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WJO covers topics concerning arthroscopy, evidence-based medicine, epidemiology, nursing, sports medicine, therapy of bone and spinal diseases, bone trauma, osteoarthritis, bone tumors and osteoporosis, minimally invasive therapy, diagnostic imaging. Priority publication will be given to articles concerning diagnosis and treatment of orthopedic diseases. The following aspects are covered: Clinical diagnosis, laboratory diagnosis, differential diagnosis, imaging tests, pathological diagnosis, molecular biological diagnosis, immunological diagnosis, genetic diagnosis, functional diagnostics, and physical diagnosis; and comprehensive therapy, drug therapy, surgical therapy, interventional treatment, minimally invasive therapy, and robot-assisted therapy.

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Distally based perforator sural flaps for foot and ankle reconstruction

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Abstract

Distally based perforator sural flaps from the posterolateral or posteromedial lower leg aspect are initially

a neurofasciocutaneous flap that can be transferred reversely to the foot and ankle region with no need to harvest and sacrifice the deep major artery. These flaps are supplied by a perforating artery issued from the deep peroneal artery or the posterior tibial artery, and the chain-linked adipofascial neurovascular axis around the sural/saphenous nerve. It is a versatile and reliable technique for soft-tissue reconstruction of the heel and ankle region with 180-degrees rotation. In this paper, we present its developing history, vascular basis, surgical techniques including flap design and elevation, flap variations in pedicle and component, surgical indications, and illustrative case reports with different perforating vessels as pivot points for foot and ankle coverage.

Key words: Fasciocutaneous flap; Distally based flap; Foot and ankle; Perforator flap; Neurocutaneous flap; Sural flap; Propeller flap

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Core tip: Distally based perforator sural flaps are perfused by a perforating artery issued from the deep peroneal or posterior tibial artery, and the longitudinal chain-linked adipofascial neurovascular axis around the sural/saphenous nerve. It is a versatile and reliable rapid procedure for soft-tissue reconstruction of the heel and ankle region with 180-degrees rotation. This paper presents the developing history, vascular basis, surgical techniques including flap design and elevation, flap variations in pedicle and component, surgical indications, and illustrative case reports with different perforating vessels as pivot points for foot and ankle coverage.

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INTRODUCTION

Reconstruction of the foot and ankle wounds, especially when complicated with deep vital structures such as bone, joint, nerves or tendon are exposed, remains a challenging problem for the treating surgeon. The foot with the features of weight bearing requirement, the lack of intervening muscle between the skeleton and the skin, and the limited movement of the overlying skin, make the soft-tissue coverage even more difficult^[1]. In general, there are several methods of surgical procedures, including vascular-pedicled loco-regional transposition and microsurgical free transfer of muscle or myocutaneous flaps, and fascial or fasciocutaneous flaps. Each procedure has its own merits and drawbacks on indications, technical requirement, flap size, range of vascular pedicle, and limitations of patient's local and general conditions^[2].

Besides free flaps with microsurgical vascular anastomosis, there are other options using pedicled vascular flaps from the ipsilateral uninjured lower leg with a distal-base, which had been developed and consequently modified in the past two decades^[3]. Currently, those reverse-transferred flaps can be categorized into three patterns^[4]: (1) The reverse-flow island flaps, such as the reversed anterior tibial artery flap, the posterior tibial artery flap, and the peroneal artery flap; (2) The distally perforator-based flaps, which avoid the sacrifice of the main deep arteries, such as the lateral and medial supra-malleolar flap; and (3) The distally based neuro-veno-fasciocutaneous flaps that are supplied by the chain-linked longitudinal directed vascular plexuses from a wide neuro-veno-adipofascial pedicle. These three loco-regional kinds of flaps can be elevated easily and substituted for microsurgical free flaps for foot and ankle reconstructions in some conditions.

HISTORIC PERSPECTIVE

The concept of fasciocutaneous flaps was first introduced by Ponten *et al.*^[5] in 1981 for lower leg soft-tissue reconstruction. The first distally based lateral sural fasciocutaneous flap was described by Donski *et al.*^[6] in 1983 for Achilles tendon coverage. The flap was supplied by a septocutaneous vessel issued from the peroneal artery that located in the postero-lateral septum of the lower leg and about 10cm above the lateral malleolus. In 1986 Amarante *et al.*^[7] reported a similar medial sural flap supplied by a perforator from the posterior tibial artery that located in the postero-medial septum of the lower leg. In 1988 Masquelet *et al.*^[8] introduced the lateral supra-malleolar flap that perfused by the anterior perforator of the peroneal artery located at 5 cm above the lateral malleolus. In 1992 Masquelet *et al.*^[9] proposed the concept of neurocutaneous flap, and described the distally based sural neurocutaneous flap for reconstructing the distal third leg, foot and ankle defects. This flap

is nourished by the lower-most septocutaneous perforator from the peroneal vessel, usually located 5 cm (4-7 cm) above the lateral malleolus as demonstrated by Hasegawa *et al.*^[10] in 1994, and the longitudinally disposed chain-linked adipofascial plexuses as well as the neuro-vascular axis around the sensitive sural nerve. In 1996 Chang^[11] pointed out that in essence, neurocutaneous flaps in the limbs was a specific example of fasciocutaneous flaps, as it was basically fasciocutaneous in flap component but strengthened in blood supply by longitudinally disposed perineural vascular plexus. These flaps also called neurofasciocutaneous flaps^[11]. In 1999 Nakajima *et al.*^[12] notified the accompanying vessels of the lesser saphenous vein and sural nerve, and proposed the term of veno-fasciocutaneous flap and neurovenofasciocutaneous flap. In 2003 Chang *et al.*^[13,14] demonstrated in experimental studies that cutaneous large superficial veins in distally-based flaps played a negative role and suggested ligate these big cutaneous veins (great/lesser saphenous vein) to prevent flap ingress. In 2004, Chang *et al.*^[15] converted the flap pedicle from wide adipofascial to septum perforator, making it easy for 180-degrees rotation. In 2007 Chang *et al.*^[16] described a new vascular basis of the sural neurocutaneous flap, which is supplied by the lateral retromalleolar perforator of the peroneal artery usually located 1 cm above lateral malleolus. To reduce the postoperative flap congestion, Chang *et al.*^[17] further modified a technique in 2014 with perforator-plus-adipofascial pedicle for sural propeller flaps.

VASCULAR ANATOMIC CONSIDERATIONS

The fasciocutaneous vascularization of the lower leg is mainly provided by septocutaneous perforators, sometimes supplemented by musculocutaneous perforators and strengthened by the neuro-veno-cutaneous plexuses^[18-22].

Vascular anatomic studies have shown that there are 2 longitudinal rows of perforators in the distal sural region. The medial row was issued from the posterior tibial artery, located between the tibia and the Achilles tendon. The lateral row was originated from the peroneal artery, located between the fibula and the Achilles tendon. As a general rule, perforators can be found above the medial or lateral malleolar tip approximately at (1) 2 cm (which is termed the retro-malleolar space perforator); (2) 5 cm (which is termed the distal-most septocutaneous perforator); and (3) 10 cm (the middle septocutaneous perforator), respectively (Figure 1). These perforators form a three-dimensional vascular architecture. There are prominent longitudinal axially of the vasculature in different tissue layers, including fascial, paraneural and perivenous vascular plexuses^[23-25].

Anatomic study also showed the possibility to

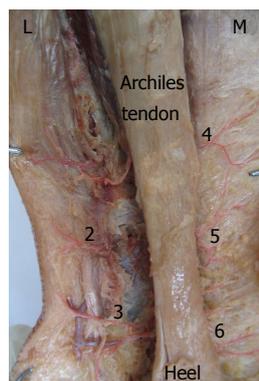


Figure 1 Two rows of perforators are distributed in the posterior lower leg sural region, originating from the peroneal artery (1, 2, and 3) in the posterolateral aspect and the posterior tibial artery (4, 5, and 6) in the posteromedial aspect, respectively. Note the lateral peroneal artery perforators are developed more robust than that of the medial posterior tibial artery.

harvest muscles with the sural flap. The gastrocnemius muscle-tendon junction was located at the mid-point (1/2) of the lower leg. The sural nerve was found passing through the deep fascia from the inter-gastrocnemius muscle groove to the superficially subcutaneous tissue at the junction of upper-middle third (1/3). Therefore, a midline “groove muscle cuff” around the inter gastrocnemius sural nerve “mesentery” would be included to form a fasciomyocutaneous flap to cure osteomyelitis and/or filling dead space^[26,27]. There was a 4 cm overlapping length (range 3 to 5 cm) between the lateral gastrocnemius muscle belly and the deep fascia foramen where the sural nerve went from the subfascial to the suprafascial. In its suprafascial route, the sural neurovascular axis gave off at least 1 branch, *i.e.*, the musculo-fascio-cutaneous perforator, reversely to the lateral gastrocnemius muscle, and usually 2 branches, reversely to the medial muscle. The diameter of these perforators was smaller than 0.5 mm (range 0.2 to 0.5 mm)^[28]. These findings provide the anatomic basis for harvesting distally based sural neuro-fasciomyocutaneous flap with the distal portion of gastrocnemius muscle. The vascular supply for the attached gastrocnemius muscle fragment beneath the deep fascia, was assumed reversely from the superficial neuroadipofascial vascular axis, which was perfused by the distal perforator of the peroneal artery^[28].

Venous drainage in distally based flaps is usually a special concern in hemodynamic physiology because the venous blood of the flap must reversely return to its distal pedicle against venous valves. Venous problems are one of the major reasons for flap complications and failures. Chang *et al.*^[13,14,29,30] proposed that the lesser saphenous vein in distally based sural flap have no positive role for venous drainage, but conduct the venous blood from the foot to ingress the flap to cause venous overloaded, which is hazardous for flap survival. Large superficial veins should be interrupted and ligated distal to the

pivot point of the flap to prevent flap congestion and swelling. Other methods to relieve venous load include venous anastomosis by microsurgical technique and leech therapy.

SURGICAL TECHNIQUE

Flap design

In designing a surgical flap, five key points should be considered: (1) pivot point, the flap is rotated around this point, which is usually the axial vascular perforator issued from the deep main vascular stem; (2) axial line, the flap is designed along this line, which is the direction of vascularization of the flap; (3) flap area, which is the size of the flap according to the defect; (4) dissection plane, which is the surface that the flap was elevated; and (5) rotation arc, which indicates the most distal point that the flap can reach by rotation.

A longitudinal line roughly represents the course of the posterior tibial artery (or peroneal artery) is drawn from the mid-point of popliteal fossa to the mid-point between Achilles tendon and medial malleolus (or lateral malleolus) in the leg. This also represents the course of the posterior branch of the saphenous nerve in the postero-medial aspect, or the superficial sural nerve and the lesser saphenous vein in the posterolateral aspect of the lower leg, respectively. All distal-based perforator flaps are centered on either of these two lines. The required skin paddle is then outlined reversely on the lower leg, according to location and the size of the tissue defect.

Flap elevation

Under continuous epidural anesthesia or intratracheal intubational general anesthesia, the patient was placed in the prone (for heel coverage), supine (for medial ankle coverage), or lateral position (for lateral ankle coverage). A thigh pneumatic tourniquet was used and the leg is exsanguinated by elevation and hand compression for 1-2 min. This maneuver allows emptying of most of the blood from the leg but retains enough in the perforating vessels to allowing for easier identification during operative exploration. After debridement of the defect, a sharp long exploratory incision (5-7 cm in length) along its posterior margin (Achilles side), is firstly made, straightly down to the deep fascia from the wound to the distal part of the flap. Temporary anchoring stitches should be used to secure the deep fascia with the skin paddle. Then the flap is elevated forward from the sub-fascial level (the surgical plane) to the septum to search the perforator. After a proper perforator is identified, the flap design is re-evaluated and adjusted, according to the exact location of the perforator. If the perforator showed nice (for example, 1 mm in diameter, at least 2 cm in length, and closer companion of the perforating artery and partner veins, and observed pulsation after pneumatic release), we recommended skeletonize the perforating vessels to achieve free-restrict rotation. If



Figure 2 Distally based fasciocutaneous island flap for lateral malleolus coverage. A: Pressure ulcer over the lateral malleolus in a 60-year-old male patient; B: Harvest of distally based fasciocutaneous island flap from the lateral sural region with a wide adipofascial pedicle; C: Flap inset to the recipient with tension-free; D: Final complete survival.

Table 1 Variations of distally based lateral sural flap

Vascular perforator
Middle septocutaneous perforator, located approximately 10 cm above malleolus
Lowermost septocutaneous perforator, located approximately 5 cm above malleolus
Retromalleolar perforator, located approximately 2 cm above malleolus
Pedicle component
Fasciocutaneous pedicle (full-thickness, peninsular)
Adipofascial pedicle (without overlying skin bridge, island)
Neurofasciocutaneous, neurovenofasciocutaneous
Perforator with septum intact
Perforator-plus-adipofascial
Perforator with septum dissection (perforator skeletonized)
Flap constituent
Fasciocutaneous flap
Neurofasciocutaneous, neurovenofasciocutaneous flap
Adipofascial flap
Fasciomyocutaneous flap (including a fragment of gastrocnemius muscle)

the perforator was not so nice, then a perforator-plus-adipofascial pedicle was preferred. Usually, at least a quarter (1/4) of adipofascial tissue was preserved in intact around the perforator. No further intra-septal dissection of the perforator was performed. Then the flap dissection proceeded from the sub-fascial plane in the proximal-to-distal direction, until the distal perforating vessel is reached. No attempts were made to sparing the superficial cutaneous nerves if they

are located in flap dimension. The flap was rotated 180 degrees to reach the recipient foot or heel and inset with tension-free. No venous anastomosis was performed for super-drainage. The sural nerves in the flaps were harvested more proximally to get extra 2 to 3 cm, and coated the proximal cut end of sural nerve to a recipient nerve (saphenous nerve or superficial peroneal nerve) in end-to-side fashion or calcaneal branch from the medial plantar nerve in side-to-side fashion to restore the flap sensation. The donor areas can be covered by split-thickness skin grafts, or directly closed provided its width is less than 5 cm.

For foot and calcaneus coverage, an anterior supportive plaster of Paris or splint was used postoperatively for immobilization for 2 wk. After plaster was removed, the patients started an active and passive physical rehabilitation program to get maximum range of ankle motion.

FLAP VARIATIONS

Many different modifications of the sural flaps have been made based on its vascular pedicle and flap components^[31,32]. Table 1 summarizes those different types of flap variations.

SURGICAL INDICATIONS

The distally based sural fasciocutaneous flaps can generally be rotated to cover any soft-tissue defect of



Figure 3 Distally based turnover adipofascial flap for calcaneal wound coverage. A: Preoperative appearance of lateral calcaneal sinus; B: Distally based adipofascial flap harvest from the lateral sural region; C: The flap was turned 180-degrees over to fill the calcaneus cavity; D: Skin graft over the adipofascial flap; E: Appearance of postoperative 3 mo; F: Successful subtarlar joint fusion.

the foot and ankle region, usually small to medium-sized defect (about 10 cm in length). In practice, it usually restricts to the middle of the foot.

Distally based adipofascial flap can be transferred by turn-over mode to provide thin and subtle coverage for exposed tendons and bone on the dorsum of the foot. The adipofascial flap is then covered with skin graft primarily or secondarily.

Distally based fasciomyocutaneous flap can provide a bulk and high metabolic viable muscle component for repairs of the soft tissue defects complicated with osteomyelitis, deep dead space and for plantar heel pad reconstruction, which need thickness.

CASE PRESENTATIONS

Case 1: Fasciocutaneous island flap

A 60-year-old paraplegic male suffered a pressure ulcer over the lateral malleolus of his left leg for 6

mo. After debridement, the wound was measured 4 cm × 3 cm in size with bone exposure. A distally based fasciocutaneous island flap from the lateral sural region was used to solve the problem. The skin paddle measured 5 cm × 4 cm in size, supplied by a 3 cm wide and 4 cm long adipofascial pedicle. The flap was rotated to the defect and inset with tension free. The donor site was closed directly. The flap survived completely, and the wound was cured successfully (Figure 2).

Case 2: Turnover adipofascial flap

A 62-year-old woman suffered calcaneus fracture of her right foot. After open reduction and plate fixation through lateral extended L-shaped incision, the wound became infected. One-year later, she was referred to us with chronic calcaneal osteomyelitis and a skin sinus. The problem was solved in three stages. In the first stage, the implant was removed and complete



Figure 4 Perforator-plus fasciocutaneous flap for medial malleolar coverage. A: Delayed wound infection after open pilon fracture; B: First stage management, debridement and vacuum-sealing-drainage; C: Perforator-plus fasciocutaneous flap harvest from the posteromedial sural region; D: Flap transfer and inset; E: Complete flap survival in two weeks.

debridement was performed, followed with a vacuum-sealing-drainage (VSD) for 1 wk. In the second stage, as the wound was clean, an adipofascial turnover flap was designed on the posterolateral aspect of the lower leg to eradicate the dead space. The flap was based on the lateral retromalleolar perforators, the pivot point was located 2 cm above the lateral malleolus, and the flap measured 13 cm × 5 cm. The flap was turned over 180-degrees to fill the cavity of the calcaneus. In the third stage, the adipofascial flap was covered with split-skin grafts, and the subtalar joint was fused with 2 screws. The patient was followed up 3 mo. The wound was cured successfully, and she was able to walk independently (Figure 3).

Case 3: Perforator-plus fasciocutaneous flap

A 52-year-old man suffered an open pilon fracture of his right leg. After open reduction and internal fixation,

the medial wound developed a delayed infection 3 mo later. The wound was first debridement and supplemented with VSD management. One week later, a distally based medial sural fasciocutaneous flap was designed to cover the defect. The flap was pivoted on the septocutaneous perforator located 10 cm above the medial malleolus, with a quarter of adipofascial to protect the perforator. The skin island measured 5 cm × 3 cm with a narrow skin bridge over the adipofascial pedicle. The flap was rotated 180-degrees to reach the recipient site, and inset with tension-free. The donor site was closed directly. Both the flap and donor site healed without complications (Figure 4).

