REM: Remifentanyl; ASA: American Society of Anesthesiologists.

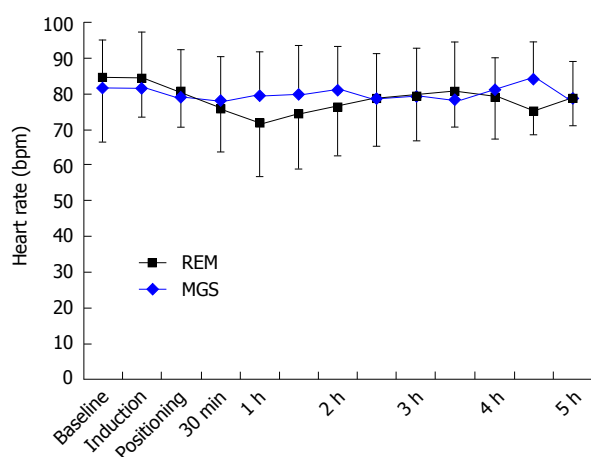


Figure 1 Temporal changes of the heart rate in both groups at the baseline, the induction of anesthesia, positioning, following 30 min and every hour thereafter. MGS: Magnesium sulfate; REM: Remifentanyl.

The baseline heart rate was  $84 \pm 18$  bpm in the MGS group and  $81 \pm 13$  bpm in the REM group ( $P = 0.67$ ). The mean heart rate changes at different time-points during surgery are shown in Figure 1. These changes were similar in both groups. The baseline MAP was  $102 \pm 12$  mmHg and  $99 \pm 11$  mmHg in the MGS and REM groups, respectively. Changes in MAP were similar in both groups (Figure 2). Five patients in the MGS group (25%) and 8 patients in the REM group (42.1%) failed to reach the target blood pressure and required NTG infusion at doses ranging from 0.5-1  $\mu$ g/kg per minute ( $P = 0.32$ ).

There were 4 episodes of hypotension ( $\text{MAP} \leq 60$ ) in the MGS group and 3 episodes in the REM group requiring pharmacological intervention (ephedrine boluses) ( $P = 0.732$ ). There was no reported arrhythmias/tachycardia in either group. A total of 3 patients in the MGS group (15%) and 1 patient in the REM group received atropine due to bradycardia ( $\text{HR} \leq 50$  b/min), which was not significant ( $P = 0.61$ ). Clinical assessment and neuromuscular monitoring of patients revealed a full recovery from the remaining effects of neuromuscular blocking drugs in all patients. Additionally, no patients had signs and symptoms of hypermagnesemia post-operatively.

## DISCUSSION

We have shown that magnesium is as effective as remi-

Table 2 Perioperative variables

	MGS <i>n</i> = 20	REM <i>n</i> = 19	<i>P</i> value
Duration of surgery (min)	168 ± 54	162 ± 42	0.32
Lowest recorded MAP (mmHg)	52 ± 13	55 ± 15	0.72
Intravenous fluids (L)	3.6 ± 0.9	3.3 ± 1.02	0.39
Urine output (mL)	959 ± 368	1043 ± 508	0.56
Intraoperative blood loss (mL)	650 ± 336	681 ± 313	0.77
Transfusion frequency (%)	3 (15%)	5 (26%)	0.21
PRBC transfused (units)	1.75 ± 0.46	1.50 ± 0.54	0.33
Preop. serum magnesium (mEq/L)	2.16 ± 0.21	2.18 ± 0.19	0.76

MGS: Magnesium sulfate; REM: Remifentanyl; MAP: Mean arterial pressure; PRBC: Packed red blood cells; Preop.: Preoperative.

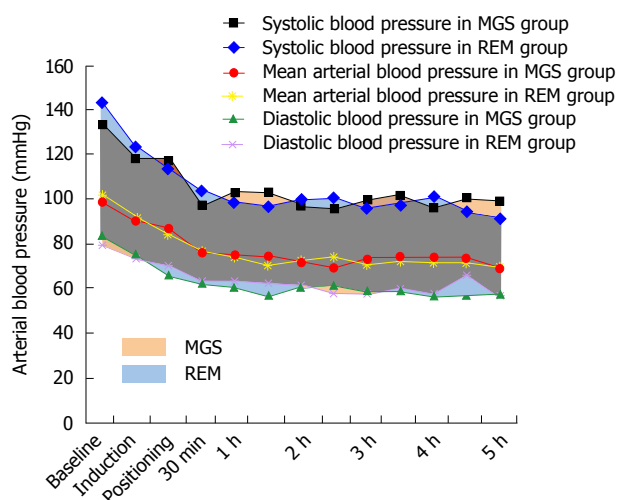


Figure 2 Temporal changes of the systolic, diastolic and mean arterial pressure in both groups at the baseline, the induction of anesthesia, positioning, following 30 min and every hour thereafter. MGS: Magnesium sulfate; REM: Remifentanyl.

fentanyl in inducing controlled hypotension during lumbar fusion surgery. Magnesium was able to reduce MAP (60-70 mmHg), similar to remifentanyl. Equal numbers of patients needed supplemental nitroglycerine infusion to decrease the blood pressure to preset target levels. There was no life-threatening bradycardia, arrhythmias or hypotension in either group.

Controlled circulation, formerly known as deliberate hypotension, is used to reduce bleeding during surgery and to reduce blood transfusion. With surgical procedures on bone and some other vessel-rich areas where direct compression of the blood vessels is not feasible due to anatomical reasons, significant bleeding may occur. Therefore, a controlled hypotension may reduce bleeding and improve the surgical exposure in these patients. Our findings showed that magnesium has a similar efficacy in reducing bleeding as remifentanyl in lumbar fusion surgeries. Additionally, surgeon satisfaction scores were used to subjectively assess the surgical bleeding and exposure. A five point Likert scale was used for this assessment. Likert scales may be subject to *central tendency* bias, where the respondents agree to neutral answers; *acquiescence* bias, where they agree with statements as presented; or *social*

desirability bias, where they try to portray themselves or their organization in a more favorable light.