Case 4: Perforator skeletonized propeller fasciocutaneous flap

A 60-year-old female suffered an open pilon fracture of her left leg. After plate fixation, the skin over the plate

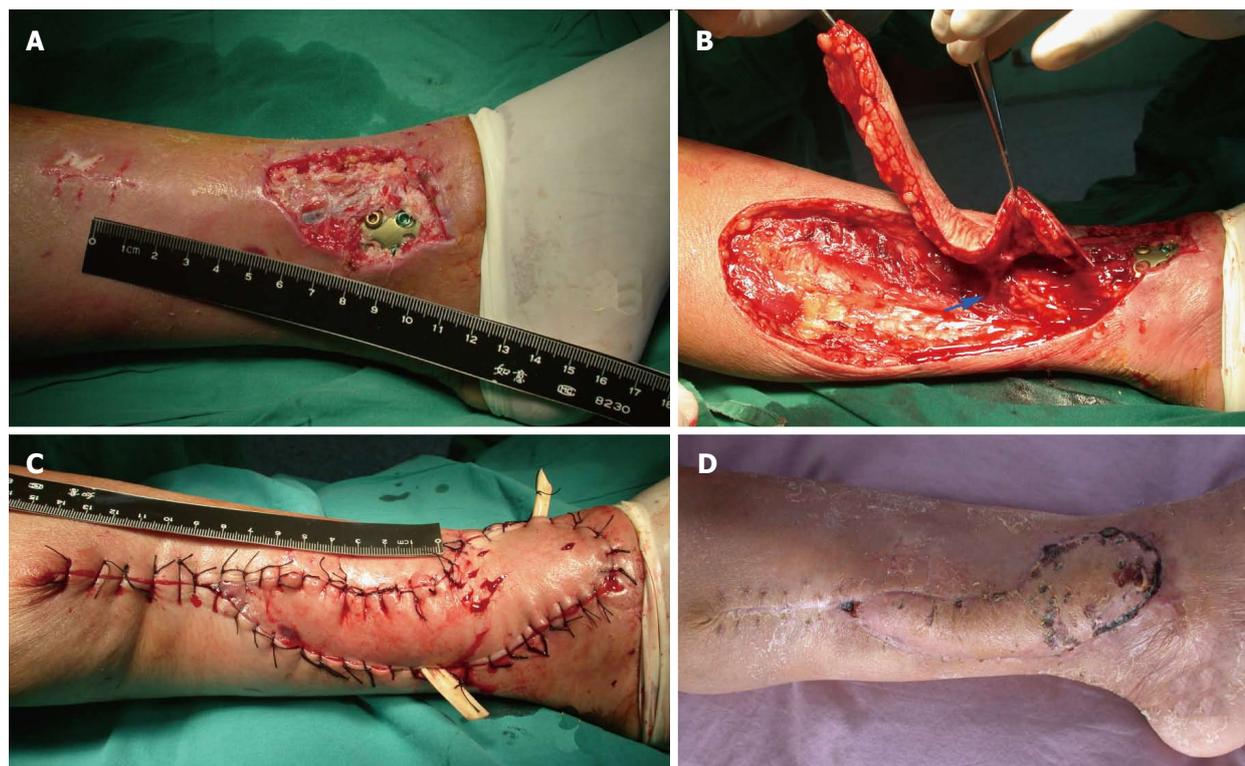


Figure 5 Perforator pedicled propeller flap for pilon wound coverage. A: Plate exposure in a 60-year-old woman with open pilon fracture; B: Posterior tibial artery perforator pedicled fasciocutaneous flap was raised, the perforator was skeletonized; C: The flap was propelled 180-degrees to the recipient site; D: Flap survival, with minor superficial marginal necrosis.

was necrotized, leaving a 5 cm × 4 cm wound with plate exposure. A medial sural island fasciocutaneous flap, nourished by a posterior tibial artery perforator ($\Phi 1.0$ mm with 2 partner veins) located 9 cm above the medial malleolus. The flap was designed as propeller flap, with large blade 10 cm × 4 cm, and small blade 4 cm × 2 cm. The flap was rotated 180-degrees to reach the wound. Both the donor and recipient sites were sutured primarily. Postoperatively, the flap showed venous congestion and swelling. This was managed with multiple small incisions over the flap to let blood out. The flap survived completely after two weeks (Figure 5).

DISCUSSION

Coverage of soft-tissue defects of the foot is a challenging procedure in trauma and reconstructive surgery. The options lie in vascular pedicled flaps and microsurgical free flaps.

Since the introduction of fasciocutaneous, neuro-cutaneous, and perforator flaps in the lower leg, the vascularization of the calf and sural region has been extensively investigated. Anatomic studies have shown that the superficial sural artery from the popliteal, the septocutaneous perforators from posterior tibial artery (medial side) and peroneal artery (lateral side), and myocutaneous perforators from gastrocnemius and soleus, form a three-dimensional vascular architecture

with prominent longitudinal orientation in the posterior lower leg^[28]. There are 4 to 5 axial communications between this longitudinal neuro-veno-adipofascial plexus and the posterolateral/posteromedial septocutaneous perforators issued from the peroneal artery/posterior tibial artery, respectively. The distal perforators, in particular, can be used effectively for coverage of defects of the heel, malleolus, Achilles tendon, and distal third of the tibia^[33].

Island flap pedicled with a single perforator, also called pedicled perforator flap, island perforator flap, local perforator flap, or perforator pedicled propeller flap, has the greatest freedom of rotation, which can reach up to 180 degrees^[34]. In recent years, there was a great increasing use of perforator-based propeller flaps in limb reconstruction, especially for the lower leg and foot, with a distal rotation^[35,36]. These flaps combine the advantages of pedicled local flaps (good color and texture match), pedicled regional flaps (up to 180 degrees arc of rotation), pedicled distant flap (larger flap size and vascular reliable), and without microsurgical vascular anastomosis. Furthermore, for most small to medium-sized defects (< 10 cm in length), it allows linear closure with direct suture of the donor site.

The distally based sural island flaps is a useful and versatile reconstructive option in patients with soft-tissue defects of the foot. The advantages include: (1) the ability to be transferred from a proximal donor site to

a distal recipient; (2) the avoidance of foot dependence; (3) the one-stage rapid procedure, which requires no microsurgical technique; and (4) it is supplied by a perforating artery and the chain-linked adipofascial vascular plexus, which is no need to harvest and sacrifice the deep major artery.

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Diabetes and its negative impact on outcomes in orthopaedic surgery

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Abstract

An estimated 285 million adults (aged 20-79 years) worldwide were diagnosed to have diabetes mellitus (DM) in 2010, and this number is projected to grow to 439 million adults by the year 2030. Orthopaedic surgeons, regardless of their subspecialty interest, will encounter patients with DM during their career since this epidemic involves both developed and emerging countries. Diabetes results in complications affecting multiple organ systems, potentially resulting in adverse outcomes after

orthopaedic surgery. The purpose of this review is to discuss the pathophysiology of DM and its potential for impacting orthopaedic surgery patients. Diabetes adversely affects the outcome of all orthopaedic surgery subspecialties including foot and ankle, upper extremity, adult reconstructive, pediatrics, spine surgery and sports medicine. Poorly controlled diabetes negatively impacts bone, soft tissue, ligament and tendon healing. It is the complications of diabetes such as neuropathy, peripheral artery disease, and end stage renal disease which contributes to adverse outcomes. Well controlled diabetic patients without comorbidities have similar outcomes to patients without diabetes. Orthopaedic surgeons should utilize consultants who will assist in inpatient glycemic management as well as optimizing long term glycemic control.

Key words: Diabetes; Orthopaedic surgery; Outcomes; Complications; Neuropathy

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Core tip: Diabetes is associated with adverse outcomes following orthopaedic surgery. The complications of diabetes such as poor glycemic control, neuropathy, end stage renal disease and neuropathy contribute to adverse outcomes. These adverse outcomes include surgical site infections, impaired wound healing, pseudarthrosis, hardware and implant failure and medical complications. Patients with diabetes who undergo orthopaedic surgery should receive optimal medical management prior to elective surgery in order to minimize complications.

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INTRODUCTION

In 2010 nearly 300 million adults were estimated to have diabetes mellitus (DM) globally, and this number is projected to grow to 439 million adults by the year 2030^[1]. Diabetes is associated with an enormous economic burden and the International Diabetes Federation (IDF) projected that the global health expenditures to prevent and treat DM and its complications totaled 376 billion United States dollars in 2010^[1]. By 2030, IDF estimates that expenditures will exceed 490 billion United States dollars^[1]. Orthopaedic surgeons, regardless of their subspecialty interest, will encounter patients with DM during their career since this epidemic involves both developed and emerging countries. Diabetes results in complications affecting multiple organ systems, potentially resulting in adverse outcomes after orthopaedic surgery. Significant alterations in glucose metabolism occur during periods of heightened stress such as major surgery, trauma and sepsis. It has been reported that diabetic patients undergoing surgery are at risk for increased morbidity and longer hospital stays. Surgical patients with DM are estimated to utilize 45% excess bed days compared to people without DM admitted to medical wards^[2-4]. In diabetic patients undergoing non-cardiac general surgery, the peri-operative mortality rate is significantly higher than the mortality seen in patients without DM^[5]. Orthopaedic surgeons who treat extremity infections may identify DM in patients not previously diagnosed with DM. A retrospective review of 1166 orthopaedic admissions identified 385 patients with an admission hyperglycemia, identified by a serum glucose \geq of 120 mg/dL^[6]. Only 45% of the hyperglycemic patients (174) were known to have DM prior to admission patients^[6]. The purpose of this review is to discuss the pathophysiology of DM and its potential for impacting orthopaedic surgery patients.

PATHOPHYSIOLOGY

Diabetes mellitus can be broadly classified into three types, based on the onset of symptoms and the absolute need for insulin replacement. Patients who have an absolute requirement for insulin, secondary to autoimmune dysfunction of the pancreatic beta cells, have type 1 DM. The vast majority of patients have type 2 DM which is associated with older patients, elevated body mass index (BMI), genetic predisposition, history of DM during pregnancy, less active individuals, and certain ethnic groups. Four out five patients with type 2 DM have an elevated BMI. Children and adolescents, particularly from certain ethnic and racial groups (African - American, Mexican American, and Pacific Islander), are being diagnosed with type 2 DM at an increasing rate. During the early stages of type 2 DM the pancreas usually produces insulin, however insulin resistance is present and glucose metabolism is negatively impacted. A small percentage of pregnant women develop

gestational DM and 40% to 60% of these patients will ultimately develop type 2 DM within 5 to 10 years.

The end result of DM, regardless of the etiology, is hyperglycemia. The primary energy source for our body is glucose, and glucose is stored as glycogen in the liver and skeletal muscle. Insulin facilitates glucose uptake into the peripheral cells, assisting with the storage of glycogen. While patients with type 1 DM have an absolute need for insulin replacement, patients with type 2 DM initially produce insulin, sometimes in high amounts. The problem is so called "insulin resistance", in which the cells become less sensitive to insulin and hyperglycemia results. Stress hyperglycemia can occur in hospitalized patients without a previous history of DM and is defined as any serum glucose $>$ 140 mg/dL. Although this hyperglycemic state typically resolves with abatement of the heightened stress, approximately 60% of patients may ultimately develop DM^[7]. Surgery, trauma and infection stimulate release of counter regulatory hormones such as glucagon, epinephrine, cortisol, and growth hormone, resulting in derangement in normal carbohydrate metabolism. This dysfunction may result in a decrease in peripheral tissue insulin uptake (*i.e.*, resistance), gluconeogenesis in the liver, decreased efficiency of tissue glucose utilization and relative insulin deficiency^[7]. Both observational studies and prospective studies in intensive care unit (ICU) patients have demonstrated a correlation between hyperglycemia and adverse outcomes during the hospitalization^[8,9]. Hyperglycemia results in inhibition of Interleukin 1 release from macrophages, impaired phagocytosis and diminished production of oxygen radicals from neutrophils, all of which contribute to a relative immunodeficiency.

Hyperglycemia at the time of admission in patients with life threatening medical problems is associated with higher mortality rates when compared to normoglycemic patients. Umpierrez *et al*^[9] reported that nearly 40% of patients admitted to the hospital had abnormally high serum glucose levels, and that patients with new onset hyperglycemia had a five times higher rate of mortality while hospitalized compared to patients with established DM. Patients with newly diagnosed DM remained in the hospital longer, required more intensive care and had to be discharged to skilled nursing units more often than patients with established DM. Orthopaedic surgeons should be aware that some patients will be diagnosed with DM during their admission, and this may be associated with inferior outcomes after orthopaedic surgery.

COMPLICATIONS OF DIABETES

Complications associated with DM result from macrovascular and microvascular disease (Table 1). Many of these complications do not directly impact the musculoskeletal system; however the indirect

Table 1 Complications of diabetes potentially affecting orthopaedic surgery patients

Retinopathy
Visual impairment leading to falls
Peripheral neuropathy
Balance issues
Gait abnormalities
Lack of protective sensation
Increased risk of surgical site infection
Increased risk of nonunion
Peripheral artery disease
Impaired lower extremity blood supply leading to faulty healing
End stage renal disease
Metabolic bone disease
Anemia of chronic disease
Poorly controlled diabetes (hyperglycemia)
Increased risk of surgical site infection
Impaired bone and soft tissue healing

effects can be significant. Cardiovascular complications such as coronary artery disease, hypertension and cerebrovascular accidents are 100%-300% more likely in patients with DM. Diabetes is associated with a two to four fold increase in cardiovascular disease including hypertension, coronary artery disease and stroke^[2,4]. Patients with retinopathy and visual impairment may injure their lower extremity due to inability to visualize objects in their path during ambulation. Patients with neuropathy may fall second to balance issues resulting in musculoskeletal trauma. Patients with diabetic nephropathy may have vitamin D deficiency that potentially weakens the osseous structures. Finally, macrovascular disease may result in atherosclerosis and can impede wound healing.

There is evidence of abnormal blood flow patterns in the neuropathic diabetic foot unrelated to ischemia. A study of patients with Type 1 DM and peripheral neuropathy demonstrated that the normal triphasic pattern of arterial blood flow was lost despite normal pulse wave velocities^[10]. No significant stenosis was identified in any of the arteries studied including distal evaluation of the dorsalis pedis and posterior tibial arteries^[10]. The mean great toe pressure in patients with DM was 64 mmHg as compared with 98 mmHg in controls. A linear correlation of decreasing toe pressures with increasing severity of neuropathy was seen ($R = 0.7$), suggesting that changes exist in the blood flow patterns in young patients with DM and neuropathy, even in the absence of lower limb ischemia. These changes may not be clinically meaningful in patients who do not undergo surgery, but may become very important if a surgical wound is created. The prevalence of peripheral artery disease (PAD) in patients aged ≥ 40 years with DM is estimated to be 10% compared to 5% in the general population, and the prevalence increases with advancing age^[11]. Diabetic related atherosclerosis has a predilection for affecting the arteries distal to the

popliteal trifurcation, and assessment of the pulses is recommended in patients undergoing lower extremity surgery.

TREATMENT OF HYPERGLYCEMIA

The management of inpatient glycemic control strives to avoid hyperglycemia, however it is generally agreed that hypoglycemia is to be avoided. Randomized studies of inpatients have demonstrated that optimal glycemic management is associated with improved outcomes^[12,13]. During heightened periods of stress (surgery, sepsis and infection), insulin is the recommended method to achieve glycemic control, even in patients who did not use insulin prior to admission. In some cases, insulin requirements are greatly increased due to stress hyperglycemia^[13]. Recent guidelines on glycemic control have focused on both the ICU setting and non-critical inpatient care settings^[4,12,13]. These guidelines are the result of input from representatives of major key organizations involved in the inpatient care of DM^[4,13]. The Endocrine Society recommends pre-prandial glucose levels of < 140 mg/dL and random serum glucose levels of < 180 mg/dL in patients not admitted to ICU^[13]. Serum glucose levels of < 150 mg/dL are recommended in ICU patients, ideally maintained with intravenous insulin and careful monitoring^[14]. Regardless of the clinical setting (ICU vs non-ICU), hypoglycemia is to be avoided (blood glucose ≤ 70 mg/dL)^[4,13,14]. Hyperglycemia is very common in ICU patients, and up to 80% of these patients may not have been diagnosed with DM prior to the ICU admission^[7]. Stress induced hyperglycemia may manifest in orthopaedic surgery patients after major surgery, sepsis or trauma.

MUSCULOSKELETAL MANIFESTATIONS OF DIABETES

Disturbances of gait

Patients with DM often have limitation of motion in the foot and ankle, resulting in biomechanical abnormalities^[15]. This reduction in joint motion is more pronounced in diabetic patients with peripheral neuropathy, and has been observed during the propulsive and swing stages of gait^[15]. Alterations in foot biomechanics and balance issues secondary to peripheral neuropathy are important factors which could lead to ground level falls and trauma (Table 2).

General issues

Diabetic polyneuropathy can result in balance and stability issues^[16]. Diabetes mellitus, independent of neuropathy, could have a direct effect on postural control during standing after a self-induced forward reaching movement^[16]. Patients with DM have been found to have thickening of the Achilles tendon and plantar fascia when compared to control patients, and

Table 2 Impact of diabetes on orthopaedic surgical subspecialties

Foot and ankle surgery
Increased risk of surgical site infection
Increased risk of nonunion, malunion and hardware failure
Increased risk of neuropathic ulcers
Spine surgery
Increased risk of surgical site infection
Increased risk of nonroutine discharges
Sports medicine
Impaired healing of soft tissues (ligaments and tendons)
Spontaneous necrosis of muscle
Total joint arthroplasty
Increased risk of surgical site infection
Increased risk of nonroutine discharges
Upper extremity
Increased risk of nerve compression syndromes
Increased risk of overuse syndromes
Inferior outcomes in rotator cuff repair and frozen shoulder

these findings may contribute to balance issues^[17].

IMPACT ON SOFT TISSUES TENDON HEALING

Tendons in patients with DM tend to be thicker and stiffer than normal tendons resulting in alterations in the normal mechanical properties^[18]. An experimental pig model evaluating patellar tendons found that proteoglycan synthesis by tenocytes was reduced in tendons exposed to high concentrations of glucose^[19]. Clinically, this may explain the high rate of tendon pathology seen in patients with DM^[19]. A diabetic rat model of patellar tendon pathology has also demonstrated a decrease in Young's modulus and high rate of intrasubstance failure^[20].

Steroid injections are commonly performed for various musculoskeletal problems, and transient elevations in serum glucose levels can occur^[21]. A study of hand surgery patients reported that a 1-mL triamcinolone acetonide injection resulted in statistically significant elevations in serum glucose on days 1, 5, and 6 d after injection. Patients with DM should be advised that a transient rise in serum glucose levels will occur after a corticosteroid injection^[21]. This finding is applicable to other areas of the musculoskeletal system where local injections of corticosteroids are used.

BONE HEALING AND METABOLISM

Alterations in bone healing as a result of DM have been demonstrated in both the clinical setting and laboratory models. Diabetes has been found to cause bone mineral alterations in a laboratory rat model^[22]. A reduction in bone mineral and crystal formation has been identified in the tibial metaphysis of diabetic rats. This results in biomechanical changes that diminishes stiffness, torsional strength and energy absorption of the fracture callus^[22]. Beam *et al*^[23] studied fracture

callus formation in diabetic rats, and observed that poor glycemic control negatively impacted fracture callus by inhibiting chondrocyte production and impeding ossification of the immature enchondral bone. Diabetic rats with optimal glycemic control did not experience these changes, and the mechanical properties of the bone were similar to non-diabetic animals^[23]. Poorly controlled DM also decreases important cytokine production and reduces new blood vessel formation at the site of callus^[24].

FOOT AND ANKLE SURGERY

The implications of DM on outcomes in orthopaedic surgery have been evaluated most extensively in foot and ankle surgery. Diabetes has a high predilection for affecting the foot and ankle largely due to the complications of DM such as neuropathy and PAD. The incidence of diabetic foot ulcers is 2% and 15%-25% of patients will develop a foot ulcer at some point in their life^[25]. Once an ulcer develops, the risk of infection rises dramatically, and it has been estimated that 85% of non-traumatic amputations are due to DM^[26]. Severe diabetic foot infections, manifested by the presence of systemic inflammatory response syndrome, may require transtibial amputation in nearly 20% of patients^[27].

Charcot neuroarthropathy (CN) is relatively unique to the foot and ankle and is associated with decreased quality of life and high risk of foot ulceration^[28]. Patients with CN and foot ulcers have a 12 times higher risk of major amputation than patients without ulcers^[29]. High rates of complications, both infectious and noninfectious, have been observed in CN patients undergoing surgical correction^[30]. Elective foot and ankle surgery in patients with DM is associated with higher complication rates. Patients with complicated DM (neuropathy, PAD or nephropathy) have a seven times higher likelihood of surgical site infection (SSI) compared with non-diabetic patients without neuropathy and nearly a four times higher likelihood of SSI compared with patients with uncomplicated DM^[31]. Peripheral neuropathy and a hemoglobin A1c of $\geq 8\%$ were independently associated with SSI^[31].

Arthrodesis surgery is commonly performed for foot and ankle problems in patients with DM, and complications of surgery are higher in diabetic patients^[32]. A retrospective review compared 74 diabetic patients and 74 non-diabetic patients. Diabetes, tobacco use and peripheral neuropathy were associated with higher complication rates. Diabetic patients experienced higher rates of infectious and noninfectious complications. Complication rates were also higher in patients with suboptimal short and long term glycemic control^[32].

Ankle fractures in patients with DM are also associated with higher complication rates when compared to patients without DM^[33,34]. Patients with complicated DM (neuropathy, PAD or and/or nephropathy) had higher rates of non-infectious complications (malunion,

nonunion or CN) and were 5 times more likely to require revision surgery when compared to patients with uncomplicated DM. Many diabetic patients are not aware that they have neuropathy and/or PAD until they experience a postoperative complication.

ORTHOPAEDIC TRAUMA

Stress hyperglycemia in orthopaedic trauma patients is associated with higher rates of postoperative infections^[35-38]. A recent retrospective study of 110 orthopaedic trauma patients without a history of DM were evaluated based on the level of postoperative hyperglycemia^[35]. Patients who manifested a serum glucose greater than 220 mg/dL had a 25% infection rate, including wound infections, pneumonia, urinary tract infections, bacteremia or severe sepsis. Perioperative glucose levels greater than 220 mg/dL increased the likelihood of infection by a factor of seven in orthopaedic trauma patients with no known history of DM^[35].

Another study evaluated 187 consecutive critically injured non-diabetic orthopaedic trauma patients who were admitted to the intensive care unit^[37]. Multivariable regression testing demonstrated a significant relationship between hyperglycemia and SSI, leading the authors to conclude that stress induced hyperglycemia was an independent predictor of SSI in nondiabetic, critically injured orthopaedic trauma patients^[37]. The same authors evaluated non-critically injured orthopaedic trauma patients^[38]. Patients with hyperglycemia (blood glucose > 140 mg/dL) had a 4.9 times increased odds of a SSI when compared to patients without hyperglycemia. Patients with two or more blood glucose levels of > 200 mg/dL experienced a 170% increased risk of SSI compared to patients who glucose remained below 200 mg/dL^[38]. Diabetes also is associated with increased risk of hip fractures in both men and women and negatively impacts the outcomes of hip fracture treatment^[39,40]. At the time of admission, diabetic patients with hip fractures were more likely to use assistive devices (canes and walkers) and were more limited in ambulation than patients without DM^[39]. After surgery, cardiac complications and decubitus ulcers were more common in diabetic patients. Although diabetic patients had a significantly longer hospital stay than non-diabetic patients, no difference in surgical complication rates were observed. Follow up at one year demonstrated that diabetic patients experienced a similar level of functional recovery compared to patients without DM^[39].

A study of hip fractures in patients with and without DM demonstrated that prior to hip fracture, diabetic complained of more pain, were less healthy and more likely to use assistive devices^[41]. Reoperation rates and medical complications were similar during the first year, however, cardiac and renal complications were more common in diabetic patients by the second year of follow up^[41]. Although diabetic patients were

more likely to complain of severe hip pain at 4 mo, by 12 mo patients with DM were more likely to return to independent living. Ultimately patients with and without DM had similar levels of ambulation, ADL's and living conditions^[41].

SPORTS MEDICINE

Diabetic patients who participate in athletic activity have to be vigilant when managing insulin requirements, carbohydrate intake and the impact of athletic activity on serum glucose levels^[42]. Prior to participating in sports, a thorough examination is necessary, and insulin dosages may need to be adjusted based on the level of activity and carbohydrate intake. Risk assessment for both hypoglycemia and ketoacidosis is mandatory based on the level of competition expected^[42]. Athletic activity and exercise improve glycemic control and has a positive impact on risk factors for cardiovascular disease, independent of any change in body mass index and fat mass. Exercise appears to enhance the effects of insulin on skeletal muscle, liver and fat. As the diabetic population increases, more and more patients will employ exercise as a method to achieve ideal body weight and glycemic control since encouraging results have been demonstrated with even moderate increases in physical activity. Orthopaedic surgeons can expect to see an increase in overuse syndromes in this population.

Claudication like symptoms in diabetic patients may be caused by PAD, radiculopathy or chronic exertional compartment syndrome of the leg, and a careful history and examination is necessary to arrive at the correct diagnosis^[43]. Seventeen patients with DM and leg pain during walking underwent intramuscular pressure measurements during exercise. Diabetic patients demonstrated significantly higher compartment pressures than a control group of non-diabetic patients with exertional compartment syndrome ($P < 0.05$)^[43]. Despite having higher compartment pressures, patients with DM achieved satisfactory results with release of the involved compartments.

TOTAL JOINT ARTHROPLASTY

Type 2 DM and obesity are commonly related and it is not surprising to see these comorbidities in patients with osteoarthritis. Both morbid obesity and DM are independently associated with deep infection after primary total knee arthroplasty^[44]. Diabetes and hyperglycemia have been shown to negatively impact outcomes in several studies of joint arthroplasty. Diabetic patients with a preadmission blood glucose of at ≥ 200 mg/dL had an increased risk of pulmonary embolism by 200% when compared with patients with a blood glucose < 110 mg/dL^[45]. The risk of thromboembolism after total knee arthroplasty was double that of total hip arthroplasty^[45].

Bolognesi *et al*^[46] reported that diabetic patients

undergoing primary and revision hip and knee arthroplasty had fewer routine discharges and higher hospital charges for all procedures. Pneumonia, cerebrovascular accidents and need for blood transfusions were more likely in patients with DM^[46]. In an effort to reduce the rate of postoperative infections, a prospective single-blinded randomized study of 78 patients evaluated the role of antibiotic-impregnated cement during primary total knee arthroplasty in patients with DM^[47]. No patients who received the cefuroxime impregnated cement experienced an infection compared to five infections (13.5%) in patients who did not receive antibiotic cement ($P = 0.021$)^[47]. Patients with type 1 DM had longer hospital stays and higher costs than patients with type 2 DM following hip and knee arthroplasty^[48]. Surgical (hemorrhage and wound infection) and nonsurgical complications (heart attack, pneumonia, urinary infections and death) were more common in patients with type 1 DM. The authors postulated that these findings were due to the differences in the duration of DM and their underlying pathologies. Since Patients with type 1 DM carry more significant overall perioperative risks and require more health care resources compared with patients with type 2 DM following hip and knee replacement^[48].

However, not all studies have demonstrated inferior results of joint arthroplasty in patients with DM. A study of primary total knee replacement patients classified the patients as having no DM, controlled DM with HbA1c < 7%, or uncontrolled DM with HbA1c $\geq 7\%$ ^[49]. Revision joint arthroplasty, deep wound infection and thromboembolism were not found to be significantly higher in diabetic patients (controlled and uncontrolled) when compared to non-diabetic patients^[49]. Another study of 275 patients with DM who underwent total knee arthroplasty found that self-reported outcome scores and patient satisfaction were not inferior compared to patients without DM^[50]. The authors acknowledged that diabetic patients had a worse postoperative outcome because of concurrent comorbidities such cardiovascular disease, liver disease, anemia, depression and back pain^[50].

PEDIATRIC ORTHOPAEDICS

Increasingly, adolescents are being diagnosed with type 2 DM and pediatric orthopaedic surgeons potentially will encounter these patients in practice. Bowen *et al*^[51] associated obesity with slipped capital femoral epiphysis, and tibia vara and DM. The 55 children with DM had a mean BMI of 36.

UPPER EXTREMITY

Several conditions of the hand have been associated with DM such as carpal tunnel syndrome, Dupuytren disease, trigger digits, and limited joint mobility^[52]. Diabetes mellitus increased the risk of Hand-Arm

Vibration Syndrome by a factor of 1.5 and Dupuytren's disease by a factor of 1.7 in a large cohort of miners^[53]. Another controlled study reported higher rate of Dupuytren's disease, tenosynovitis, carpal tunnel syndrome and reduced joint motion in patients with DM compare to patients without DM^[53]. Several factors were associated with increased severity of the pathology including the use of insulin, older patients, longer duration of DM and microangiopathic changes^[54].

Diabetic patients who undergo arthroscopic surgery for adhesive capsulitis of the shoulder have inferior results when compared to non-diabetic patients^[55]. One study reported the results of arthroscopic rotator cuff repair in patients with DM, while showing improvement, do not achieve the same level of functional recovery as seen in patients without DM^[56]. Another retrospective controlled study of arthroscopic rotator cuff repair reported significant improvement in ROM in patients with and without DM^[57]. When comparing the two groups the authors found that patients with DM had less ROM and decreased outcome scores as compared to the non-diabetic cohort. No differences in rates of complications or recurrent tears were observed between the two groups^[57].

Hand infections in patients with DM are potentially limb threatening. Diabetic patients who present with a hand abscess had an amputation rate of 17.5%^[58]. Nearly 50% of the infections were polymicrobial and hand infections may mimic foot infections in patients with DM^[58].

SPINE SURGERY

Nonsurgical treatment

It has been demonstrated that a significant elevation in blood glucose levels occurs after epidural steroid injections, a common treatment for patients with lumbar radiculopathy^[59]. A transient rise of nearly 80% occurred, however the serum glucose level normalized with 48 h of the procedure. Diabetic patients should be advised that a temporary elevation in blood glucose is likely post injection^[59].

Lumbar surgery

A study of nearly 200000 patients who underwent lumbar spine surgery evaluated complication rates in patients with and without DM^[60]. The diabetic cohort represented 5.6% of the study population (11000 patients). Patients with DM had higher rates of infection, higher rates of nonroutine discharges, longer hospital stays, more need for blood transfusion and higher hospital charges than patients without DM^[60]. Another study of 195 patients demonstrated that DM increased the risk of a SSI by a factor of four^[61]. Similar to studies on total joint arthroplasty, not all studies regarding spinal surgery associate DM with negative outcomes. A study of 23 adult patients with noninsulin

Table 3 Take home messages for orthopaedic surgeons treating diabetic patients

Optimize the patient's medical care preoperatively
Strive for long term glycemic control of HbA1c \leq 8%
Thorough preoperative workup for cardiovascular disease
Identify anemia if present and treat accordingly if major blood loss is anticipated (<i>i.e.</i> , spine surgery or total joint surgery)
Thorough assessment of the vascular system preoperatively
If an abnormal examination is present proceed with non-invasive testing and vascular consultation
Perioperative care
Strive for inpatient glycemic control as recommended by major societies
Pre-meal glucose of < 140 mg/dL
Random glucose of < 180 mg/dL
Avoid hypoglycemia!!
Glucose levels of > 200 mg/dL have been associated with increased rates of complications in orthopaedic patients
Recognize that patients with poorly controlled diabetes and comorbidities are at increased for postoperative complications
Cardiovascular complications
Myocardial infarction
Stroke
Deep vein thrombosis and pulmonary embolism
Infection
Surgical site
Urinary tract
Pneumonia
Iatrogenic pressure ulcers
Pad bony prominences such as the sacrum and heels
Noninfectious complications
Hardware failure
Nonunion or malunion
Impaired wound healing
Inform patients that local injections of corticosteroids (trigger point injections, epidural steroid injections, <i>etc.</i>) will cause a temporary elevation in serum glucose for 24-48 h

dependent DM (matched with 23 nondiabetic patients) did not identify DM as a risk factor for perioperative complications or need for additional surgery^[62]. The results of lumbar spine decompression for spinal stenosis in 25 diabetic patients and 25 non-diabetic patients were compared after an average follow up of 3.4 years. This study did not identify any difference in outcomes, and the authors proposed that patients with DM could expect to have similar improvement in symptoms as non-diabetic patients^[63].

Cervical surgery

The impact of DM on complications after cervical spine surgery was assessed in a review of nearly 38000 patients^[64]. These patients underwent decompression and fusion for cervical myelopathy^[64]. The authors found that uncontrolled DM was an independent risk factor for poorer outcomes after cervical fusion. A retrospective controlled study of outcomes from the surgical treatment of cervical myelopathy reviewed a group of patients with DM and compared them to a cohort of patients without DM^[65]. Diabetic patients demonstrated poorer return of lower extremity neurologic function (sensory and motor) than non-

diabetic patients^[65]. Suboptimal glycemic control was associated with inferior outcomes as higher levels of preoperative Hgb A1c were associated with poorer rates of neurologic recovery^[65].

CONCLUSION

Diabetes mellitus is associated with negative outcomes across the spectrum of orthopaedic surgery and its subspecialties. The take home message for orthopaedic surgeons is to optimize preoperative, perioperative and postoperative medical management in patients with DM (Table 3). Higher rates of SSI have been observed in patients with DM, particularly in total joint arthroplasty, spine surgery and foot and ankle surgery. Higher rates of other complications such as myocardial infarction, pulmonary embolism and urinary tract infections have been demonstrated as well. Diabetic patients tend to have longer hospital stays and more non-routine discharges than patients without DM. Research produced over the past few decades indicate that DM in and of itself may not be culprit in negative outcomes. Rather, the complications of DM such as poor glycemic control, neuropathy, end stage renal disease and PAD most likely increase the risk of adverse outcomes. Patients with uncomplicated DM and optimal glycemic control generally have similar outcomes to patients without DM.

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Knee salvage procedures: The indications, techniques and outcomes of large osteochondral allografts

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Abstract

The overall incidence of osteochondral defect in the general population is estimated to be 15 to 30 per 100000 people. These lesions can become symptomatic causing pain, swelling and decreased function of the knee, and may eventually progress to osteoarthritis. In the young and active population, partial or total knee arthroplasty (TKA) is rarely the treatment of choice due to risk of early failure. Osteochondral allograft transplantation has been demonstrated to be a safe and effective treatment of large osteochondral and chondral defects of the knee in appropriately selected patients. The treatment reduces pain, improves function and is a viable limb salvage procedure for patients,

especially young and active patients for whom TKA is not recommended. Either large dowels generated with commercially available equipment or free hand shell allografts can be implanted in more posterior lesions. Current recommendations for fresh allografts stored at 4°C advise implantation within 21-28 d of procurement for optimum chondrocyte viability, following screening and testing protocols. Higher rates of successful allograft transplantation are observed in younger patients, unipolar lesions, normal or corrected malalignment, and defects that are treated within 12 mo of symptom onset. Patients with bipolar lesions, uncorrectable malalignment, advanced osteoarthritis, and those over 40 tend to have less favourable outcomes.

Key words: Osteochondral allograft; Knee; Salvage; Shell; Dowel

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Core tip: Osteochondral allograft transplantation has been demonstrated to be a safe and effective treatment of large osteochondral and chondral defects of the knee in appropriately selected patients. The treatment reduces pain, improves function and is a viable limb salvage procedure for patients, especially young and active patients for whom total knee arthroplasty is not recommended. Current recommendations for fresh allografts stored at 4°C advise implantation within 21-28 d of procurement for optimum chondrocyte viability, following screening and testing protocols. Higher rates of successful allograft transplantation are observed in younger patients, unipolar lesions, normal or corrected malalignment, and defects that are treated within 12 mo of symptom onset.

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INTRODUCTION

The overall incidence of osteochondral defect in the general population is estimated to be 15 to 30 per 100000 people. These lesions can become symptomatic causing pain, swelling and decreased function of the knee, and may eventually progress to osteoarthritis. In the young and active population, partial or total knee arthroplasty (TKA) is rarely the treatment of choice due to risk of early failure. The need for alternate options has propelled the development and use of biologic interventions to repair damaged osteochondral lesions in the past few decades. Such treatments include microfracture, chondroplasty, autologous chondrocyte implantation, osteochondral autograft transplant and osteochondral allograft transplant. Amongst the numerous biologic interventions available for osteochondral and chondral defects, osteochondral allograft transplantation emerges to be the most suitable option for large lesions (> 4 cm²) with associated bony defects. Osteochondral allograft transplantation can restore the entire osteochondral unit with both viable hyaline cartilage and bone in a single procedure^[1]. Improvements in allograft procurement protocols and surgical techniques over time have led to increase use of osteochondral allografts for knee salvage procedures.

In addition to transplantation of architecturally sound bone and viable articular cartilage capable of maintaining metabolic activity after implantation, osteochondral allografts offer many other advantages. Size and surface contours of the lesion may be matched with that of the donor graft, which also eliminates donor site morbidity associated with autograft transfers. Articular cartilage is aneural and relatively avascular, obtaining its nutrition from surrounding synovial fluid through diffusion, optimizing it for transplantation^[2,3]. Allogenic cartilage is immunologically privileged tissue as the intact cartilage matrix acts as a barrier between donor chondrocytes and host antibodies, protecting chondrocytes from host immune surveillance^[4]. This permits long-term survival of transplanted donor chondrocytes and makes tissue matching or therapeutic immunosuppression unnecessary. Retrieval studies at 25 years following transplantation have demonstrated survival of the allograft chondral tissue^[5].

INDICATIONS AND CONTRAINDICATIONS

Osteochondral allograft transplantation in the knee is typically indicated for patients with large focal full-thickness chondral or osteochondral defects (> 2 cm²), for which other techniques such as microfracture, osteochondral autograft transplantation and autologous chondrocyte implantation are inadequate due to

the size, location or depth of the lesion. It is also indicated as a salvage procedure for previously failed restoration treatments of the knee. Osteochondral allograft transplantation is indicated for treatment of osteonecrosis, post-traumatic osteochondral defects (Figure 1), osteochondritis dissecans (OCD), patellofemoral arthrosis and uni-compartmental degenerative tibiofemoral arthrosis.

Contraindications for osteochondral allograft transplantation include advanced or diffuse degenerative changes as seen on weight-bearing radiographs and advanced multi-compartmental arthrosis. It is also relatively contraindicated in patients with uncorrectable malalignment, ligamentous instability, meniscal insufficiency, and inflammatory arthropathies. Osteochondral allografting should be avoided in patients who are obese or may have altered bone metabolism, as seen in smoking, chronic steroid use and alcohol abuse. Low success rate is observed in patients over 40^[6], who may be considered for arthroplasty if criteria for joint replacement is met.