Previously, Ryu *et al.*<sup>[22]</sup> compared the efficacy of remifentanyl with magnesium to induce controlled hypotension in middle ear surgery. These authors demonstrated that magnesium and remifentanyl were comparable in inducing controlled hypotension; however, the patients reported less post-operative pain in the magnesium group. Additionally, magnesium was associated with a lower incidence of postoperative nausea and/or vomiting and shivering during emergence from anesthesia when compared to those receiving remifentanyl. Our findings confirmed the results reported by these investigators. Analgesic effects of magnesium were attributed to its ability to inhibit NMDA receptors in a non-competitive way. Although we did not study the analgesic effects of magnesium particularly, the intraoperative pain profile and requirement for morphine supplement was similar to remifentanyl. Several other investigators also showed that the use of magnesium reduced the analgesic requirement after surgery<sup>[19,23,24]</sup>.

Magnesium is used to induce controlled hypotension due to its inherent vasodilatory effects. Yosry *et al.*<sup>[25]</sup> successfully used magnesium to induce controlled hypotension for choroid melanoma (a highly vascular tumor with a tendency to bleed) surgery. They compared magnesium to nitroprusside and eloquently demonstrated that choroidal blood flow as measured by laser Doppler flowmetry was reduced with magnesium, comparable to nitroprusside. There was no need for a pharmacological supplement in either group in order to decrease the blood pressure to the target levels. Although we needed to supplement our patients with intravenous NTG in 25% of patients to attain the preset target MAPs down to the 60-70 mmHg range, there was no difference between the REM and MGS groups in the amount of surgical bleeding. Similarly, Göral *et al.*<sup>[26]</sup> demonstrated that magnesium significantly decreased the amount of surgical bleeding following lumbar discectomy surgery and improved the surgical exposure compared to normal saline controls. These authors used normal saline as a control, a strategy that we could not establish for both therapeutic and ethical reasons.

Cerebral perfusion is the main point of concern when deliberate hypotension is used in clinical settings. Although an intact auto-regulation is supposed to maintain a constant blood flow to the brain as long as MAPs are maintained equal to or greater than 50 mmHg, the adequacy of perfusion depends on cerebral metabolic rates. Controversy remains regarding the effects of magnesium on cerebral blood flow. While magnesium has been shown to increase cerebral blood flow in patients with preeclampsia, Wong *et al.*<sup>[27]</sup> were unable to show any increase in regional cerebral blood flow using perfusion magnetic resonance imaging among 12 patients following acute subarachnoid hemorrhage following intravenous MGS infusion. In experimental settings, magnesium treatment preserves the ischemia-induced reduction in S-100 proteins, possibly by restoration of blood brain

permeability during hypoxia<sup>[28]</sup>. Additionally, Mori *et al.*<sup>[29]</sup> have described neuro-protective effects following intrathecal infusion of magnesium in a rat model of subarachnoid hemorrhage. Neuroprotective effects of magnesium are considered advantageous during controlled hypotension.

Cardiovascular complications associated with magnesium infusion, such as arrhythmia, hypotension, bradycardia and tachycardia, were similar between the MGS and REM groups in our study. Although the number of patients studied in our series was not powered to comment about the safety of magnesium, the incidence of these complications in patients after a similar dose of magnesium was rare in the literature. Moreover, previous research showed that magnesium might in fact be beneficial in reducing post myocardial infarction incidence of dysrhythmias, pump dysfunction and death<sup>[30]</sup>. Even the issue of retention of muscle relaxant drugs after surgery was not very concerning<sup>[31]</sup>.

## COMMENTS

### Background

Bleeding becomes an important intraoperative issue when surgery is being performed on bone and other non-compressible tissues. Lumbar spine surgery, especially posterior spinal fusion, is not an exception to this complication. While other methods of hemostasis are rendered ineffective, deliberate reduction of the blood pressure has been effective in decreasing surgical bleeding and the likelihood of transfusion.

### Research frontiers

Various drugs have been used to reduce blood pressure, including vasodilators, alpha-2 receptor agonists, alpha-1 antagonists and beta-adrenergic antagonists. However, hypotensive agents have several disadvantages, such as reflex tachycardia and tachyphylaxis. Therefore, it is necessary to use compounds with dose-response effects that are predictable. In recent years, remifentanyl as a short acting opioid receptor agonist has been used for this purpose. This agent was used as a treatment arm in this study.

### Innovations and breakthroughs

The authors concluded that administration of intravenous magnesium could be used as a good alternative to induce controlled hypotension, decrease surgical bleeding and provide a better surgical exposure in spinal surgeries. Although a pharmacoeconomic comparison was not the authors main objective in this study, the lower cost of magnesium compared to the other pharmacological alternatives may make it more cost effective.

### Applications

The lack of a control group that received no magnesium and/or remifentanyl may be a limitation of this study. The authors have shown that magnesium is as effective as remifentanyl in inducing controlled hypotension during lumbar fusion surgery. Magnesium has been able to reduce mean arterial pressure (60-70 mmHg), similar to remifentanyl. There was no life-threatening bradycardia, arrhythmias or hypotension in either group.

### Peer review

The manuscript is well prepared and this is a well designed clinical trial. The study has been reviewed and approved by the institutional review board, following the ethical guidelines of human research. The only possible deficiency is the choice of remifentanyl for induced hypotension because this is not a commonly used hypotensive agent.