OSTEOCHONDRAL ALLOGRAFT STORAGE

Fresh allografts

Previously, grafts were implanted within 24 h of procurement. Today, grafts undergo strict protocols of screening and testing to reduce the risk of disease transmission^[7], leading to a minimum of 14 d before fresh grafts are implanted. Following harvest and 24 h of treatment in antibiotic solution, fresh allografts are refrigerated at 4 °C in either lactated Ringer's solution or a physiologic culture medium to maintain chondrocyte viability. An inverse relationship has been demonstrated between storage time and chondrocyte viability and density: at 4 d of storage nearly all chondrocytes are viable, at 7 d 98% remain viable and at 28 d chondrocyte viability significantly declines to 70%^[3]. Graft storage in physiologic culture medium has produced higher chondrocyte viability percentage compared to Ringer's solution^[8]. Chondrocyte function is paramount in achieving clinical success. However, the exact association between cell viability and clinical outcomes has yet to be determined^[8]. Current recommendations advise implantation of grafts within 21-28 d of procurement^[9], with a maximum storage period of 42 d^[10] of fresh allografts. Residual donor cells within the allograft are a potential source of an immune reaction. Disease transmission in fresh allograft tissue remains an issue of concern despite extensive tissue bank screening guidelines.

Fresh-frozen allografts

Fresh-frozen osteochondral allografts undergo deep freezing to -80 °C and have the advantages of indefinite storage period, decreased immunogenicity and reduced disease transmission relative to other graft types.



Figure 1 Anterior-posterior radiograph of knee with a large post-traumatic osteochondral defect secondary to gunshot injury.

But this is at the expense of 95% chondrocyte death, lost of mature articular cartilage cells and damage to the extracellular matrix within the graft^[11-13]. Studies on retrieved large allografts have also demonstrated deterioration of cells and matrix over time^[14].

Cryopreserved allografts

Cryopreserved allografts undergo rate-controlled freezing to -70°C in a cryoprotectant storage medium of either glycerol or dimethyl sulfoxide to preserve cellular viability. In an animal study chondrocyte viability of allografts preserved with glycerol was 77% in weight-bearing joints^[15]. Another study investigating a cryopreserved allograft using dimethyl sulfoxide demonstrated that chondrocyte viability was limited only to the superficial layer of the articular cartilage^[16] due to failure of the cryopreservant to penetrate the deeper zones. In an ovine model, cryopreserved allografts produced intermediate results when compared to fresh autografts, and it was observed that the membrane integrity of the allograft chondrocytes were the most reliable predictor of long-term outcomes of the graft^[17].

Pre-operative planning

A detailed history, examination and imaging must be conducted to assess the mechanical and biologic condition of the cartilage and subchondral bone of the knee. Pre-operative evaluation includes comprehensive use of radiographs and magnetic resonance imaging (MRI), as well as careful planning of necessary concurrent procedures, such as ligament reconstruction and meniscus transplantation. From the images, the femoral condyle or tibial plateau size is measured with correction for magnification. An appropriate allograft is identified with donor-recipient size matched within 2 mm.

Imaging

Diagnostic arthroscopy is utilized to assess the size and location of the lesion and identify any concomitant pathology that necessitates treatment. Radiographs usually required include: lower extremity alignment views; weight-bearing anteroposterior and flexion

posteroanterior views; lateral and patellar views. The images will determine the degree of joint space narrowing and allow measurement of the mechanical axis through the knee. Corrective osteotomy may be considered for any observed varus or valgus malalignment to return mechanical axis to neutral. Normal joint alignment is crucial for successful allograft transplantation^[6] and it is essential to correct malalignment prior to implantation of allograft^[18]. MRI is used to determine size, depth and condition of the lesion, as well as any associated meniscal or ligament deficiencies. Sizing of the allograft is also established from MRI evaluation.

Surgical technique

The two main surgical techniques are cylindrical dowel grafts or free-hand shell grafts. Allografts should be size-matched and be of the same compartment.

Dowel allograft

The patient is positioned supine and the lower limb placed in a leg holder to position the knee at an angle of flexion that facilitates appropriate access to the lesion. A limited lateral or medial arthrotomy over the involved compartment without subluxation of the patella is usually sufficient. If greater exposure is needed, the incision can be extended using a quadriceps-sparing sub-vastus approach or mid-vastus approach.

Once adequate exposure is achieved and the lesion identified, a cylindrical dowel is used to outline and determine the size of the proposed graft. A guide wire is placed in the center of the sizing dowel, perpendicular to the articular surface. A core reamer is then used to remove a total of 5-8 mm of cartilage and subchondral bone to form a base of healthy cancellous bone. For lesions of fibrous and necrotic bone from osteochondritis dissecans or osteonecrosis, deeper reaming may be necessary until healthy, bleeding osseous bone is reached. For even deeper lesions, morselized autologous bone graft may be required to pack any defects, which can be collected from the reaming. The guide wire is removed and depth measurements of the prepared recipient site in all four quadrants are made to harvest a matching allograft. A reference mark is made on the recipient site for allograft plug orientation.

A plug is retrieved from the corresponding anatomic location on the donor allograft that is held in a workstation. The same reference mark is made on the allograft before a size-matched coring reamer is used to harvest the plug. Following extraction of the plug, corresponding depth measurements of the four quadrants from the recipient site are marked on the plug and then cut to the appropriate thickness. Multiple attempts of trimming of the plug may be necessary in order to achieve precise thickness. When the graft is prepared and ready, high-pressure lavage is used to remove all marrow elements to reduce any potential

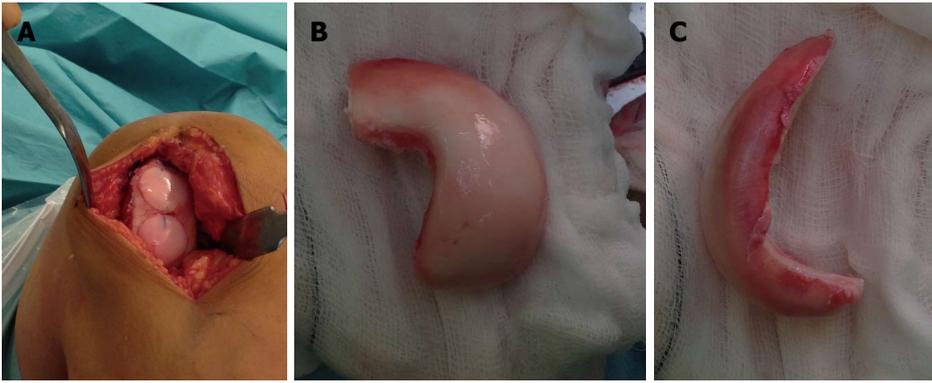


Figure 2 Dowel (A) and Shell (B, C) allograft in the lateral femoral condyle.



Figure 3 Anterior-posterior and lateral view radiographs of left knee post uni-compartment allograft replacement.

immunological reaction.

The graft is inserted into the recipient site by hand, matching the reference marks to allow proper orientation and then gently press-fitted into place until flush with the surrounding articular surface (Figure 2A). This step should be carried out with care to minimize insult to the articular surface of both the recipient and donor tissue in order to protect chondrocyte viability. The knee is then taken through a full range of motion to access graft stability and identify any catching or soft tissue obstruction. Additional fixation is usually not required, however if it is determined necessary or if the graft is large, absorbable pins or screws are used to provide stability (Figure 3).

Shell allograft

The shell technique is typically used for defects that are located posteriorly, which are difficult to access perpendicularly with a dowel, or defects of the tibial plateau. After identification of the lesion, the edges are defined with a surgical pen, with attempts to create a geometric shape recipient site that allows hand crafting of a matching shell graft. The recipient site is cut to a depth of 4-5 mm with burr and osteotomes to remove all tissue in the marked area. A slightly larger matching graft is cut freehand from donor tissue, and then excess cartilage and bone is gradually removed

as the graft is shaped to fit the recipient site (Figure 2B). A foil or paper template of the recipient site may be used to shape the graft. The shell allograft is then inserted until flush with the articular surface and fixed with bioabsorbable pins and screws, if necessary.

OUTCOMES

Femur

The femoral condyles are the most common site to implant osteochondral allografts in the knee. Bakay *et al*^[6] reported the results of 18 patients following cryopreserved femoral condyle plug-shaped allografts and reported 4 failures, 13 excellent or good and 5 fair or poor clinical results. The average success rate for femoral allograft transplantation was 72%. In 3 patients, allograft transplantation was performed upon moderate varus knees without corrective realignment and each graft disintegrated within 6 mo. In 3 other patients where corrective realignment procedures were carried out, the grafts healed with good results.

Davidson *et al*^[19] analysed 10 knees in 8 patients using second-look arthroscopic evaluation and biopsy at a mean of 40 mo post fresh allograft transplantation in the distal femur. The mean International Knee Documentation Committee (IKDC) score significantly improved from 27 to 79 ($P = 0.002$). The mean Lysholm score significantly improved from 37 to 78 ($P = 0.002$). The mean Tegner activity level improved from 4.3 to 5.3 ($P = 0.16$). The mean Short Form 36 (SF-36) physical score significantly improved from 38 to 51 ($P = 0.002$). The mean SF-36 mental score showed minimal improvement. Histological analysis post-operatively showed no significant difference between native and graft cartilage biopsy specimens for mean thickness of articular surface ($P = 0.625$), chondrocyte cellular viability ($P = 0.555$) and cell density ($P = 0.129$). MRI and plain radiographs demonstrated complete incorporation of the bony compartment of the graft in all patients, and mean modified Outerbridge MRI scores improved from 4.3 pre-operatively to 0.6 post-operatively ($P = 0.002$).

Pearsall *et al*^[20] evaluated the results of 12

Table 1 Location of allografts from Murphy *et al*^[27]

Location	Number
Femur	
Medial condyle	18
Lateral condyle	15
Trochlea	2
Patella	3
Tibial plateau	1
Multiple sites	4

fresh allograft, 12 frozen allograft and 24 autograft transplantations on 48 patients with an average follow up of 37.1 mo. Femoral condyles constituted more than half of the treated lesions. The mean Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score significantly improved for pain from 10.9 pre-operatively to 14.5 post-operatively ($P = 0.0001$); for stiffness from 4.1 pre-operatively to 5.6 post-operatively ($P = 0.00001$); and for function from 38.3 pre-operatively to 49.7 post-operatively ($P = 0.0002$). The mean Knee Society Score (KSS) improved significantly from 112.8 pre-operatively to 154.2 post-operatively ($P = 0.0001$). Eight allografts did not improve after transplantation and underwent knee arthroplasty. No significant difference was observed in outcome improvement scores between autografts and allografts for WOMAC ($P = 0.1$), KSS ($P = 0.8$), knee range of motion ($P = 0.2$) and pain ($P = 0.7$).

McCulloch *et al*^[21] prospectively assessed 25 patients who underwent fresh osteochondral allograft transplantation for femoral condyle defects for an average follow up of 35 mo. Statistically significant improvements from pre-operative to post-operative evaluations were reported. Patients reported 84% overall satisfaction with transplantation results and 79% satisfaction with functionality compared to the unaffected knee. Radiographic assessment revealed 22 grafts (88%) had incorporated into host bone.

Williams *et al*^[22] prospectively analyzed 19 patients treated with fresh osteochondral allografts for defects of the knee with an average follow up of 48 mo. MRI evaluation at a mean interval of 25 mo post-operatively demonstrated that, in general, thickness of the implanted allograft articular cartilage was maintained. Activities of Daily Living score significantly increased from 56 pre-operatively to 70 pre-operatively ($P < 0.05$) and SF-36 score significantly increased from 51 pre-operatively to 66 post-operatively ($P < 0.005$). Osseous trabecular incorporation was complete in 3, partial in 11 and poor in 4 allografts. Four grafts failed clinically.

In a prospective non-randomized study, Gross *et al*^[23] performed fresh femoral condyle allograft reconstruction surgery on 60 patients with an average follow up of 10 years. 20% of grafts failed and required graft removal alone or with TKA. Survivorship analysis

Table 2 Pre-operative and post-operative comparison of outcome measures from study by Murphy *et al*^[27]

Outcome measure	Pre-operative	Post-operative
IKDC scores		
Pain	5.7 ± 2.7 (0-10)	2.5 ± 2.4 (0-8)
Function	3.7 ± 1.9 (0-9)	7.8 ± 1.7 (4-10)
Total	42.0 ± 16.6 (14-98)	75.2 ± 20.2 (33-100)
Modified D'Aubigne Postel 18-point score	13.1 ± 2.1 (9-18)	16.6 ± 1.6 (12-18)
Knee Society Function score	69.3 ± 18.8 (45-100)	89.4 ± 16.3 (40-100)

Results presented as mean ± SD (range). All comparisons statistically significant ($P < 0.05$). IKDC: International Knee Documentation Committee.

demonstrated 95% survival at 5 years and 85% survival at 10 years. Of the 48 remaining intact grafts, the average modified Hospital for Special Surgery (HSS) score was 83 out of 100, with excellent or good results achieved in 40 patients.

Emmerson *et al*^[24] reported on the use of fresh osteochondral allografts in the surgical management of type 3 and 4 osteochondritis dissecans of the femoral condyles. Sixty-six knees in 64 patients were assessed pre-operatively and post-operatively using an 18-point modified D'Aubigne and Postel scale^[25,26]. Forty-seven of 65 knees reported excellent or good results; mean D'Aubigne and Postel scale significantly increased from 13.0 pre-operatively to 16.4 post-operatively ($P < 0.01$). Survival analysis revealed 91% survivorship at 2 years and 76% survivorship at 10 and 15 years. 92% of the 59 patients who completed a patient questionnaire were satisfied with their treatment and 90% reported less pain.

Murphy *et al*^[27] reported on osteochondral allograft transplantation of the knee in the pediatric and adolescent population in a case series of 43 knees in 39 patients with an average follow up of 8.4 years. The most common site of lesions was at the femoral condyles (Table 1). OCD (61%), avascular necrosis (16%) and traumatic chondral injury (14%) were the most common causes of the lesions. 5 knees experienced failure of the allograft at a median of 2.7 years; 4 knees were consequently successfully salvaged with an additional allograft transplant and 1 knee underwent prosthetic arthroplasty 8.6 years after revision allograft. Allograft survivorship of the entire patient cohort was 90% at 10 years. Pre-operative and post-operative comparison of patients with allografts in situ at final follow-up showed improvement in all outcome measures (Table 2).

In a prospective study of 43 athletes treated with fresh-stored osteochondral allograft transplantation, Krych *et al*^[28] evaluated the clinical outcomes and rate of return to athletic activity with an average 2.5 year follow up. 38 of 43 (88%) athletes achieved limited return to sport, with full return to pre-injury level possible in 34 of 43 (79%) athletes at 9.6 ±

3.0 mo after the procedure. Statistically significant increases from baseline to the most recent follow up was reported in Activities of Daily Living Score from 62.0 to 82.8 ($P < 0.01$), IKDC score from 46.2 to 79.2 ($P < 0.01$) and Marx Activity Rating Scale from 5.5 to 8.4 ($P = 0.01$). The study also showed that risk factors affecting the ability to return to sport were age more than 25 years ($P = 0.04$) and pre-operative duration of symptoms more than 12 mo ($P = 0.003$).

Raz *et al.*^[29] reviewed 58 cases of osteochondral allograft transplantation to the distal femur with an average follow up of 21.8 years. 13 of 58 cases required further surgery of graft removal or TKA, and 1 case underwent multiple debridements before above-the-knee amputation. Kaplan-Meier analysis revealed graft survivorship of 91%, 84%, 69% and 59% at 10, 15, 20 and 25 years, respectively. A mean modified HSS score of 86 was reported for patients with a surviving allograft at 15 years or more post-operatively. Radiographic evidence was available for 55 of 58 patients at 10 or more years following surgery. Graft sclerosis and fragmentation was seen in 10 patients, non-union was seen in 5 patients and successful graft incorporation to host was observed in 40 patients.

Tibia

Sixty-five patients, all with post-traumatic tibial plateau fractures, received fresh osteochondral allografts for reconstruction of the tibial plateau with an average follow up of 11.8 years in a prospective non-randomized study by Gross *et al.*^[23]. Survivorship analysis revealed 95% survival at 5 years and 80% survival at 10 years and 65% at 15 years. Twenty-one patients required knee arthroplasty after graft failure. At the end of the study period, the mean modified HSS score was 85.3 for the intact grafts.

In a study by Bakay *et al.*^[6] post-traumatic defects of the tibial condyle were treated with cryopreserved allografts with additional metal fixation screws in 5 patients with an average 2 years follow up. Three cases were successful and reported excellent or good clinical results. Two cases of failures were reported in patients both aged over 40 years; 1 graft disintegrated and 1 graft was implanted technically incorrectly, producing a poor clinical result.

Ghazavi *et al.*^[30] reported on the use of fresh osteochondral allografts to reconstruct post-traumatic defects in 126 knees of 123 patients with a mean follow up of 7.5 years. The locations of the lesions were: tibial plateau (63), femoral condyles (50), bipolar tibial and femoral (8) and patellofemoral (2). One hundred and eight of 126 knees (86%) were successfully reconstructed, whilst 18 of 126 grafts (14%) were reported as failures (4 of 8 bipolar grafts and 14 of 118 unipolar grafts). Survivorship analysis revealed 95% survival at 5 years, 71% at 10 years and 66% at 20 years. The mean modified HSS Knee score of successful

cases increased from 66 pre-operatively to 83 post-operatively.

Colangeli *et al.*^[31] compared results of 10 patients who underwent total knee modular megaprosthesis and 8 patients who underwent osteochondral allograft transplantation for reconstruction of the knee with proximal tibia bone tumours. When compared to total knee replacement, patients treated with osteochondral allografts had a lower incidence of knee extension lag; higher rate of normal knee pattern during gait; and superior knee extensor strength. Abnormal knee kinematics and knee motion during gait observed in 5 patients treated with allograft were attributed to a shortened patellar tendon and an oversize mismatch of the femur. Osteochondral allograft transplantation, when optimally reconstructed, gave superior functional results compared to total knee replacement.

Musco *et al.*^[32] retrospectively reviewed 58 osteochondral allograft transplantations after resection of proximal tibial bone tumours in 52 patients, with an average follow up of 10.3 years. Six patients died from tumour-related causes without allograft failure before 5 years follow up. At the most recent follow up, from 32 of the 52 remaining allografts 20 had failed, Kaplan-Meier survival analysis revealed 65% graft survivorship at 5 and 10 years. Of the 32 surviving allografts, the average musculoskeletal tumour society functional score was 26 out of 30 points and the average International Society of Limb Salvage radiographic score was 87%, an excellent radiographic result. Similarly, Hornicek *et al.*^[33] and Shi *et al.*^[34] both reported on limb salvage procedures with osteochondral allograft after resection of proximal tibia tumours, with success rates of 66% and 80%, respectively. Infection and allograft fractures are the main causes of failures in these studies.

Patella

Jamali *et al.*^[35] retrospectively analyzed 20 knees in 18 patients treated with fresh osteochondral allograft transplantation of the patellofemoral joint with an average clinical follow up of 94 mo. Procedures were performed on the patella in all 20 knees and on the trochlea in 12 knees. Indications for surgery included secondary arthrosis from patellar subluxation (7 knees); post-traumatic arthrosis (6 knees); primary patellofemoral arthrosis (4 knees); and primary chondromalacia patellae (3 knees). Five patients experienced clinical failures, defined as revision allograft surgery, TKA or arthrodesis. The remaining 13 patients were classified as having successful clinical outcomes. For the knees with successful results, the average modified 18-point D'Aubigne-Postel score significantly improved from 11.7 pre-operatively to 16.3 at the most recent follow up ($P = 0.001$). Sixty percent of all patients reported excellent or good results and Kaplan-Meier survivorship analysis revealed at 10 years allograft survival was 67%.

Bakay *et al.*^[6] performed whole patellar surface

Table 3 Demographic details of all studies included in review

Ref.	Population	Indication	Location	Patient no.	No. of knees	Mean age (yr)	Mean follow up	Failure rate
Bakay <i>et al</i> ^[6]	-	Osteoarthritis; post-traumatic; OCD; chondromalacia	MFC, LFC, T, P, bipolar	18	33	48	19 mo	-
Ghazavi <i>et al</i> ^[30]	Young, active patients	Post-traumatic	MFC, LFC, T, bipolar, P	123	126	35	7.5 yr	15%
Langer <i>et al</i> ^[14]	Young, active patients	Post-traumatic; OCD; osteonecrosis; osteoarthritis	MFC, LFC	60	60	27	10 yr	20%
Gross <i>et al</i> ^[5]	Young, active patients	Tibial plateaus fractures	T	65	65	42.8	11.8 yr	32%
Jamali <i>et al</i> ^[35]	-	Post-traumatic; patella subluxation; primary patellofemoral arthrosis; primary chondromalacia patellae	P, FT	18	20	-	94 mo	28%
Colangeli <i>et al</i> ^[31]	-	Proximal tibia bone tumour	T	8	8	23.1	37 mo	-
Davidson <i>et al</i> ^[19]	-	OCD; post-traumatic	MFC, FT	8	10	32.6	40 mo	-
Emmerson <i>et al</i> ^[24]	-	OCD	MFC, LFC	64	66	28.6	7.7 yr	15%
McCulloch <i>et al</i> ^[21]	-	Degenerative; post-traumatic; OCD; osteonecrosis	MFC, LFC	25	25	35	35 mo	4%
Williams <i>et al</i> ^[8]	-	Full-thickness cartilage defect; OCD; osteonecrosis	MFC, LFC	19	19	34	48 mo	21%
Pearsall <i>et al</i> ^[3]	-	Full-thickness cartilage defect	MFC, LFC, FT, P	48	24	46	37.1 mo	19%
Muscoletto <i>et al</i> ^[32]	-	Proximal tibia bone tumour; previous allograft failure	T	52	58	24	10.3 yr	39%
Krych <i>et al</i> ^[28]	Athletes	Post-traumatic; non-traumatic focal chondral and osteochondral lesion; OCD	MFC, LFC, FT, multiple sites	43	43	32.9	2.5 yr	-
Murphy <i>et al</i> ^[27]	Pediatric and adolescent population	OCD; avascular necrosis; post-traumatic; osteochondral fracture; degenerative lesion	MFC, LFC, FT, P, T, multiple sites	39	43	16.4	8.4 yr	12%
Raz <i>et al</i> ^[29]	Young, active patients	Post-traumatic; OCD	MFC, LFC	58	58	28	21.8 yr	22%

MFC: Medial femoral condyle; LFC: Lateral femoral condyle; FT: Femoral trochlea; P: Patella; T: Tibia; OCD: Osteochondritis dissecans.

replacement with mushroom-shaped cryopreserved osteochondral allografts in 8 patients. Six excellent or good and 2 fair clinical results were reported, producing an average success rate of 75%. One graft fragmentation failure occurred due to hyper-pressure of the patellofemoral joint in a patient aged over 45 years. The study also found that patellar allografts produced superior results to femoral allografts, showing more rapid revascularization and better integration of the mushroom-shaped allografts.

Bipolar

Bipolar lesions are considered a contraindication for treatment with osteochondral allograft transplantations and studies have reported poor results in reconstructed bipolar cases. Bakay *et al*^[6] reported 2 cases of medial compartment bipolar allograft transplantations. Both grafts disintegrated within 6 mo with very poor clinical results. Beaver *et al*^[18] performed 19 bipolar allograft reconstructions with an average follow up of 68 mo. Bipolar graft survivorship analysis was 60% at 5 years and 40% at 10 years. In this study, when compared to unipolar grafts, bipolar grafts show a lower success rate ($P = 0.09$). However, the proportion of bipolar grafts was greater in patients aged over 60. An

example of such a case is shown in Figure 2.

The demographic details of all studies are summarized in Table 3; survivorship analysis results of all studies are summarized in Table 4; outcome scores and results of all studies are summarized in Tables 5-7.

Immediate continuous passive motion (CPM) is traditionally used after osteochondral allografting and any chondral resurfacing procedures. Patients are generally permitted unrestricted, full-range of motion unless a concomitant reconstructive procedure dictates knee motion restrictions. Braces are typically not necessary except maybe for patellofemoral joint allografts, where flexion is limited to 45° for 4 to 6 wk, and for bipolar tibial and femoral allografts, in which an unloader brace can prevent excessive stress on the reconstructed sites. CPM is used for 6 to 8 h per day for the initial 6 wk to avoid adhesions, promote the healing process and encourage graft nutrition.

Supervised physical therapy commences after initial post-operative visit and the patient is kept non-weight bearing or toe-touch weight bearing for first 6-12 wk, depending on the size of the graft, type of fixation and radiographic signs of incorporation. By 3 mo patients are expected to have full range of motion and regain

Table 4 Summary of survivorship analysis of all studies included in review

Ref.	Location	No. of knees	Survivorship				
			5 yr (%)	10 yr (%)	15 yr (%)	20 yr (%)	25 yr (%)
Bakay <i>et al</i> ^[6]	MFC, LFC, T, P, bipolar	33	-	-	-	-	-
Ghazavi <i>et al</i> ^[30]	MFC, LFC, T, bipolar, P	126	95	71	66	-	-
Langer <i>et al</i> ^[4]	MFC, LFC	60	95	85	-	-	-
Gross <i>et al</i> ^[5]	T	65	95	80	-	-	-
Jamali <i>et al</i> ^[35]	P, FT	20	-	67	-	-	-
Colangeli <i>et al</i> ^[31]	T	8	-	-	-	-	-
Davidson <i>et al</i> ^[19]	MFC, FT	10	-	-	-	-	-
Emmerson <i>et al</i> ^[24]	MFC, LFC	66	91	76	76	-	-
McCulloch <i>et al</i> ^[21]	MFC, LFC	25	-	-	-	-	-
Williams <i>et al</i> ^[8]	MFC, LFC	19	-	-	-	-	-
Pearsall <i>et al</i> ^[3]	MFC, LFC, FT, P	24	-	-	-	-	-
Muscoletto <i>et al</i> ^[32]	T	58	65	65	-	-	-
Krych <i>et al</i> ^[28]	MFC, LFC, FT, multiple sites	43	-	-	-	-	-
Murphy <i>et al</i> ^[27]	MFC, LFC, FT, P, T, multiple sites	43	-	-	-	-	-
Raz <i>et al</i> ^[29]	MFC, LFC	58	-	91	84	69	59

MFC: Medial femoral condyle; LFC: Lateral femoral condyle; FT: Femoral trochlea; P: Patella; T: Tibia.

normal quadriceps strength. At 4-6 mo functional rehabilitation should be complete and patients can begin light recreational activities but avoid excessive impact of allografts. By 12 mo return to higher impact activities can be considered.

Risks and complications

Risk of disease transmission is a potential disadvantage of fresh osteochondral allograft transplantations. Although exceedingly rare due to careful donor screening protocols, allograft-associated infections can still potentially be fatal. Safety guidelines established by the American Association of Tissue Banks require extensive donor screening, with a detailed medical history and social history; serologic testing; viral and bacteriologic testing; procurement and storage requirements; and graft quarantine until negative testing results are confirmed^[36].

Based on an observational study of 11391 donors to United States tissue banks between 2000 and 2002, the estimated risk of viral transmission at time of donation was 1 in 34000 for Hepatitis B, 1 in 42000 for Hepatitis C, 1 in 55000 for human immunodeficiency virus (HIV) and 1 in 129000 for human T-lymphotropic virus^[37]. Despite these high risks of donor viremia observed in the study, the estimated actual risk of disease transmission with allograft tissue transplantation is low. Risk of HIV transmission is 1 in 1.6 million^[38], with the only reported case of disease transmission from allogeneic graft before screening standards were set up in 1985^[39].

Deep infection should be distinguished from superficial infection, by physical examination and joint aspiration if necessary, and be treated with irrigation, surgical debridement and graft removal. Graft fragmentation and collapse are the main causes of failure, commonly presenting as new onset of pain, joint effusion, and mechanical symptoms. Failure of allograft transplantation

most often occurs in the osseous portion of the graft due to subchondral collapse, delayed union or non-union. Larger grafts are at higher risk of these complications. MRI can assess causes of symptoms and host-graft incorporation, however caution must be taken when interpreting MRI images as well-functioning grafts can demonstrate signaling abnormalities that may resolve over time as creeping substitution occurs.

Allograft subsidence may also occur as a milder complication. Some patients may have persistent pain following fresh osteochondral allograft transplantation due to low-grade chronic inflammatory reaction to the graft.

CONCLUSION

Osteochondral allograft transplantation has been demonstrated to be a safe and effective treatment of large osteochondral and chondral defects of the knee in appropriately selected patients. The treatment reduces pain, improves function and is a viable limb salvage procedure for patients, especially young and active patients for whom TKA is not recommended. Current recommendations for fresh allografts stored at 4 °C advise implantation within 21-28 d of procurement for optimum chondrocyte viability, following screening and testing protocols. Higher rates of successful allograft transplantation are observed in younger patients, unipolar lesions, normal or corrected malalignment, and defects that are treated within 12 mo of symptom onset. Patients with bipolar lesions, uncorrectable malalignment, advanced osteoarthritis, and those over 40 tend to have less favourable outcomes.

Future research should explore the effects of the duration of prolonged storage of allografts on clinical outcomes. Investigation should be carried out on techniques to maximize storage time, whilst maintaining viability of chondrocytes during storage

Table 5 Summary of outcome scores and results of all studies included in review

Ref.	Location	No. of knees	D'Aubigne and Postel		HSS		IKDC		Lysholm		KSS		KSF		ADL		MTS		ISLS		SF-12		SF-36		Tegner		Outerbridge		Marx			
			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2		
Bakay <i>et al</i> ^[6]	MFC, LFC, T, P, bipolar	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Ghazavi <i>et al</i> ^[30]	MFC, LFC, T, bipolar, P	126	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Gross <i>et al</i> ^[5]	MFC, LFC	60	-	-	83/100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Gross <i>et al</i> ^[23]	T	65	-	-	85.3/100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Jamali <i>et al</i> ^[35]	P, FT	20	11.7	16.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Colangeli <i>et al</i> ^[31]	T	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Davidson <i>et al</i> ^[19]	MFC, FT	10	-	-	-	-	27	79	37	78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Emmerson <i>et al</i> ^[34]	MFC, LFC	66	13	16.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
McCulloch <i>et al</i> ^[21]	MFC, LFC	25	-	-	-	-	29	58	39	67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Williams <i>et al</i> ^[8]	MFC, LFC	19	-	-	-	-	-	-	-	-	-	-	-	-	56	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pearsall <i>et al</i> ^[20]	MFC, LFC, FT, P	24	-	-	-	-	-	-	-	-	110	119	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Muscolo <i>et al</i> ^[32]	T	58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26/30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kryuch <i>et al</i> ^[28]	MFC, LFC, FT, multiple sites	43	-	-	-	-	46	79	-	-	-	-	-	-	62	82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Murphy <i>et al</i> ^[27]	MFC, LFC, FT, P, T, multiple sites	43	13.1	16.6	-	-	42	75	-	-	-	-	69.3	89.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Raz <i>et al</i> ^[29]	MFC, LFC	58	-	-	86/100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1: Pre-operative; 2: Post-operative; IKDC: International Knee Documentation Criteria; SF-36: Short form 36; SF-12: Short form 12; KSS: Knee society score; KSF: Knee society function score; ADL: Activities of daily living; HSS: Hospital for special surgery; MTS: Musculoskeletal tumour Society; ISLS: International Society of Limb Salvage radiographic; MFC: Medial femoral condyle; LFC: Lateral femoral condyle; FT: Femoral trochlea.

Table 6 Summary of Knee injury and osteoarthritis outcome scores of study by McCulloch *et al*^[21]

Year	Ref.	Location	No. of knees	KOOS Pain		KOOS Symptoms		KOOS ADL		KOOS SRF		KOOS QOL	
				Pre-operative	Post-operative								
2007	McCulloch <i>et al</i> ^[21]	MFC, LFC	25	43	73	46	64	56	83	18	46	22	50

KOOS: Knee injury and osteoarthritis outcome score; ADL: Activities of Daily Living; SRF: Sports and Recreation Function; QOL: Quality of life; MFC: Medial femoral condyle; LFC: Lateral femoral condyle.

Table 7 Summary of Western Ontario and McMaster Universities Osteoarthritis index score of study by Pearsall *et al* Post-operative considerations

Year	Ref.	Location	No. of knees	WOMAC Pain		WOMAC Stiffness		WOMAC Function	
				Pre-operative	Post-operative	Pre-operative	Post-operative	Pre-operative	Post-operative
2008	Pearsall <i>et al</i> ^[20]	MFC, LFC, FT, P	24	10.9	14.5	4.1	5.6	38.3	49.7

WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; MFC: Medial femoral condyle; LFC: Lateral femoral condyle; FT: Femoral trochlea.

and implantation. The influence of impaction at graft insertion remains to be established, as well as the role of post-operative protected weight bearing. Further research may work to produce a valid radiographic criterion for outcome assessment; functional MRI techniques can be applied to non-invasively assess biochemical health of cartilage after allograft transplantation. Improvement in allograft-host fixation and graft incorporation will likely further advance patient short- and long-term outcomes. Modulating the healing response by donor-recipient matching or the use of bioactive growth factors, may further improve outcomes of osteochondral allograft transplantations.

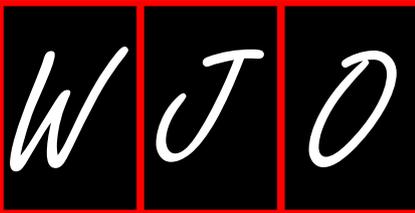
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Complications associated with prone positioning in elective spinal surgery

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these complications remain uncommon, the range of possible morbidities is wide and includes multiple organ systems. Perioperative visual loss (POVL) is a well described, but uncommon complication that may occur due to ischemia to the optic nerve, retina, or cerebral cortex. Closed-angle glaucoma and amaurosis have been reported as additional etiologies for vision loss following spinal surgery. Peripheral nerve injuries, such as those caused by prolonged traction to the brachial plexus, are more commonly encountered postoperative events. Myocutaneous complications including pressure ulcers and compartment syndrome may also occur after prone positioning, albeit rarely. Other uncommon positioning complications such as tongue swelling resulting in airway compromise, femoral artery ischemia, and avascular necrosis of the femoral head have also been reported. Many of these are well-understood and largely avoidable through thoughtful attention to detail. Other complications, such as POVL, remain incompletely understood and thus more difficult to predict or prevent. Here, the current literature on the complications of prone positioning for spine surgery is reviewed to increase awareness of the spectrum of potential complications and to inform spine surgeons of strategies to minimize the risk of prone patient morbidity.

Key words: Spine; Patient positioning; Prone position; Complications; Prevention and control

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Core tip: This review addresses the complications of prone positioning for spine surgery, which is an important and relatively underrepresented topic in the literature. Here, we address the wide range of complications by system, covering the most common complications, current understanding of pathophysiology, and strategies for prevention. Individual cases of very rare complications are also addressed. This article provides increased awareness and understanding of the risks of prone positioning, which is important for patient morbidity.

Abstract

Complications associated with prone surgical positioning during elective spine surgery have the potential to cause serious patient morbidity. Although many of

DePasse JM, Palumbo MA, Haque M, Ebersson CP, Daniels AH. Complications associated with prone positioning in elective spinal surgery. *World J Orthop* 2015; 6(3): 351-359 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v6/i3/351.htm> DOI: <http://dx.doi.org/10.5312/wjo.v6.i3.351>

INTRODUCTION

Prone surgical positioning is commonly utilized for procedures requiring the posterior approach to the spine. Prone positioning is associated with several important and potentially catastrophic complications which can result in permanent disability. Complications include hemodynamic changes resulting in hypoperfusion, a range of ophthalmologic conditions, central nervous system lesions, peripheral nerve compression injuries, compartment syndrome, and pressure ulcers. Other complications include airway swelling and peripheral arterial compression. Though most of these complications are rare, familiarity with the spectrum of potential complications and strategies for prevention can limit morbidity in prone spine surgery.

Research

A comprehensive literature review utilizing PubMed was performed identifying relevant articles that addressed complications associated with prone surgical positioning in spine surgery. Search terms in the primary search were MESH terms "spine" and "prone position." Current and relevant literature was then reviewed. Reference lists from papers retrieved from the primary search were also searched for additional current and relevant work.

HEMODYNAMIC COMPLICATIONS

The prone position poses unique hemodynamic challenges. Compression of the abdomen may restrict blood flow through the inferior vena cava. The resultant engorgement of the paravertebral and epidural veins can increase bleeding in the surgical field. Because there is baseline postural hypotension and decreased cardiac function in the prone position, hypovolemia in the prone patient can exacerbate hypoperfusion to multiple organ systems and may increase the likelihood of acute kidney injury, especially during procedures with high blood loss^[1,2].

In order to minimize intra-abdominal pressure and blood loss, currently available tables and frames have been engineered to leave the abdomen free and prevent an increase in intra-abdominal pressure. The various tables and frames differ in their effect on spinal alignment, location of pressure points, and hemodynamic derangement in the prone position. In 1969, Relton and Hall described a frame that possessed two parallel but separate V-shaped supports, one under the upper thoracic cage and the other under the pelvis.

These lateral supports provide stability for deformity correction/scoliosis procedures. This frame allows for a free abdomen, but can potentially hyperextend the vertebral column^[3].

The Andrews and the Wilson frames were both designed for prone lumbar spine surgery (Figure 1). The Andrews frame positions the patient in a modified knee-chest position allowing for some control of lumbar sagittal plane alignment. By adjusting hip flexion with a mobile tibial support this frame creates relative kyphosis of the lumbar spine. The resultant increase in interlaminar distance facilitates access to the spinal canal during decompressive procedures.

The Wilson frame has two parallel, longitudinal curved pads which support both sides of the patient's torso. The degree of curvature of the bolsters is adjustable, which also allows the surgeon to alter the patient's lumbar sagittal plane alignment. The C-arm fluoroscopy machine can be integrated with both frames, with the Wilson frame providing a full 360 degrees of radiolucency when placed on the Jackson table^[3]. The Jackson table also offers complete axial rotation capability for combined approaches. Both the Andrews and the Wilson frame can produce substantial hemodynamic compromise as a result of decreased preload and increased afterload, respectively^[2].