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## Neurovascular complications due to the Hippocrates method for reducing anterior shoulder dislocations

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### Abstract

In spite of the fact that the Hippocrates method hardly has been evaluated in a scientific manner and numerous associated iatrogenic complications have been reported, this method remains to be one of the most common techniques for reducing anterior shoulder dislocations. We report the case of a 69-year-old farmer under coumarin anticoagulant therapy who sustained acute first time anterior dislocation of his dominant right shoulder. By using the Hippocrates method with the patient under general anaesthesia, the brachial vein was injured and an increasing hematoma subsequently caused brachial plexus paresis by pressure. After surgery for decompression and vascular suturing, symptoms declined rapidly, but brachial plexus paresis still was not fully reversible after 3 mo of follow-up. The hazardousness of using the Hippocrates method can be explained by traction on the outstretched arm with force of the operator's body weight, direct trauma to the axillary region by the physician's heel, and the topographic relations of neurovascular structures and the dislocated humeral head. As there is a variety of alternative reduction techniques which have been evalu-

ated scientifically and proofed to be safe, we strongly caution against the use of the Hippocrates method as a first line technique for reducing anterior shoulder dislocations, especially in elder patients with fragile vessels or under anticoagulant therapy, and recommend the scapular manipulation technique or the Milch technique, for example, as a first choice.

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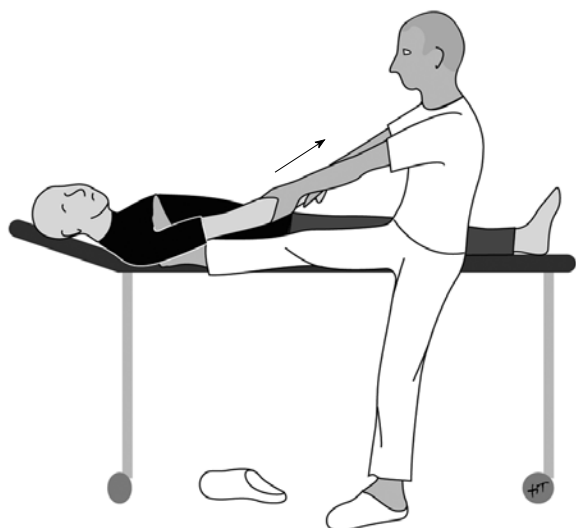
**Key words:** Anterior shoulder dislocation; Reduction technique; Hippocrates method; Complications; Brachial plexus paresis; Brachial vein injury; Scapular manipulation technique

**Core tip:** By using the Hippocrates method for reducing an anterior shoulder dislocation with the patient under general anaesthesia, the brachial vein was injured and an increasing hematoma subsequently caused brachial plexus paresis. The hazardousness of the Hippocrates method can be explained by traction on the outstretched arm with force of the operator's body weight, direct trauma to the axillary region by the physician's heel, and the topographic relations of neurovascular structures and the dislocated humeral head. Therefore we strongly caution against the use of the Hippocrates method as a first choice.

Regauer M, Polzer H, Mutschler W. Neurovascular complications due to the Hippocrates method for reducing anterior shoulder dislocations. *World J Orthop* 2014; 5(1): 57-61 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v5/i1/57.htm> DOI: <http://dx.doi.org/10.5312/wjo.v5.i1.57>

### INTRODUCTION

Shoulder dislocations account for about 50% of all major joint dislocations presenting to emergency departments,



**Figure 1** The most famous Hippocrates method for reducing anterior shoulder dislocations using the operator's heel in the patient's axilla for counter-traction. The operator can use his whole body weight to perform traction on the injured arm.

and the most common type (95%-98%) of this frequent injury is the anterior shoulder dislocation<sup>[1-9]</sup>. Acute anterior shoulder dislocations usually represent impressing orthopaedic emergency cases, and reduction should be performed as soon as possible, as reduction is the most effective pain relief therapy.

More than 2500 years ago Hippocrates (460-377 B.C.) described in detail various methods for reducing shoulder dislocations, and reduction with the heel has become the most famous one (Figure 1). Hippocrates stated, that "reduction is to be effected, if possible, immediately while still warm, otherwise as quickly as it can be done for reduction will be a much quicker and easier process for the operator and a much less painful one to the patient if effected before swelling comes on"<sup>[10-14]</sup>.

Since that time, at least 34 different methods for reducing shoulder dislocations have been reported in the literature and are used, often not evidence based and with little scientific theory behind their use<sup>[2,8,10-13,15-34]</sup>. And in spite of the fact that the Hippocrates method hardly has been evaluated in a scientific manner and numerous associated iatrogenic complications have been reported, this method remains to be one of the most common techniques for reducing anterior shoulder dislocations, especially in European countries<sup>[8,25,26,35-40]</sup>.

We report the case of a 69-year-old farmer under coumarin anticoagulant therapy who sustained acute first time anterior dislocation of his dominant right shoulder. By using the Hippocrates method with the patient under general anaesthesia, the brachial vein was injured and an increasing hematoma subsequently caused brachial plexus paresis by pressure.

## CASE REPORT

A 69-year-old farmer fell off his tractor and thereby sustained a traumatic first-time anterior dislocation of his

dominant right shoulder. Due to cardiac arrhythmia he has been under coumarin anticoagulant therapy since 15 years. On admission at a foreign clinic in a rural area more than six hours after the occupational accident the neurovascular status of the right arm was documented as regular. The right shoulder region revealed the typical clinical signs of an anterior shoulder dislocation, but there were absolutely no signs of soft tissue swelling or hematoma. Radiological evaluation of the right shoulder (true anteroposterior and outlet views) confirmed a sub-coracoidal anterior shoulder dislocation with a classical Hill-Sachs lesion. Closed reduction was performed subsequently under general anaesthesia using the Hippocrates method. Post-reduction X-rays showed successful relocation of the right shoulder and the already known Hill-Sachs lesion, but additional fractures could be excluded.