OPHTHALMOLOGIC COMPLICATIONS

Ophthalmologic complications of prone positioning were first reported in 1948 by Slocum *et al.*^[4] who described a case of blindness resulting from malpositioning on a Bailey headrest. Subsequent reports established the causal relationship between increased intraocular pressure, decreased tissue perfusion, and perioperative visual loss (POVL). The rarity of this devastating complication has limited research^[5].

The incidence of POVL after spine surgery ranges from 0.019% to 0.2%, with an increased risk during procedures involving prone positioning and in surgery for spinal deformity^[6-8]. There is also an increased risk in patients with comorbidities such as diabetes mellitus with end organ damage, coagulopathy, neurologic disorders, and paralysis^[6].

Despite the absence of large prospective studies, several etiologies of POVL have been described, including anterior and posterior ischemic optic neuropathy (AION and PION), central retinal artery occlusion (CRAO), and cortical blindness^[5] (Table 1). Other rare etiologies have also been reported, including POVL associated with acute closed-angle glaucoma and amaurosis^[9,10].

Ischemic optic neuropathy

Ischemic optic neuropathy (ION) is thought to be the most common cause of POVL following prone spine surgery. ION was cited as the etiology of 89% of cases of POVL in the American Society of Anesthesiologists' Postoperative Visual Loss Registry^[11]. However, only 28% of the cases in a recent NIS analysis of POVL

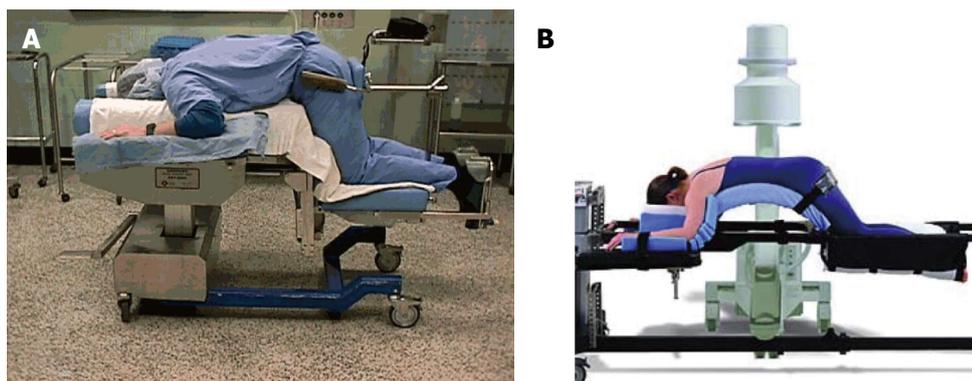


Figure 1 Patient positioning on an Andrews frame (A) and Wilson frame (B). Prone-Andrews frame. Digital image. www.pitt.edu; Wilson frame. Digital Image. Mizuho OSI. www.mizuhoosi.com. Accessed Jan 22 2015.

Table 1 Positioning complications and risk factors

Complication	Risk factors
Ophthalmological complications	
ION ^[14]	Obesity, male sex, Wilson frame use, longer anesthetic duration, greater estimated blood loss, increased ratio of crystalloid to colloid
Posterior ION ^[13]	Blood loss greater than 4 L, persistent relative hypotension
Anterior ION ^[16]	Atherosclerosis, diabetes
Central retinal artery occlusion ^[5,13]	External compression of the eye
Cortical blindness ^[13]	Profound hypotension, prolonged hypoxia, cardiac arrest, thromboembolism
Neurologic complications	
Acute cervical myelopathy ^[20]	Cervical spondylosis, neck extension, paralytic anesthesia
Brachial plexopathy ^[21]	Extension, external rotation, and abduction of the arm, ipsilateral rotation and lateral flexion of neck, shoulder braces
Ulnar nerve palsy ^[30]	Obesity, inadequate elbow padding
Myocutaneous complications	
Compartment syndrome ^[34-36]	Padding directly over the compartment, obesity
Pressure ulcers ^[37,38]	Procedure duration, advanced age, obesity, steroid administration
Femoral head avascular necrosis ^[42]	Pressure over the groin, hypotension

ION: Ischemic optic neuropathy.

after spinal fusions were attributed to ION^[6]. ION is categorized anatomically based on the location of the ischemia. AION affects the optic disc supplied by the posterior ciliary arteries. PION affects the retrobulbar or intracanalicular optic nerve supplied by penetrating vessels from the pial circulation. Both forms of ION can be further subdivided into arteritic and non-arteritic types. Arteritic ION is not seen as a surgical complication. Non-arteritic ION is most often caused by hypovolemia or anemia, although vascular disease can also cause spontaneous AION^[5].

ION during spine surgery is often due to a combination of hypotension, blood loss and increase in orbital venous pressure. Compression of the abdomen during prone positioning, Trendelenburg positioning, and placement of the head below the heart can all raise orbital venous pressure; reverse Trendelenburg positioning reduces orbital pressure^[12]. Increased orbital venous pressure worsens interstitial edema, compressing perforating vessels and decreasing tissue perfusion^[5,13]. A multivariate analysis of the American Society of Anesthesiologists (ASA) Postoperative Visual

Loss Registry demonstrated that independent risk factors for ION after spine surgery in the prone position include obesity, male sex, Wilson frame use, longer anesthetic duration, greater estimated blood loss, and decreased percent colloid administration^[14]. This analysis supports the theory that decreased perfusion as a result of an altered pressure gradient is the primary mechanism for development of ION. On the other hand, a retrospective case-control study by Holy *et al*^[15] reported no difference in blood loss and perioperative hemodynamics, including vasopressor use, in patients who developed ION versus control patients.

Although AION is more common in general, PION is more common following spine surgery^[13]. PION was implicated in 60% of the cases in the ASA Postoperative Visual Loss Registry^[11]. PION is associated with large intraoperative blood loss, especially with blood loss over 4 L, as well as relative hypotension extended over the duration of the case^[13]. Patients with PION report vision loss upon waking from general anesthesia which is often bilateral and can result in complete blindness^[16]. Some patients may report a prodrome of blurred vision^[13].

Fundoscopic examination is initially normal; optic nerve atrophy and pallor is visible after four to six weeks. The vision loss is often permanent with no effective treatment available^[16].

AION is a multifactorial condition that is triggered by acute hypoperfusion or occlusion of the posterior ciliary arteries^[16]. Patients with atherosclerosis and diabetes are at increased risk for this complication. In contrast to PION, fundoscopic examination reveals segmental or diffuse edema of the optic disc and occasionally splinter hemorrhages^[5]. Visual loss resulting from AION can also be permanent, though there may be a role for treatment with high-dose corticosteroids^[16].

CRAO (headrest syndrome)

CRAO is the second most commonly encountered cause of POVL after prone spine surgery. In 1954 Hollenhorst *et al*^[17] first reported CRAO in neurosurgical patients who were placed in a horseshoe-shaped headrest. CRAO subsequently became known as "headrest syndrome". In the ASA Visual Loss Registry, CRAO accounted for 11% of the cases of POVL with perioperative eye trauma noted in seven of the ten cases^[11]. Proposed mechanisms of CRAO include thromboembolism or increased intraocular pressure from direct compression of the globe^[13] which in turn causes decreased perfusion of the retina.

Patients with CRAO most often suffer severe visual loss unilaterally, and they may have other evidence of extended periods of unilateral compression, such as periorbital ecchymosis and edematous sclera^[13]. Fundoscopic examination reveals a cherry-red spot on the macula. There is no effective treatment; the visual loss is almost always irreversible.

Cortical blindness

Cortical blindness results from decreased perfusion of the visual cortex in the occipital lobes (which receive blood from the posterior cerebral arteries). It is the most common form of POVL after spinal fusions or spinal deformity surgery, according to a recent analysis of data from the NIS^[6]. Etiologies include profound hypotension, prolonged hypoxia, cardiac arrest, or thromboembolism^[13]. Patients may have very subtle symptoms and may have difficulty recognizing their visual impairment. However, these patients cannot react to threat or respond to optokinetic stimulation^[13]. Fundoscopic examination and papillary reaction to light is normal, but visual field defects corresponding with the affected cortical area will be noted on ophthalmologic examination or visual field testing. Unilateral cortical blindness most commonly results in contralateral homonymous hemianopsia. Bilateral cortical blindness may cause complete peripheral vision loss. Symptoms often improve from the initial ischemic insult without specific treatment, but complete recovery is rare^[5].

Rare causes of POVL

POVL have been described infrequently as a consequence

of acute angle-closure glaucoma and amaurosis^[9,10]. Provocative tests in the office have demonstrated that acute angle-closure glaucoma can result from facedown positioning in susceptible individuals. Singer *et al*^[10] reported a case of bilateral acute angle-closure glaucoma after spine surgery. The patient reported nausea and eye pain; exam demonstrated diffuse corneal edema and fixed, mid-dilated pupils. The patient was treated with aqueous suppressants and steroid drops with improvement in the intraocular pressure^[10]. Definitive treatment is laser peripheral iridotomy.

Similar to PION, amaurosis represents the loss of vision without an apparent ocular lesion. It may be permanent or transient (amaurosis fugax). Amaurosis may result from thrombosis of the ophthalmic artery or remote plaque rupture, commonly at the carotid artery bifurcation, causing an embolic event in the ophthalmic artery. Zimmerer *et al*^[9] reported a case of amaurosis during lumbar disc surgery in the prone position which was complicated by an episode of hypotension requiring catecholamines and the need for Trendelenburg positioning^[9]. Immediately after the surgery, the patient complained of impaired vision bilaterally which worsened to complete visual loss in the right eye six hours post-operatively. The patient was ultimately diagnosed with complete occlusion of the right ophthalmic artery. Investigation revealed that the patient's antihypertensive pharmacologic regimen had been increased two days prior to surgery. The authors concluded that the combination of medication, arteriosclerosis, and intraoperative hypotension resulted in the amaurosis^[9].

Subconjunctival hemorrhage

Subconjunctival hemorrhage is an uncommon ophthalmologic complication of spine surgery^[18]. It does not cause visual loss. Akhaddar *et al*^[18] reported a case of a patient who developed a painless subconjunctival hemorrhage after lumbar disc surgery in the prone position. The patient's visual acuity and fundoscopic examination were normal. Subconjunctival hemorrhages present as blood trapped beneath the transparent conjunctiva and white sclera. Though the impressive appearance can be concerning to patients and health care workers, these hemorrhages are asymptomatic and resolve without treatment.

Prevention of ophthalmologic complications

Although POVL can occur even under optimal conditions, several strategies can be used to reduce the risk of occurrence (Table 2). As noted above, the increase in orbital venous pressure or intraocular pressure and concurrent decrease in perfusion pressure is the most common etiology for POVL, thus methods for reducing this shift in pressures may reduce the risk of POVL. Reverse Trendelenburg positioning and frames that allow for a free abdomen can limit the increase in orbital venous pressure. Additionally, the use of Gardner-Wells tongs on a Jackson table with 10-15 pounds of weight

Table 2 Strategies for minimizing risk during prone surgical procedures

Complication	Avoidance strategy
Ophthalmological complications	
ION ^[14]	Reverse trendelenburg positioning, colloid administration by anesthesia, limit prolonged intraoperative hypotension
Posterior ION ^[13]	Limit prolonged intraoperative hypotension
Anterior ION ^[16]	None
Central retinal artery occlusion ^[5,13]	Avoid compression of the globe
Cortical blindness ^[13]	Limit prolonged intraoperative hypotension
Neurologic complications	
Acute cervical myelopathy ^[20]	Thorough history and preoperative imaging, careful neck positioning during patient transfers and surgical procedure
Brachial plexopathy ^[21]	Careful anatomic positioning of the arm, limiting extension and external rotation of shoulder
Ulnar nerve palsy ^[30]	Avoid compression and pressure at the elbow, maintain arm position during procedure (avoid arm falling off of arm board)
Myocutaneous complications	
Compartment syndrome ^[34-36]	Avoid pressure on anterior thigh and leg, avoid extremely long surgical procedures. Extra care with obese patients
Pressure ulcers ^[37,38]	Pad bony prominences. Consider Garner-Wells tongs to eliminate pressure on the face during lengthy procedures
Femoral head avascular necrosis ^[42]	Avoid pressure directly over the groin

ION: Ischemic optic neuropathy.

prevents any pressure on the face, which limits the increase in intraocular pressure. Adequate resuscitation, blood pressure maintenance, invasive monitoring, and staged procedures can limit blood loss and duration of anesthesia, thus reducing the severity and total time of decreased perfusion. Still, informed consent for POVL should be obtained in high-risk patients, including obese patients, patients with diabetes or vascular disease, or patients for whom a large estimated blood loss or long procedure is expected.

NEUROLOGIC COMPLICATIONS

The risk of neurological injury is inherent to nearly all spine surgery procedures. Certain neurological complications (*e.g.*, acute cervical myelopathy, spinal cord infarction and brachial plexopathy) may be directly attributed to prone positioning^[19-22] (Table 1).

Spinal cord dysfunction

Acute cervical disc herniation resulting in neurologic deficits can occur in patients with pre-existing cervical spine disease during spinal surgery, though it is very rare. It may result from a combination of neck extension during endotracheal intubation and prone positioning, loss of muscle support when anesthetized, and agitation during surgery^[20]. Chen *et al.*^[20] described a case of a patient who underwent an uneventful lumbar laminectomy for spinal stenosis but was found to have paralysis of his lower extremities postoperatively. An MRI demonstrated an acute C6-C7 disc herniation. Despite urgent discectomy, the patient remained paralyzed^[20]. The patient later recalled a history of episodic paresthesia in his right hand, but his cervical spine was never a primary complaint. Though only a handful of case reports document this devastating complication, it is important

to be cognizant of coexisting cervical spine disease and to carefully handle the cervical spine during intubation, patient transfers, and patient positioning^[20,23,24].

Spinal cord infarction following prone positioning is also rare, but has been documented in patients with skeletal dysplasia and chest wall deformity^[19]. Several case reports have suggested that the decrease in cardiac output observed with prone positioning is even greater in patients with chest wall deformity, such as those with pectus excavatum^[19,25,26]. These patients can experience severe intraoperative hypotension, particularly when hypovolemic. Tong *et al.*^[19] reported on a young patient with Morquio syndrome who sustained an ischemic injury to her upper thoracic spinal cord during an occipitocervical decompression for cervical myelomalacia secondary to atlantoaxial instability^[19]. Upon awakening from anesthesia, she was found to have complete sensory and motor deficits below T4, which did not improve. The absence of motor evoked potentials in the lower limbs during the case was incorrectly assumed to be due to the patient's Morquio syndrome, which emphasizes the need to obtain recordings prior to positioning^[19].

Brachial plexopathy

Postoperative brachial plexopathy and other peripheral nerve injuries are considerably more common than spinal cord dysfunction. The neural lesion generally takes the form of a neuropraxia or axonotmesis and may occur as a result of patient positioning^[21]. The brachial plexus innervates all upper limb musculature (except for the trapezius and levator scapulae) and supplies sensation to the upper limb with the exception of the axillary, superior shoulder, and dorsal scapular-innervated regions. The plexus is fixed at the cervical vertebrae and the axillary fascia^[21], increasing the

risk of traction injury. Additionally, the plexus passes three mobile bony structures: the clavicle, first rib, and humeral head. The position of these osseous structures relative to the plexus may compress or stretch the neural elements resulting in ischemia to the vasa nervorum. Hypovolemia, hypothermia, diabetes mellitus, and alcoholism increase the risk of nerve injury^[21].

A recent review of postoperative brachial plexus injuries identified 17 out of 517 patients who sustained brachial plexopathies during spine surgery in the prone position^[21]. Abduction of the arm greater than 90 degrees placed patients at highest risk^[21]. Extension, external rotation and abduction of the arm, rotation and lateral flexion of neck in the same direction, and application of shoulder braces were also associated with an increased risk of brachial plexus injury^[21]. Evidence of injury was detected with intraoperative electrophysiological monitoring (SSEPs and MEPs) in 15 patients, preventing the development of symptoms. The remaining two patients, who experienced no monitoring abnormalities, reported upper extremity weakness postoperatively that resolved within two weeks^[21]. A review of 22 patients with postoperative brachial plexus dysfunction found that surgery in the prone position was more likely to result in motor deficits^[27]. As expected with neuropraxias, recovery from brachial plexus injury often occurs, but it is not always complete^[28].

Other peripheral neuropathies

Ulnar nerve palsy has also been reported following prone positioning for spine surgery^[29]. Ulnar nerve injury can occur due to direct pressure over the cubital tunnel at the elbow, excessive flexion of the elbow (> 90 degrees), malposition of a blood pressure cuff, or with accidental change in position of the arm during surgery, such as the arm falling off of the armboard. Chung *et al*^[30] noted in a recent study that the ulnar nerve is more vulnerable to ischemia from brachial artery compression than are the median and radial nerves, with immediate loss of SSEPs seen in that case. They also noted that obesity was a risk factor for the development of ulnar nerve palsy following prone positioning. Intraoperative neuromonitoring can help detect and prevent the development of symptoms^[30]. A preoperative physical exam is also valuable for identifying pre-existing cubital tunnel syndrome, which increases the likelihood of post-operative palsy.

Lateral femoral cutaneous nerve neuropathy, also called meralgia paresthetica, has been reported from direct compression with an incidence as high as 24% after posterior spinal surgery^[31]. Compression most often occurs from placement of pelvic bolsters near the anterior superior iliac spine. Additionally, if the bolsters are too close together the likelihood of bilateral meralgia paresthetica increases^[31]. Risk factors include duration of surgery greater than 3.5 h and degenerative spinal disease with pre-existing damage to the second or

third lumbar nerve roots. Interestingly, some authors have noted an increased risk in obese patients, while Gupta *et al*^[32] reported an increased incidence in thinner patients^[32,33]. Post-operatively, patients may complain of sensitivity or paresthesia in the thigh, though complete resolution within 6 mo is the rule. Steroid injections or decompression can be considered in severe cases. The condition may in some cases be prevented with adequate placement and additional padding.

MYOCUTANEOUS COMPLICATIONS

Compartment syndrome and cutaneous complications such as pressure ulcers are well-known complications of prone surgical positioning (Table 1). Compartment syndrome after spine surgery is rare, although anterior thigh and anterior tibial compartment syndromes have both been reported^[34-36]. The diagnosis of postoperative compartment syndrome is often delayed or missed because the symptoms are similar to other postoperative conditions including nerve root injury, persistent nerve root compression, traction neuropraxia, or peripheral nerve palsy.

Dahab *et al*^[34] report a case of a patient who developed severe right thigh pain and swelling after an L4-S1 posterolateral instrumented fusion for degenerative spondylolisthesis. The procedure took five hours but was otherwise uncomplicated. Computed tomography angiogram demonstrated vessel patency with low density changes in rectus femoris and vastus intermedius, and anterior compartment pressure measured 150 mmHg. Fasciotomy was performed, and the patient improved. The patient was positioned on a standard padded Wilson frame with attention to pressure areas, but the patient was obese (BMI 34), and the authors believe that this may have increased his risk^[34].