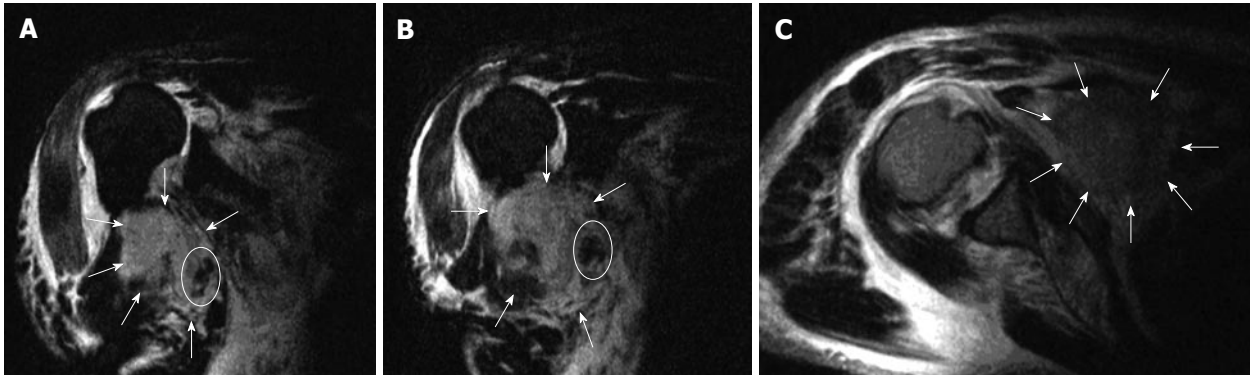
Twelve hours after reduction the patient complained about an increasing swelling in the right axillary region combined with paresthesia of the whole right hand. Clinical examination revealed a right drop hand, and active flexion of the right elbow was not possible anymore. Coumarin medication had already been stopped at admission, but the current international normalised ratio value was still 3.1. Open magnetic resonance imaging (MRI) examination showed ruptures of the rotator cuff and of the short tendon of the biceps muscle as well as a massive retropectoral hematoma (5.0 cm × 7.5 cm × 8.5 cm) compressing the axillary neurovascular bundle (Figure 2). Thereupon the patient was transferred to our level one trauma centre for surgical treatment.

Immediate surgical exploration of the right axillary region was performed under medical promotion of coagulation by prothrombin complex concentrate (PPSB) and showed extensive soft tissue trauma with disruption of the short tendon of the biceps muscle, rupture of the coracobrachial muscle and 300 mL retropectoral hematoma which was evacuated. The whole neurovascular bundle was surrounded by hematoma and there was severe soft tissue edema especially at the course of the radial nerve near to the outflow of the deep brachial artery. After meticulous exposure of the neurovascular bundle we finally found a small tear of the proximal brachial vein which had to be sutured microsurgically. The radial, median and ulnar nerves as well as the deep brachial artery were found to be intact.

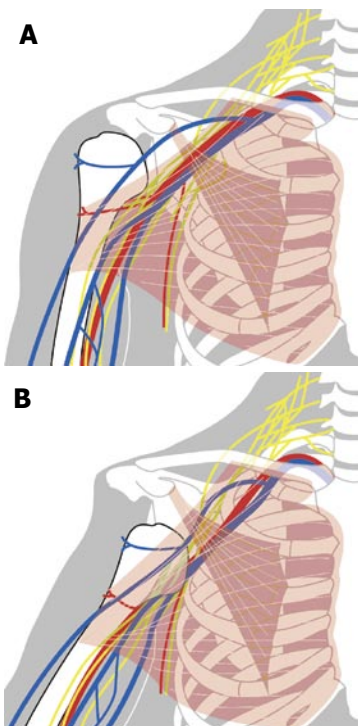
After recovery from general anaesthesia motor function of the right arm increased rapidly, but neurological examination three days after surgery still revealed incomplete brachial plexus palsy without sensory deficits. Therefore the patient performed prolonged physiotherapy, and six months after trauma motor function of the right hand had fully recovered. Activities of daily living were nearly not restricted and working as a farmer was possible again, but due to the rotator cuff tears the patient still had problems performing overhead activities like combing hair, for example.

## DISCUSSION

The presented case report shows that the Hippocrates



**Figure 2** Open magnetic resonance imaging coronar STIR T2 (A and B) and axial TSE T2 (C) sequences representing a large retropectoral hematoma (arrows) compressing the neurovascular bundle (ellipse). Note striking raised position of the humeral head due to massive rotator cuff tears (A and B).



**Figure 3** Topographic relations between the axillary neurovascular bundle and the humeral head in normal (A) and anteriorly dislocated (B) position. The humeral head, acting as a fulcrum, and the tight caudal rim of the pectoralis minor muscle can lead to pincer-like forces on the neurovascular bundle during performing the Hippocrates method for reducing anterior shoulder dislocations.

method for reducing anterior shoulder dislocations can at least in inexperienced hands and feet lead to severe iatrogenic complications. In this case we have the rare advantage of an extensive and accurate documentation of the initial treatment in the foreign clinic, as a standardized documentation is mandatory when treating an occupational accident. Documented lapse of symptoms as well as intraoperative findings confirm the strong suspicion that the described neurovascular complications were iatrogenically caused by the use of the Hippocrates method under general anaesthesia and not by the primary trauma, as the first symptoms of neurovascular damage occurred twelve hours after reduction and as the whole neurovascular bundle was surrounded by hematoma and

there was a severe soft tissue edema at the course of the radial nerve near to the outflow of the deep brachial artery, and this is exactly where the operator's heel has been positioned while performing the reduction.

Of course it is not always possible to decide if a vascular injury had been caused by the dislocation trauma itself or iatrogenically by the reduction manoeuvre. A lesion of a vein or a smaller artery caused by the initial trauma might primarily be occluded by the dislocated humeral head and might start bleeding not before a successful reduction has diminished the occluding pressure on the injured vessel. But in our case the patient was under coumarin anticoagulant therapy and the first clinical examination was performed more than six hours after trauma, so that it is very unlikely that the tear of the proximal brachial vein was caused by the initial trauma without development of a significant axillary haematoma within six hours.

Allie reported that 19 out of 27 patients with primary axillary artery injuries after shoulder dislocation showed a striking axillary mass already at the time of initial presentation<sup>[37]</sup>.

Regarding the Hippocrates method for reducing anterior shoulder dislocations numerous iatrogenic complications have been reported in the literature<sup>[35,36,38-40]</sup>. Schmal reported a tear of the subscapular artery, for example, and Cyffka recognized an iatrogenically caused displaced humeral head fracture after performing the Hippocrates method<sup>[35,36]</sup>.

Several pathogenic mechanisms can be proposed in order to explain neurovascular damage caused by performing the Hippocrates method. On the one hand, the dislocated humeral head can act as a fulcrum over which the neurovascular bundle is bent while performing traction on the injured arm, and the operator's heel can push the vessels against the tight inferior rim of the pectoralis minor muscle and thus cause a pincer-like shear stress on the vessels as well as severe direct local damage (Figure 3). On the other hand, simple tethering of the axillary vessels by their subscapular and circumflex branches can lead to disruption by performing traction on the arm and counter-traction by use of the heel, whereupon excessive forces are possible by use of the whole body weight



(Figure 1).

Predisposing factors for vascular injuries during shoulder reduction are old age with associated atherosclerotic changes of the vessels and recurrent shoulder dislocations, as repeated trauma can cause periscapular fibrosis and adhesions with fixation of the axillary artery and vein branches, which may lead to tearing of the vessels during a subsequent reduction manoeuvre<sup>[39]</sup>.

Another relevant risk factor for iatrogenic damage by performing shoulder reductions might be the primary use of general anaesthesia, as the physician can not get any feedback from the patient during as well as a certain period after reduction until the patient is conscious again. In our case, the patient might have recognized the ongoing development of neurovascular damage some hours earlier without the use of general anaesthesia. And in our long-time experience more than 90% of anterior shoulder dislocations can successfully be reduced without the use of general anaesthesia (unpublished data).

According to the original description of the Hippocrates reduction method by use of the heel “the patient must lie supine, usually on the floor. The doctor must stand on the side of the injured shoulder. He holds the upper extremity with both hands, pulls it toward his side, and by using, for example, his right heel in the right axilla, he counterpushes the head of the humerus, which is thus easily reduced.” Hippocrates additionally stated that “it is wise to put a small hard cotton ball in the axilla before starting to push to minimize trauma and maximize the surfaces where pressure is applied”<sup>[12]</sup>. But this ancient advice is usually not considered anymore today.

There are at least 33 alternative reduction techniques for anterior shoulder dislocations reported in the literature, among which the Kocher method, the Milch technique and the Scapular Manipulation technique have been evaluated scientifically in several studies each<sup>[2,8,10-13,15-34]</sup>.

Like the Hippocrates method, also the Kocher method is associated with iatrogenic complications and thus should not be used as a first choice in our opinion<sup>[12,33]</sup>. The Milch technique and the Scapular Manipulation technique, however, have proved to be safe as well as successful<sup>[10,16,27-32]</sup>. According to these data we are primary using a modified Scapular Manipulation technique for reducing anterior shoulder dislocations at our department<sup>[33]</sup>.

In conclusion, the hazardousness of using the Hippocrates method can be explained by traction on the outstretched arm with force of the operator's whole body weight, direct trauma to the axillary region by the physician's heel, and the topographic relations of neurovascular structures and the dislocated humeral head. As there is a variety of alternative reduction techniques which have been evaluated scientifically and proofed to be safe, we strongly caution against the use of the Hippocrates method as a first line technique for reducing anterior shoulder dislocations, especially in elder patients with fragile vessels or under anticoagulant therapy, and recommend the Scapular Manipulation technique or the Milch technique, for example, as a first choice.

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## Isolated dorsal approach for the treatment of neglected volar metacarpophalangeal joint dislocations

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radiological outcomes.

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**Key words:** Metacarpophalangeal dislocation; Neglected dislocation; Surgical treatment; Dorsal surgical approach; Metacarpophalangeal dislocation rehabilitation

**Core tip:** Irreducible complex metacarpophalangeal (MP) dislocations are rare. Volar MP dislocations are very rare. There are no data in the literature reporting volar MP dislocations. We also observed neglected volar MP dislocations in our study. A dorsal or volar approach can be applied toward the surgical treatment of MP joint dislocations. In this study, we observed that isolated dorsal open reduction and K wire fixation results in a successful functional outcome in neglected volar MP dislocations. Volar exposure was not necessary for reduction and stabilization.

### Abstract

Here, we present the clinical and radiological results of three neglected volar metacarpophalangeal dislocations in 2 patients, which were treated with open reductions 10 and 24 mo after the dislocations. There was a mean of a 20° (range 10°-30°) limitation of extension and a 53.3° (range 30°-70°) limitation of flexion preoperatively. Postoperatively, there was no limitation of extension (at 8 and 12 mo) in any of the fingers. In terms of flexion, one finger had full function, one had a 10° and the last one had a 30° limitation of flexion. Two of the fingers presented anesthesia preoperatively, which improved to hypesthesia postoperatively. One finger had hypesthesia, which improved postoperatively. During surgery, a ruptured dorsal capsule was found to have interposed into the joint, making closed reduction impossible. Our experience with these two patients demonstrated that, even in neglected cases, open reduction using an isolated dorsal approach may result in satisfactory clinical and

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### INTRODUCTION

Irreducible complex metacarpophalangeal (MP) dislocations are rare. Among these, volar dislocations are even rarer<sup>[1,2]</sup>. The reduction in complex dislocations is usually achieved *via* open reductions<sup>[3]</sup>. To our knowledge, there are no data in the literature reporting the results of late open reductions of neglected volar MP dislocations. In this study, we aimed to report the results of the open reductions of 3 volar MP dislocations of 2 patients using



**Figure 1** Preoperative and postoperative clinical radiological images of case 1. A: Pre-operative 30° limitation of flexion in the 4<sup>th</sup> and 60° limitation of flexion in the 5<sup>th</sup> metacarpophalangeal (MP) joint; B: Preoperative AP and lateral radiographies; C: 4<sup>th</sup> MP joint has 20° and 5<sup>th</sup> MP joint has 30° limitation of flexion at 2 mo postoperative; D: Full flexion at the 4<sup>th</sup> MP joint and 10 degrees limitation of flexion at the 5<sup>th</sup> MP joint at postoperative 12<sup>th</sup> month; E: Radiographies at 12<sup>th</sup> month. The reduction is maintained and the osteotomy line at the 4<sup>th</sup> proximal phalanx had fused.

an isolated dorsal approach.