Ahmad *et al*^[35] reported two additional cases of anterior thigh compartment syndrome after lumbar spine surgery. Both patients were positioned on a Jackson table with well-padded bony prominences, but the thigh and iliac crest pads were switched in order to increase lumbar lordosis^[35]. Both patients were also obese. Postoperatively, both patients complained of pain and stiffness in their bilateral thighs and mild quadriceps weakness. One patient steadily improved, and he remained undiagnosed until MRI of the thighs performed two weeks postoperatively revealed local muscle necrosis. The other patient developed intense swelling and pain and was taken to the operating room for bilateral fasciotomies on postoperative day two. He also developed rhabdomyolysis and acute kidney injury^[35].

Geisler *et al*^[36] reported two cases of anterior tibial compartment syndrome after lower lumbar surgery performed in the prone-sitting position on an Andrews frame. Both patients complained of shin pain, foot drop, and decreased sensation between the first and



Figure 2 Facial pressure ulcer from use of the Andrews frame. From Goodwin *et al.*^[38].



Figure 3 Gardner-Wells Tongs utilized to free the face during prone spine surgery.

second toes. After intracompartmental pressures were found to be significantly elevated, both underwent urgent fasciotomy^[36].

Pressure ulcers can also occur as a result of prone positioning, though investigation has shown that the prone position results in lower pressure on bony prominences than the supine or lateral positions^[37]. Prone positioning places pressure on the forehead, chin, shoulders, thorax, pelvis, knees, and ankles. Tissue ischemia may occur after two to six hours of pressure; necrosis occurs after six hours. The duration of the surgical procedure is the largest risk factor for the development of ulcers, although advanced age, obesity, and administration of steroids can increase the risk^[38]. Bilateral iliac crest ulcers have been reported in a patient who was positioned prone in the intensive care unit, though no spine surgery was performed^[37]. Facial pressure ulcers on the chin or forehead may occur in patients positioned on an Andrews frame for prolonged spine procedures (Figure 2). Use of a Mayfield clamp or Gardner-Wells tongs with 10-15lbs of traction to free the face from pressure may reduce the risk of facial pressure ulcer^[38] (Figure 3). Appropriate padding and attention to bony prominences is critical to avoiding cutaneous complications (Table 2).

OTHER COMPLICATIONS

Prone positioning for spine surgery has also been associated with rare airway and vascular complications. Massive tongue swelling resulting in airway obstruction has been reported in patients in a flexed thoracic-cervical position; corticosteroid administration improved these symptoms^[39]. Airway obstruction has also been reported in a patient with Duchenne muscular dystrophy and lordoscoliosis^[40] with concomitant airway malacia who underwent spine surgery in the prone position. Shifting the patient to the semi-lateral position resolved his symptoms^[40].

Vascular complications including femoral artery ischemia and avascular necrosis of the femoral head are other rarely-described complications of prone

positioning (Table 1). Tseng *et al.*^[41] reported a case of bilateral lower extremity hypoperfusion in a pediatric patient with idiopathic scoliosis, which was detected with intraoperative neuromonitoring. Loss of SSEPs and MEPs prompted examination of the patient, who was found to have no pulses in his distal lower extremities. The thigh pads were moved proximally and pulses then returned^[41].

Pressure on the arteries and inguinal area combined with reduced venous outflow and hypotension from anesthesia has been implicated in cases of avascular necrosis of the femoral head^[42]. Orpen *et al.*^[42] report two cases of bilateral avascular necrosis and one case of unilateral avascular necrosis after lumbar spine surgery in patients with no other risk factors for avascular necrosis. All three spine surgeries were uncomplicated. Preoperative radiographs showed early osteoarthritis in all five affected joints, which may have increased their susceptibility to ischemic insult^[42].

CONCLUSION

Prone positioning complications associated with spine surgery can cause serious patient morbidity. Awareness of these complications, careful patient positioning, efficient use of anesthesia time, and avoidance of intraoperative hypotension may help reduce the incidence of prone positioning related complications.

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Patients' preferred mode of travel to the orthopaedic theatre

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METHODS: Data was collected prospectively over a 2-wk period at an elective Orthopaedic Treatment Centre. Patients were asked to complete a patient satisfaction questionnaire following their surgery on their experience and subsequent preferred mode of transport to theatre. The data was then recorded in a tabulated format and analysed with percentages. Fisher's exact test was used to determine if there was any statistical association between patients' preference to walk and various groups; in-patient or day case procedures, and whether patients were < 60 years or > 60 years of age.

RESULTS: Seventy patients (40 females and 30 males) fully completed the questionnaire. In total there were 33 d-cases and 37 in-patients. The spectrum of orthopaedic sub-specialties included was knee (41%), hip (17%), foot and ankle (24%), spine (13%) and upper limb (4%). Patient satisfaction for overall experience of travelling to theatre was either excellent (77%) or good (23%). Following their experience of travelling to theatre, 87% (95%CI: 79%-95%) of the total cohort would have preferred to walk to the operating theatre. There was a statistically significant association ($P = 0.003$) between patients' preference to walk and whether they were day-case or in-patients. Similarly, there was a statistically significance association ($P = 0.028$) between patients' preference to walk and whether they were < 60 years or > 60 years of age.

CONCLUSION: This study confirms the majority of Orthopaedic elective patients would prefer to walk to theatre, when given the choice and if practically possible.

Key words: Patient satisfaction; Orthopaedic theatre; Patient autonomy

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Core tip: There were previously no studies focusing primarily on how Orthopaedic patients prefer to travel

Abstract

AIM: To determine the preferred mode of travel to the operating theatre for elective orthopaedic patients.

the operating theatre. Questioning unproven and habitual protocols is essential to improve delivery of care. Our study highlights elective orthopaedic patients should predominantly walk to theatre with a nurse to enhance independence, maintain dignity and improve efficiency of the process; however the patient's autonomy must be respected and pre-operative mobility taken into account.

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INTRODUCTION

Changing clinical routine can be challenging, but questioning unproven and habitual protocols is essential to improve delivery of care. With the model of orthopaedic services changing nationwide, with designated regional trauma units and local elective centres, there is an opportunity to implement improved guidelines with evidence-based medicine. The majority of surgical patients travel to the operating theatre by trolley accompanied by a porter and a nurse, however a high proportion of patients across the surgical specialties prefer to walk to their operation if given the choice^[1].

There are no current studies focusing primarily on how Orthopaedic patients prefer to travel the operating theatre. Due to the nature of trauma surgery, especially lower limb injuries, patients practically cannot always be given this option. However, in planned procedures, when patients have walked into hospital they should have more autonomy. Therefore the aim of the study is to determine the preferred mode of travel to the operating theatre, specifically for elective orthopaedic patients, so a protocol can be unified within treatment centres.

MATERIALS AND METHODS

Data was collected prospectively over a 2-wk period at an elective Orthopaedic Treatment Centre. Patients were asked to complete a patient satisfaction questionnaire following their surgery, either in the discharge area for day-cases or on the ward for in-patients.

The tick-box questionnaire had 11 questions covering patient demographics (age group, sex, gender), basic operative information (limb operated on, day-case or in-patient), usual mobility outside the house (independent, stick, frame, wheelchair), mode of transport to theatre (walking, chair, trolley), to rate the overall travel experience (good, fair, poor), whether dignity was maintained (yes or no), preferred mode of transport after the experience and text box to give reasons for their decision.

The data was then recorded in a tabulated format

and analysed with percentages. SPSS version 22 was used for statistical analysis. Fisher's Exact test was used to determine if there was any statistical association between the following variables: patients' preference to walk whether they were in-patient or day case procedures and patients' preference to walk whether they were < 60 or > 60 years of age. The reason for using Fisher's Exact test was that at least one cell had an expected count of less than 5 in each of the χ^2 analyses mentioned above.

Statistical analysis

The statistical methods of this study were reviewed by Dr. Muzaffar Malik, senior lecturer medical statistics, Postgraduate Medicine, Division of Medical Education, Brighton and Sussex Medical School, University of Brighton, Falmer, Brighton BN1 9PH, United Kingdom.

RESULTS

Seventy patients (40 females and 30 males) fully completed the questionnaire. In total there were 33 d-cases and 37 in-patients; 41 were under 60 years of age and 29 above 60 years of age. The spectrum of orthopaedic sub-specialties included was knee (41%), hip (17%), foot and ankle (24%), spine (13%) and upper limb (4%). As per protocol the mode of transport to theatre was decided pre-operatively on the day of the operation between the nursing staff and the patient. Options included, walking accompanied by a nurse, chair with a porter and a nurse or trolley with a porter and a nurse. No pre-medications were administered prior to arrival on the anaesthetic induction room.

Overall, 89% (62/70) of patients walked to theatre for their operation, 7% (5/70) travelled by trolley and 4% (3/70) by chair. Patient satisfaction for overall experience of travelling to theatre was either excellent (77%) or good (23%). All patients confirmed their dignity was maintained throughout the experience. There were no issues regarding patient safety.

Following their experience of travelling to theatre, 87% (61/70) of the total cohort would have preferred to walk to the operating theatre, 11% (8/70) to travel by trolley and 1% (1/70) by chair.

For the day-case patients everyone (33/33) would have opted to walk. For the in-patients 76% (28/37) would have opted to walk. There was a statistical significant association ($P = 0.003$) between patients' preference to walk and the type of patient (day case or in-patient). Of the nine in-patients who would have chosen a trolley or chair, all under-went lower limb or spinal surgery; the majority required walking aids outside the house, either a walking stick or a frame.

In all the age groups, the majority of patients preferred to walk to the Orthopaedic theatre; 98% (40/41) < 60 years, 73% (16/22) 60-75 years and 71% (5/7) > 76 years. There was a statistically significance association ($P = 0.028$) between the

patients' preference to walk and the patients being over or under 60 years of age.

In the comments section, the main reasons for a preference to walking were patients feeling in-control and maintaining their independence. The patients requiring a chair or trolley highlighted age, comfort and poor mobility as contributing factors.

DISCUSSION

The protocol within our department for decisions on mode of transport to theatre incorporates patients' choices and practical considerations. The aim of the study was to ascertain the patients' preferred mode of travel to the operating theatre. As detailed in the results, 87% (95%CI: 79%-95%) of the patients preferred to walk. Its benefit to patient well-being is also highlighted with 100% excellent or good patient satisfaction and 100% dignity maintained throughout.

Although patients require surgery, many do not consider themselves to be ill; therefore giving the patient a choice provides a sense of control in what is perceived as an uncontrolled environment^[2]. Patients want to be included in the decision making process in their travel to the operating theatre and actively embrace change^[3].

Walking into the operating theatre rather than lying on a trolley can reduce patient pre-operative anxiety, allowing for easier communication with the accompanying staff, in order to help relax patients^[4]. Walking can also improve efficiency, with patients arriving on time to the operating theatre, by reducing a potential limiting factor of porter availability^[5]. Without the need for a regular porter, the workforce can be redistributed within the hospital.

Not all patients will be able to comfortably walk to theatre due to the very nature of the specialty and due to potential debilitating co-morbidities. Also, the feasibility will depend on the distance from the surgical admission unit to the theatre department, an issue that should be addressed with modern hospital design. Others may not wish to walk, as they can feel exposed in a hospital gown, but providing a dressing gown is a potential solution.

In our study the mode of transport to theatre was decided pre-operatively between the nursing staff and patient on the day of surgery, however this could also be addressed easily in a pre-admission assessment clinic.

In conclusion, we advocate elective orthopaedic

patients should predominantly walk to theatre with a nurse to enhance independence, maintain dignity and improve efficiency of the process; however the patient's choice must be respected and pre-operative mobility taken into account. This study confirms our practice is safe and beneficial to the overall care of the patient. It can have further impact on other Orthopaedic Treatment Centre protocols and future design.

COMMENTS

Following admission to hospital, all patients need to travel to the operating theatre to undergo their surgery. In many institutions patients are automatically transported to the theatre in a chair or trolley without being given a choice, even though they are able to independently walk. The aim of study is to ascertain patients' preferred mode of transport to the elective Orthopaedic theatre, in order to provide evidence to potentially change clinical practice.

Research frontiers

Previously, there are no studies focusing primarily on how elective Orthopaedic patients prefer to travel the operating theatre.

Innovations and breakthroughs

The study highlights the majority patients generally prefer to walk to the Orthopaedic theatre if given the choice and are physically able to do so.

Applications

Elective orthopaedic patients should predominantly walk to theatre with a nurse to enhance independence, maintain dignity and improve efficiency of the process; however the patient's choice must be respected and pre-operative mobility taken into account. The study confirms this practice is safe and beneficial to the overall care of the patient. It can have a practical application with Orthopaedic hospital protocols.

Terminology

Orthopaedics is an area of surgery managing conditions affecting the musculo-skeletal system. An elective operation refers to a procedure that is pre-planned in advance. Operating theatre is a facility in a hospital where surgical operations are performed.

Peer-review

The rational of this review is good, and it is an interesting. The article is also well organized and well written.

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Multiligament knee injuries with associated tibial plateau fractures: A report of two cases

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Informed consent: Both patients have provided written informed consent supporting their inclusion in this case report.

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Multiligament knee injury (MKI) in traumatic knee injury remains controversial, and there are evolving treatment recommendations. Currently, there are no studies focusing on older adult patients with MKI's in combination with tibia fractures. As a result, there is no well-established treatment algorithm for older adult patients with these complex injuries. We report two cases of MKI's with concomitant fractures in patients fifty years of age or older. Both patients were treated surgically for their associated tibial plateau fractures, but were managed with conservative treatment of the multiligamentous knee injuries. We also provide a review of the literature and guidelines for older adult patients with these types of complex traumatic injuries. Early to mid term acceptable outcomes were achieved for both patients through surgical fixation of the tibial plateau fracture and conservative treatment of the ligament injuries. We propose a comprehensive treatment algorithm for management of these complex injuries.

Key words: Multiligamentous knee injuries; Tibial plateau fracture; Knee dislocation; Surgical fixation; Treatment algorithm; Conservative treatment

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Core tip: Extensive review of the literature illustrates the limited evidence on these types of complex knee injuries. Patients with multiligament knee injury (MKI) and tibial plateau fractures require a complex treatment algorithm optimized to patient specific injuries and expectations. We propose an algorithm for treating MKI with concomitant fracture in middle aged-patients.

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Abstract

The management of a combination of fracture and

INTRODUCTION

Multiligament knee injuries (MKIs) with associated fractures are rare but serious injuries that pose diagnostic and therapeutic challenges. These complex knee injuries usually occur during participation in contact sports or a high energy motor vehicle accident. Several studies have shown a significant delay in the diagnosis of ligamentous injuries in patients presenting with ipsilateral femoral or tibial fractures^[1-4]. In addition, there are varying opinions on treatment of these injuries^[1,5,6]. Fracture stabilization as well as ligamentous instability must be addressed in surgical planning^[7].

The potential morbidity of these knee injuries are significant, with instability and pain being reported many years after the initial injury^[5,8-10]. Functional outcomes and pain control remain the standard for determining successful treatment of knee injuries. While consensus in the literature suggests the most effective treatment of tibial plateau fractures is open reduction and internal fixation (ORIF)^[11,12], no similar consensus has been reached in regards to restoring ligament function with MKIs^[5]. Conservative treatment with immobilization has demonstrated moderate success^[13], however, current Level III studies demonstrate improved functional outcomes with surgical repair or ligament reconstruction over nonoperative treatment^[8,14]. Because these injuries account for less than 1% of all orthopaedic injuries, there is a lack of high level evidence, especially in the middle-aged patient, on which to base treatment decisions. Our study reviews the treatment and outcomes for two middle aged (\geq fifty years old) patients with both tibial plateau fractures and multi-ligamentous knee injuries. We also provide a review of the literature and define guidelines for treatment for a middle-aged patient population who sustain these complex traumatic injuries.

CASE REPORT

Patient 1

A 52-year-old male presented to the Emergency Department (ED) status post-MVA with multiple injuries including a left proximal humerus fracture and a severe right knee injury. Radiographs and computed tomography demonstrated a comminuted Schatzker IV tibial plateau fracture dislocation and a femoral condyle fracture (Figure 1). Neurovascular examination was unremarkable and Ankle-Brachial index was 1.0 on the injured leg. The patient initially underwent a closed reduction of knee dislocation in the ED which corrected his alignment in the sagittal plane but there was continued subluxation and displacement in the coronal plane. Given his fracture displacement and instability was subsequently taken to the OR for closed reduction and placement of an external fixator. Examination under anesthesia revealed excessive anteroposterior laxity and medial laxity. Fluoroscopic imaging confirmed increased anterior and posterior laxity with markedly comminuted

intra-articular fracture through the lateral tibial plateau and tibial spines and severe depression of the lateral tibial plateau. A post-fixation MRI demonstrated comminuted tibia spine fracture with partial tearing of anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) tibial sided insertions with a complete tear of inferior portion of superficial medial collateral ligament (MCL).

At 2.5 wk post-injury, the external fixator was removed and an open reduction internal fixation of the tibial plateau fractures was performed with medial and lateral peri-articular locking plates as well as a lateral meniscal repair. Intraoperative examination of the knee showed comminution of lateral tibial plateau articular surface and tibial spines with a competent MCL that did not require reconstruction. The lateral femoral condyle fracture was treated nonoperatively, based on intraoperative evaluation. The patient was discharged to a rehabilitation facility with a full extension splint. Potential staged ligament reconstruction was discussed with the patient.

At 8 wk post-injury, the patient's pain is well controlled. Radiographs demonstrated stable hardware fixation of the comminuted tibial plateau fracture with maintenance of knee joint alignment and fracture reduction (Figure 2). Given the complexity of his injury, the patient remained non-weight bearing for 12 wk but continued with his knee range of motion and brace wear. X-rays demonstrate continued tibial plateau fracture healing with maintenance of plate and screw hardware fixation and increased valgus deformity. The patient progressed to full weight bearing without assisted device by 5 mo post injury, at which time he had been discharged from rehab and remained pain free without narcotic medications.

At 16 mo post injury, patient was ambulating without assisted devices or brace and was pain free. Physical exam demonstrates active right knee range of motion of 15° to 85° and no extensor lag, no joint line tenderness and a 15° valgus deformity, 1+ laxity with Lachmans, anterior and posterior drawer with firm endpoint, symmetric with the contralateral side. There is 3+ laxity at the MCL; however, there is an endpoint, and no laxity with varus stress. Radiographs at that time demonstrated union at the fracture site and stable hardware fixation with no interval articular loss of reduction, valgus deformity of knee with lateral joint space narrowing, and posterior bony calcification, which may represent loose bodies. The patient is able to perform his duties at work without any difficulty, can perform all ADLs, and has minimal knee pain-he was able to play 18 holes of golf. Physical exam showed a moderate knee effusion, 3+ valgus laxity with endpoint, 15 degree valgus deformity, active range of motion 15-85 degrees, and no extensor lag. Knee replacement was discussed with the patient, however, he is happy with his outcome and he is not pursuing further surgery. His International Knee Documentation Committee (IKDC) score was 54.02.