## CASE REPORT

### Case 1

A 22-year-old male presented with complaints of pain, anesthesia of (and inability to move) the 4<sup>th</sup> and 5<sup>th</sup> fingers and deformity of the 4<sup>th</sup> and 5<sup>th</sup> MP joints of his left hand. He had suffered a dorsal laceration of his left hand during a traffic accident. The laceration had extended from the 2<sup>nd</sup> MP joint to the 5<sup>th</sup>. Six hours after the injury, a closed reduction was attempted at another center, and 24 h later, the 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> extensor tendons were repaired. He was followed with a below elbow cast for 2 wk. After 2 wk, the cast was removed, and passive and active exercises were started. Since removal of the cast, he noticed stiffness at the 4<sup>th</sup> and 5<sup>th</sup> MP joints and hypesthesia on the radial side of the 4<sup>th</sup> and 5<sup>th</sup> fingers. Despite these complaints, he did not seek further medical care. After 18 mo, he started a new job that required heavy manual labor, which increased the hypesthesia and eventually progressed to anesthesia of both the 4<sup>th</sup> and 5<sup>th</sup> fingers 23 mo after the injury. When he presented 24 mo after injury, he had anesthesia of the radial side of both fingers. The 4<sup>th</sup> MP joint had a 30° limitation of flexion and a 20° limitation of extension. The 5<sup>th</sup> MP joint had a 60° limitation of flexion and a 30° limitation of extension (Figure 1A). X-rays revealed a dislocated 5<sup>th</sup> MP joint and a bone fragment distal to the 5<sup>th</sup> metacarpal. The 4<sup>th</sup>

MP joint was also dislocated together with a deformity of the dorsal joint surface of the proximal phalanx (Figure 1B).

### Case 2

A 34-year-old male presented with complaints of pain, hypesthesia and an inability to move the 4<sup>th</sup> finger due to deformity of the 4<sup>th</sup> MP joint of his right hand. His complaints began after punching a wall 10 mo prior. He was given a below elbow splint for 10 d, followed by 4 wk of physical therapy, which improved his joint range of motion but worsened his hypesthesia. His pain and hypesthesia had increased over time because of his job (bus driver). When he presented 10 mo after the injury, the 4<sup>th</sup> MP joint had a 70° limitation of flexion and a 10° limitation of extension. The 4<sup>th</sup> finger was hypesthetic. His X-rays revealed a 4<sup>th</sup> MP joint dislocation with deformity dorsal to the proximal phalanx proximal joint surface (Figure 2A).

### Surgical technique

A dorsal approach was performed under regional anesthesia and tourniquet hemostasis. A longitudinal cut was made over the MP joint. The ulnar sagittal band of the extensor mechanism was cut longitudinally. When the capsule was exposed, it was found to have ruptured in all three fingers. Achieving exposure of the joint was difficult because of adhesions to the surrounding structures. The dorsal capsular adhesions were released to expose





**Figure 2** Preoperative and postoperative clinical radiological images of case 2. A: Preoperative 70 degrees of limitation of flexion at the 4<sup>th</sup> metacarpophalangeal joint. There is a deformity dorsal to the proximal phalanx proximal joint surface; B: 30 degrees of limitation of flexion and union of the proximal phalangeal osteotomy line at 8<sup>th</sup> month control.



**Figure 3** Exposure of the dislocated metacarpophalangeal joint with a dorsal approach. Because of the deformation of the dorsal joint surface of the 4<sup>th</sup> proximal phalanx, a volar closing wedge osteotomy was done, which was then stabilized with a K wire.

the joint (Figure 3). In the first patient, the radial digital arteries and nerves of the 4<sup>th</sup> and 5<sup>th</sup> fingers were compressed between the distal end of the metacarpal and the proximal end of the proximal phalanx. The bone fragment that had fused with the distal volar surface of the 5<sup>th</sup> metacarpal in the 1<sup>st</sup> patient was excised, and the MP joint was reduced. The reduction was maintained using a K wire (Figure 3). Because both patients presented a deformation at the dorsal end of both proximal phalanges, a shortening together with a volar closing wedge osteotomy was performed in each case to enhance the joint congruity (Figure 3). The reduction was maintained using a K wire. After reduction, the digital arteries and nerves were observed to have decompressed. The dorsal capsule and the ulnar sagittal band of the extensor mechanism were then repaired.

The 4<sup>th</sup> and 5<sup>th</sup> fingers were kept in a below-elbow splint for 4 wk. Subsequently, the K wires were removed. A removable splint was applied, and passive and active assisted joint range of motion exercises were assigned for 2 wk. At the end of the 6<sup>th</sup> week, active exercises were assigned, and the removable splints were discontinued after 8 wk.

Improvements were observed in terms of pain, hypesthesia and function in all fingers in both patients (Figure 1C). At the 12<sup>th</sup> month control, the range of motion had improved with full flexion of the 4<sup>th</sup> MP joint and a 10° flexion limitation of the 5<sup>th</sup> MP joint (Figures 1D, 4). In both fingers, there was no extension limitation (Figure 4). During the early postoperative period (2 mo), the anesthesia of both fingers improved to hypesthesia, and this improvement persisted to the 12<sup>th</sup> month. There was





**Figure 4** Full flexion at the 4<sup>th</sup> metacarpophalangeal joint and 10 degrees limitation of flexion at the 5<sup>th</sup> metacarpophalangeal joint at postoperative 12<sup>th</sup> month. The 4<sup>th</sup> and 5<sup>th</sup> metacarpophalangeal joints have full extension.

no pain in the 3 affected fingers in either patient at the 12<sup>th</sup> month control visit. The 12<sup>th</sup> month X-rays revealed a maintenance of the reduction with a fully united osteotomy line (Figure 1E).

The 2<sup>nd</sup> patient achieved a 30° limitation of flexion at the 8<sup>th</sup> month control visit. There was no limitation of extension (Figure 2B). The hypesthesia of the 4<sup>th</sup> finger decreased. The 8-mo X-rays revealed a maintenance of the reduction with a fully united osteotomy line (Figure 2B).

Both patients were able to return to their former jobs after surgery with an improved functional status.

## DISCUSSION

Complex volar MP dislocation is a frequent consequence of a proximal translational force acting on the proximal phalanx while the MP joint is in hyperflexion<sup>[2,4]</sup>. This phenomenon was the mechanism of injury in our patients. In addition, the extensor mechanisms of the 4<sup>th</sup> and 5<sup>th</sup> fingers were lacerated.

When the MP joint is dislocated during extension, the volar plate can avulse and interpose into the joint, thereby precluding a closed reduction<sup>[5]</sup>.

A dorsal or volar approach can be applied during the surgical treatment of MP joint dislocations. The dorsal approach enables an evaluation of the dorsal capsule, the osteochondral injury on the metacarpal head and even the volar plate. The risk of neurovascular injury is extremely low with this approach. If a volar plate rupture is detected, it can be repaired through a separate volar incision. The dorsal capsule cannot be repaired using a volar approach, and the risk of neurovascular injury is higher<sup>[6,7]</sup>. In our patients, we used an isolated dorsal approach, dissected the avulsed dorsal capsule from the surrounding structures, reduced the joint and repaired the capsule. Typically, the volar plate is not ruptured during volar MP dislocations, and no further approach seems to be necessary.

Complex dorsal MP joint dislocations are frequently observed in the 2<sup>nd</sup> and 5<sup>th</sup> fingers because of the lack of a deep transverse metacarpal ligament, which is a natural stabilizer<sup>[8]</sup>. In our patients, 2 injuries were observed on

the 4<sup>th</sup> finger and 1 was observed on the 5<sup>th</sup> finger.

There are no data in the literature regarding neglected volar MP dislocations. In this study, we have demonstrated that isolated dorsal open reduction and K wire fixation result in a successful functional outcome in neglected volar MP dislocations.

## COMMENTS

### Clinical diagnosis

Main clinical findings of neglected volar metacarpophalangeal (MP) joint dislocations were pain, stiffness of MP joint, anesthesia or hypesthesia of the finger.

### Differential diagnosis

Neglected volar MP joint dislocations must be differentiated from flexor tenosynovitis, metacarpal and phalangeal fractures.

### Imaging diagnosis

Radiographies reveal neglected volar MP joint dislocation with disruption of joint sequence and deformity dorsal to the proximal phalanx proximal joint surface.

### Treatment

Dorsal surgical approach was choiced to reduce the MP joint dislocation and provide MP joint congruency.

### Related reports

The authors gave informations about related reports in discussion but in literature there are a few study over MP joint dislocations.

### Term explanation

The ulnar sagittal bands arise from the palmar plate of the finger MP joint and the adjacent intermetacarpal ligaments, which attach to the meta-carpal neck. They pass around the sides of the meta-carpophalangeal joints and attach to zone 5 of the extensor tendon. It is through the sagittal bands that the finger extensor tendons extend the MP joints and also stabilize the extensor tendons on the dorsum of the MP joints and prevent them from subluxing ulnarly, into the intermetacarpal spaces.

### Experiences and lessons

The authors experience with these two patients demonstrated that, even in neglected cases, open reduction using an isolated dorsal approach may result in satisfactory clinical and radiological outcomes.

### Peer review

The authors present the clinical and radiological results of open reduction using an isolated dorsal approach in only three neglected volar MP dislocations. If the study consisted more cases and compared two different surgical approach, power of the study have increased.

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## Insights into Avicenna's knowledge of the science of orthopedics

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### Abstract

The art of orthopedics traces its history back to ancient civilizations like those of the Egyptians. The evolution of this branch of medicine is indebted to investigations of many scientists, including Greek, Roman and Persian scholars. The Persian physician Avicenna (980-1037 AD) is one such scientist who investigated different aspects of orthopedics. It is possible to analyze Avicenna's knowledge of orthopedics and his contributions to this branch of medicine by an examination of his epic encyclopedia of medicine, *Al-Qanun fi al-Tibb (The Canon of Medicine)*.

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**Key words:** Avicenna; Bone fractures; Canon; History of

medicine; Persia

**Core tip:** The Persian scientist Avicenna investigated facets of orthopedics such as bone fractures and dislocations and ways of diagnosing and managing them. He contributed cutting-edge ideas relative to his era; among them, an early description of compartment syndrome and distinguishing between nerves and tendons.

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### TO THE EDITOR

"*Ibn Sina*" (980-1037 AD), commonly known as "*Avicenna*" in the west, was a renowned Persian physician who lived in the midst of the *Golden Age of Islamic Medicine* (9<sup>th</sup>-12<sup>th</sup> centuries AD). His full name was "*Abu Ali al-Hussain ibn Abdullah ibn Sina*"<sup>[1,2]</sup>. His contributions to various aspects of science influenced not only Persian medicine, but also medical sciences in Europe<sup>[3]</sup>. Avicenna's prominent medical compendium was entitled *Al-Qanun-fi-al-Tibb (The Canon (or Law) of Medicine)* (Figure 1)<sup>[4]</sup>. The Canon of Medicine was the standard textbook of medical education in the West until the 16<sup>th</sup> century<sup>[5]</sup>. It could be said that The Canon is the most influential medical compendium ever written<sup>[1]</sup>.

The Canon is composed of five volumes<sup>[6]</sup>. Bone fractures and dislocations are the main topics of focus in the fourth volume in the chapter entitled *Al-Jabr* ("orthopedics" in modern nomenclature). This chapter is divided into three parts. In the first part, Avicenna initially generally describes *Al-Khala* (bone dislocation) and then specifically discusses ways to diagnose and manage bone dislocations in fifteen bones of the upper and lower extremities<sup>[7]</sup>.

The next two parts are devoted to bone fractures. The



**Figure 1** Opening of the forth book of canon (probably, belonging to the beginning of 15<sup>th</sup> century, Iran). (Courtesy United States National Library of Medicine).

second is entitled *Fil Kasr Kalam-e Kolli fil Kasr* (Bone Fractures as a Whole) and focuses on the diagnosis and treatment of bone fractures in general. Avicenna discusses the types of manipulation to reduce fractures and classifies the types of fracture. For instance, he describes a fracture in which the bone breaks into several parts ("comminuted fracture" in current terminology). He distinguishes between open and closed fractures and considers different modes of management for them. Avicenna advocated the use of tools such as a drill and different types of saws to manage bone fractures<sup>[7]</sup>.

The third subdivision is entitled *Fi Kasr Oẓv Oẓv* (Fracture in Each Part of the Body) and describes nineteen types of bone fracture<sup>[7]</sup>.

In addition to bone fractures and dislocations, Avicenna used his knowledge of human anatomy to study tendon injury and repair. In his opinion, tendons differed from nerves. In contrast to his predecessors, apparently for the first time in the history of medicine, Avicenna recommended suturing of tendon lacerations to treat tendon tears. He also was a pioneer in peripheral nerve repair<sup>[7-9]</sup>.

Some of Avicenna's views on the management of bone fractures are remarkable and can be regarded as early descriptions of current medical knowledge. One example is his description of fixation of the extremities for bone fractures. Avicenna strongly proscribed the use of tight bandaging, which was a common practice of

the day. He explained that a tight bandage obstructs the blood supply to the extremity, which results in severe pain at rest and the eventual loss of viability of the extremity, leading to amputation. This description is an early explanation of compartment syndrome (a condition that involves an increased pressure in a confined anatomical space and adversely affects blood circulation) eight centuries before the work of *Richard von Volkmann* (1830-1889) who explained compartment syndrome in 1881<sup>[7,10,11]</sup>.

Taken as a whole, Avicenna's discourses on bone fractures, dislocations and related issues establish his knowledge and contributions to the advancement of the science of orthopedics.

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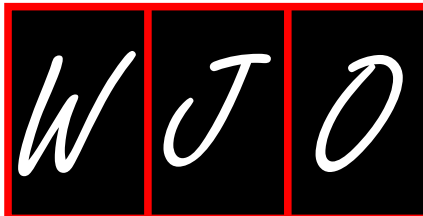
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## INSTRUCTIONS TO AUTHORS

### GENERAL INFORMATION

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In press

- 3 **Tian D**, Araki H, Stahl E, Bergelson J, Kreitman M. Signature

of balancing selection in Arabidopsis. *Proc Natl Acad Sci USA* 2006; In press

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- 4 **Diabetes Prevention Program Research Group**. Hypertension, insulin, and proinsulin in participants with impaired glucose tolerance. *Hypertension* 2002; **40**: 679-686 [PMID: 12411462 PMID:2516377 DOI:10.1161/01.HYP.0000035706.28494.09]

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- 5 **Vallancien G**, Emberton M, Harving N, van Moorselaar RJ; Alf-One Study Group. Sexual dysfunction in 1, 274 European men suffering from lower urinary tract symptoms. *J Urol* 2003; **169**: 2257-2261 [PMID: 12771764 DOI:10.1097/01.ju.0000067940.76090.73]

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- 6 21st century heart solution may have a sting in the tail. *BMJ* 2002; **325**: 184 [PMID: 12142303 DOI:10.1136/bmj.325.7357.184]

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- 8 **Banit DM**, Kaufer H, Hartford JM. Intraoperative frozen section analysis in revision total joint arthroplasty. *Clin Orthop Relat Res* 2002; (**401**): 230-238 [PMID: 12151900 DOI:10.1097/00003086-200208000-00026]

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- 9 Outreach: Bringing HIV-positive individuals into care. *HRS-A Careaction* 2002; 1-6 [PMID: 12154804]

### Books

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Chapter in a book (list all authors)

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- 12 **Breedlove GK**, Schorffheide AM. Adolescent pregnancy. 2nd ed. Wiczorek RR, editor. White Plains (NY): March of Dimes Education Services, 2001: 20-34

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- 14 **Christensen S**, Oppacher F. An analysis of Koza's computational effort statistic for genetic programming. In: Foster JA, Lutton E, Miller J, Ryan C, Tettamanzi AG, editors. Genetic programming. EuroGP 2002: Proceedings of the 5th European Conference on Genetic Programming; 2002 Apr 3-5; Kinsdale, Ireland. Berlin: Springer, 2002: 182-191

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- 15 Morse SS. Factors in the emergence of infectious diseases. Emerg Infect Dis serial online, 1995-01-03, cited 1996-06-05; 1(1): 24 screens. Available from: URL: <http://www.cdc.gov/ncidod/eid/index.htm>

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- 16 **Pagedas AC**, inventor; Ancel Surgical R&D Inc., assignee. Flexible endoscopic grasping and cutting device and positioning tool assembly. United States patent US 20020103498. 2002 Aug 1

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