Figure 1 Radiographs demonstrate a comminuted Schatzker VI tibial plateau fracture dislocation, non-displaced oblique fracture through the proximal fibula, and a comminuted displaced lateral femoral condyle fracture.



Figure 3 Radiograph shows a Schatzker II tibial plateau fracture, tibial spine fracture, and concomitant knee dislocation.



Figure 2 Radiographs show healing of comminuted bi-columnar tibial plateau fracture with maintenance of hardware and knee joint alignment.

Patient 2

A 59-year-old male presented to the ED after a motorcycle accident with a Schatzker II tibial plateau fracture and an avulsed tibial spine fracture causing rotational subluxation of the medial femoral condyle (Figure 3). While in the ED, he underwent an exam and an attempted reduction, which was unsuccessful due to intra-articular fragments. He was subsequently taken to the OR where left knee arthroscopy demonstrated an ACL injury with a tibial spine fracture button-holed through the MCL, which blocked the previous attempted reduction. The tibial spine was excised which allowed for reduction of the knee dislocation and subsequent ORIF of the left tibial plateau fracture. Intraoperative examination of the knee did not demonstrate valgus laxity and it was determined that the MCL injury did not require treatment. A plan of staged ligament reconstruction was discussed with the patient. He was discharged to an inpatient rehab center and instructed to maintain a non-weight bearing protocol in a hinged knee brace locked in extension for 6-8 wk.

Postoperatively at 1 mo, the patient had a pain level of 6 out of 10 and continued mild knee effusion in the left knee. Radiographs of the left knee showed



Figure 4 Radiographic evaluation demonstrated interval healing of the tibial plateau, maintenance of implant alignment, and lateral subluxation of the tibia.

abnormal widening of the medial compartment and lateral subluxation of the tibia; however, the tibial implants remained intact. On exam he had no definite endpoint when MCL was stressed at 0° and 30° of flexion. The patient was advised to continue non-weight bearing, and use of a brace locked in full extension. The patient was referred to a sports medicine trained orthopaedic surgeon who recommended a plan to stage MCL reconstruction after the tibial plateau fracture healed. The patient elected to proceed with conservative management of his MCL injury.

At two months post-op, he remained non weight bearing with minimal pain, 2/10 and passive ROM of 0°-75° flexion. Radiographic evaluation demonstrated interval healing of the tibial plateau with stable internal fixation, reduction of the tibial spine fracture, and valgus alignment of the knee with lateral subluxation of the tibia (Figure 4). He was instructed to begin passive range of motion exercises and to increase weight bearing with his knee brace locked in full extension.

At three months post-op, patient reported minimal pain with full weight bearing. He demonstrated significant atrophy of the left quadriceps, active flexion of 15-90. Radiographs showed increased callus formation at the fracture site with stable fixation of the hardware. Given the loss of joint space and persistent lateral subluxation of the tibia, the patient was referred to a total joint replacement specialist who recommended

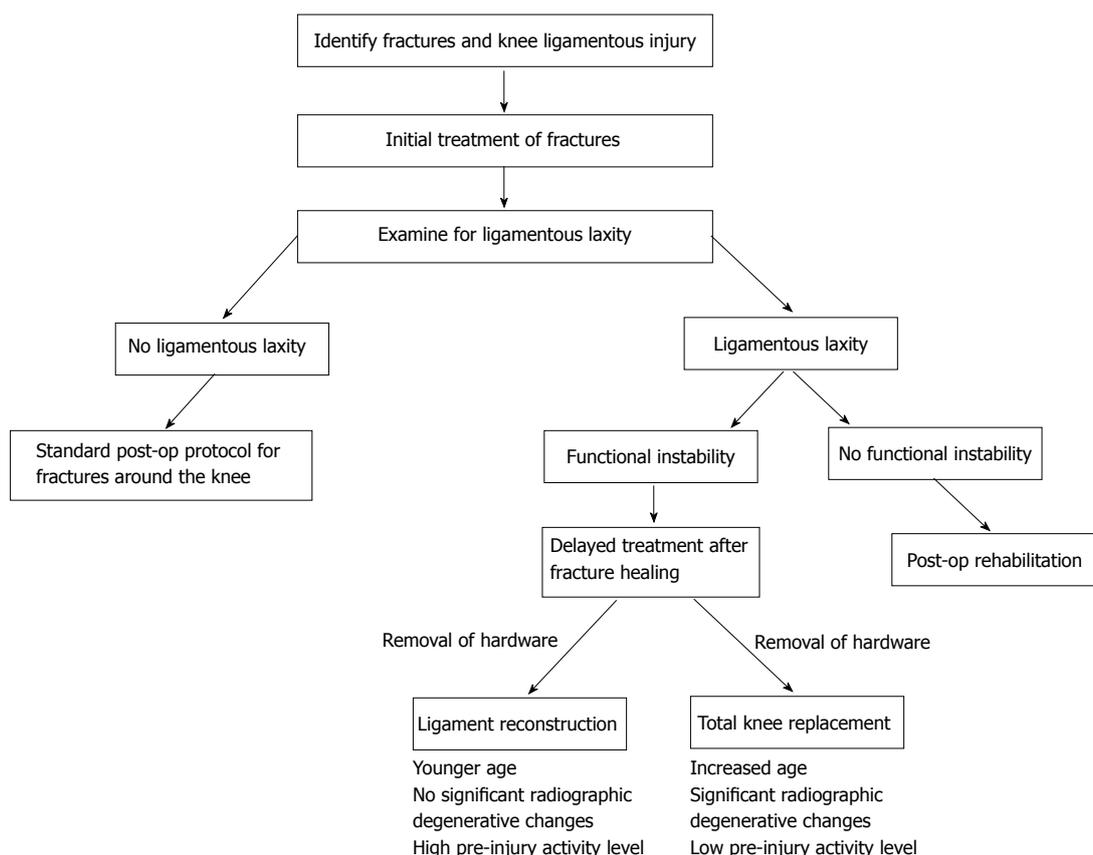


Figure 5 Treatment algorithm for multiligament knee injury with associated fractures.

implant removal and total knee arthroplasty. The patient elected to delay total knee replacement and continue PT and strengthening. At 1.5 years post injury, the patient is satisfied with his function and stability, and feels they are adequate to perform job related activities and activities of daily living. Consequently, he continues to delay total joint replacement. Overall, he continues to have minimal pain, and demonstrates continued valgus laxity and lateral subluxation. His IKDC evaluation score was 32.2.

DISCUSSION

MKIs with tibial plateau fractures are severe, potentially life-altering injuries. Current literature describes treatment options for traumatic knee dislocations in younger populations who have isolated multiligamentous knee injuries, but there is no literature that describes treatment algorithms for middle-aged patients with multiligament knee reconstruction combined with tibial plateau fractures. The most pertinent aspect of our case reports is the decision making process that underlies the treatment of combined long bone fractures and multiligamentous knee injuries in an older middle aged patient. The difficulty in development of a treatment algorithm for these complex injuries lies in the low quality evidence (level III or IV studies) that have been published on these injuries. The limited literature

examines various treatment methods and surgical techniques with a spectrum of outcome measures that are difficult to compare.

We propose the following algorithm for treating MKI with concomitant fracture in middle aged-patients. At initial presentation, a thorough examination for both bony and soft tissue injuries is performed. If a fracture is identified, treat surgically or non-surgically as appropriate, and re-evaluate ligamentous stability at 6 wk post-injury. As recommended by Stannard *et al*^[15], the fracture should be treated first, and ACL and PCL injuries may be treated after fracture healing. If continued radiographic and clinical signs of instability are observed, a recommendation for staged reconstruction of ligamentous injury should be considered after bony union has been achieved. Surgical intervention is determined on a case by case basis, taking into account a patient’s pre-injury activity level and goals. If radiographic signs of instability are present but patient is asymptomatic for instability, consider nonoperative management of the injuries (Figure 5).

There are a few cases reported in the literature on this particular subset of 50-60 years old with multiligament knee injuries. Subbiah *et al*^[16] reports on a 55 years old patient who underwent ACL and PCL reconstruction, resulting in a satisfactory Lysholm score of 90 and IKDC grading of B at fifteen months.

Similarly, Ríos *et al*^[9] performed multiligament reconstructions on two patients in their 60's, resulting in good Lysholm scores twelve months after surgery, while also reporting on a 61-year-old patient treated conservatively for a PCL, MCL, and LCL injury which resulted in a poor rating^[9]. According to results reported by Wasserstein *et al*^[17] the risk of total knee arthroplasty for tibial plateau fractures alone is increased 5.3 times compared to normal age matched population and this risk increases even further when over 48 years of age. Furthermore there is also an increased risk of total knee replacement after isolated ACL reconstructions especially among patients older than 50 year of age^[18], therefore it is not unreasonable to consider nonoperative treatment in these older patients for their combined tibial plateau and multiligamentous knee injuries.

Recent literature has shown early operative treatment with ligament reconstruction of MKIs leads to the most effective results in terms of return to prior activity^[6]. While the data for nonoperative management has demonstrated poorer results, there is some evidence that these approaches can be successful. As we demonstrate in this case report, nonoperative treatment can provide good patient satisfaction and adequate functional outcomes. We describe two patients with complex knee injuries, involving both ligaments and bone fractures, who were treated nonoperatively for their ligamentous injuries with good final outcomes and patient satisfaction. We also describe a treatment algorithm for these complex injuries.

There is a need for further study in middle-aged to elderly patients, who may achieve successful outcomes and pain control from nonoperative treatment which has lower morbidity as well as requires less dependence on medical resources. We recommend counseling patients that nonoperative management for ligamentous injury is an option, but that knee arthroplasty may be indicated if posttraumatic arthritis develops.

COMMENTS

Case characteristics

Two patients in their 50's presenting after high impact motor vehicle collisions with multiple skeletal injuries.

Clinical diagnosis

The patient's main complaints were chronic swelling with recent onset of mechanical symptoms, specifically popping, catching, and locking while performing daily activities.

Imaging diagnosis

Radiographic and CT imaging was performed on both patients.

Treatment

Both patients were treated with open reduction internal fixation.

Related reports

Current literature describes treatment options for traumatic knee dislocations in younger populations who have isolated multiligamentous knee injuries, but there is no literature that describes treatment algorithms for middle-aged patients with multiligament knee reconstruction combined with tibial plateau fractures.

Experiences and lessons

These cases indicate a need for further study in middle-aged to elderly patients,

who may achieve successful outcomes and pain control from nonoperative treatment which has lower morbidity as well as requires less dependence on medical resources.

Peer-review

This is an interesting report on tibia plateau fractures and complex ligament injury. The paper is written and presented quite well and therefore publication is recommended.

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Synovial lipomatosis: A rare cause of knee pain in an adolescent female

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Ethics approval: The study was reviewed by and received exemption from the Borgess Medical Center Institutional Review Board.

Informed consent: The study participant provided written informed consent for inclusion in this case report.

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the subsynovial adipose which can lead to a variety of presentations. Cases of synovial lipomatosis in children or adolescents are rare. This case report describes an adolescent patient with a rare bilateral presentation of synovial lipomatosis. She had been treated for years prior to her presentation for juvenile idiopathic arthritis. She presented with chronic bilateral knee pain, swelling, and mechanical symptoms. Bilateral MR imaging demonstrated effusions, hypertrophy of the synovium, and polyp-like projections of tissue with the same signal intensity as fat which is pathognomonic for synovial lipomatosis. Arthroscopic synovectomy and extensive debridement of polyp like fat projections of the right knee was performed. Histopathology was consistent with the synovial lipomatosis diagnosis. Postoperatively, the patient was satisfied with her outcome with improved pain relief and function in her right knee.

Key words: Synovial lipomatosis; Lipomatosis; Knee arthroscopy; Lipoma arborescens; Arthroscopy; Villous lipomatous proliferation of the synovial membrane; Knee pain

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Core tip: This case demonstrates a unique presentation of bilateral knee synovial lipomatosis occurring in an adolescent. Arthroscopic treatment of this disease can yield a successful outcome. This case presentation will increase the awareness of this condition and decrease the tendency toward delayed diagnoses in the adolescent patient.

Miladore N, Childs MA, Sabesan VJ. Synovial lipomatosis: A rare cause of knee pain in an adolescent female. *World J Orthop* 2015; 6(3): 369-373 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v6/i3/369.htm> DOI: <http://dx.doi.org/10.5312/wjo.v6.i3.369>

Abstract

Synovial lipomatosis is a benign proliferative disease of

INTRODUCTION

Synovial lipomatosis, also known as lipoma arborescens or villous lipomatous proliferation of the synovial membrane, is a benign proliferation of subsynovial adipose. Although this process is more likely reactive than neoplastic in origin, it is rare with unknown etiology. There is limited literature on this topic to guide both diagnosis and optimal treatment of this disease^[1-11].

Synovial lipomatosis appears to occur at any age, with reports of a patient as young as one year old with protein energy malnutrition to patients well into their eighth decade of life. The most common reported cases are in middle aged males. Patients typically present with pain and swelling of the affected joint. Although it appears to have a predilection for the knee, synovial lipomatosis has also been reported in the wrist and ankle, indicating that it could be a rarer cause of pain in smaller joints^[1]. Often times, as seen in our patient, it is missed or undiagnosed for many years.

The recommended treatment is complete synovectomy either arthroscopically or *via* formal open debridement. The optimal method is debatable but both have good reported results despite limited follow up outcomes data^[2]. Although the location of presenting symptoms can be variable, radiologic evaluation and histomorphology appear to be relatively consistent. This case report provides insight into the presentation, keys in diagnosis, and treatment of this rare entity.

CASE REPORT

Our patient is an 18 years old female [body mass index (BMI): 42 kg/m²], who presented to our clinic with a long standing history of bilateral knee pain, right worse than left. Past medical history was significant for juvenile idiopathic arthritis (JIA) which had been diagnosed clinically nine years prior to presentation and was treated by a Pediatric Rheumatologist. She was placed on a high dose non-steroidal anti-inflammatory drugs and had multiple steroid injections, but was not treated with disease modifying antirheumatic drugs. She initially had improved pain and symptom control with these modalities; however, she eventually became refractory to this treatment and her symptoms worsened.

On presentation to our office, the patient's main complaints were chronic swelling with recent onset of mechanical symptoms, specifically popping, catching, and locking while performing daily activities. She denied any trauma to the area. Examination of her knees revealed bilateral knee effusions with no instability with varus and valgus stress testing. In addition, the patient had a negative posterior and anterior drawer and Lachman's maneuver. She had normal patellar tracking bilaterally and full active knee range of motion without crepitus or clicking. She had no joint line tenderness and

a negative McMurrays and Apley grind test. X-rays and a magnetic resonance imaging (MRI) were obtained. Bilateral knee X-rays revealed no degenerative joint changes, fractures, avascular necrosis or osteochondral lesions. However, the X-rays did demonstrate diffuse soft tissue swelling. Bilateral knee MRIs demonstrated effusion in the suprapatellar bursa and hypertrophic synovium in the right knee worse than left with leaf-like projections of tissue which has the same signal intensity as fat. MRIs were negative for bony, meniscal, or ligament pathology bilaterally. MRI findings were consistent with synovial lipomatosis. Typical MRI findings of this entity include the villous like projections into the joint that are the same signal intensity as fat on both T1 and T2 weighted images (Figures 1 and 2).

Since the patient had clear MRI findings consistent with synovial lipomatosis with continued mechanical symptoms and pain after extensive nonoperative management, a detailed discussion was done regarding surgical treatment options including arthroscopic synovectomy of her right knee.

Patient elected to proceed with arthroscopic synovectomy, extensive debridement and biopsy for suggested synovial lipomatosis. Intraoperative findings demonstrated a significant amount of small lipoma nodules throughout the knee joint. These nodules were identified in the patellofemoral space, in the medial and lateral gutter, and in the medial and anterior joint. There did not appear to be any anterior cruciate ligament, posterior cruciate ligament, medial or lateral meniscal pathology. The articular surface was normal in appearance and no signs chondromalacia evident. The hypertrophic lipomatous nodules were methodically debrided and over 60 cc captured with some sent for pathology examination. Gross description revealed multiple lobulated tan-yellow soft tissue fragments admixed with fibrous tissue. Microscopic description demonstrated benign synovial tissue and fragments of adipose present beneath the synovial surface (Figure 3).

The patient was subsequently discharged home post-operatively. At her two week follow up, her pain was controlled without narcotic medications and swelling was improved. She denied any mechanical symptoms and had regained much of her range of motion. At six weeks follow up she continued to do well and began to discuss options for intervention on the contralateral side. At the patient's eight month post-operative visit, she had full range of motion of her operative knee, denied return of mechanical symptoms, and continued to be pain free. The patient's effusion was resolved and her knee was stable on examination.

DISCUSSION

Synovial lipomatosis is a rare disease which typically presents with symptoms of swelling and joint pain^[3]. Synovial lipomatosis can be differentiated from other diagnoses by particular characteristics. When compared

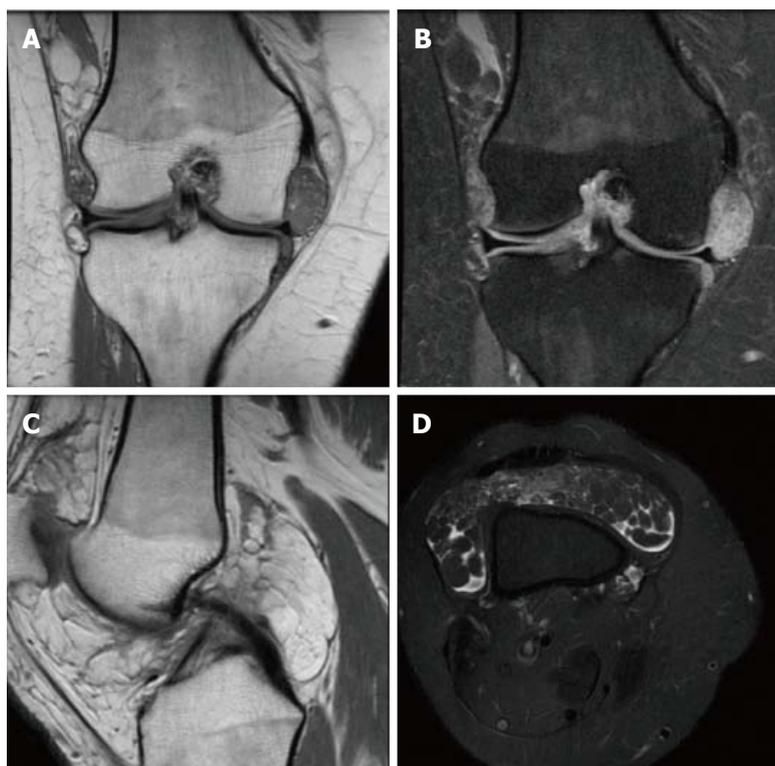


Figure 1 Right knee magnetic resonance imaging demonstrating effusion in the suprapatellar bursa and hypertrophic synovium with leaf-like projections of tissue which has the same signal intensity as fat. A: Coronal proton density (PD); B: Coronal PD fat saturation; C: Sagittal PD; D: Axial T2 fat saturation.

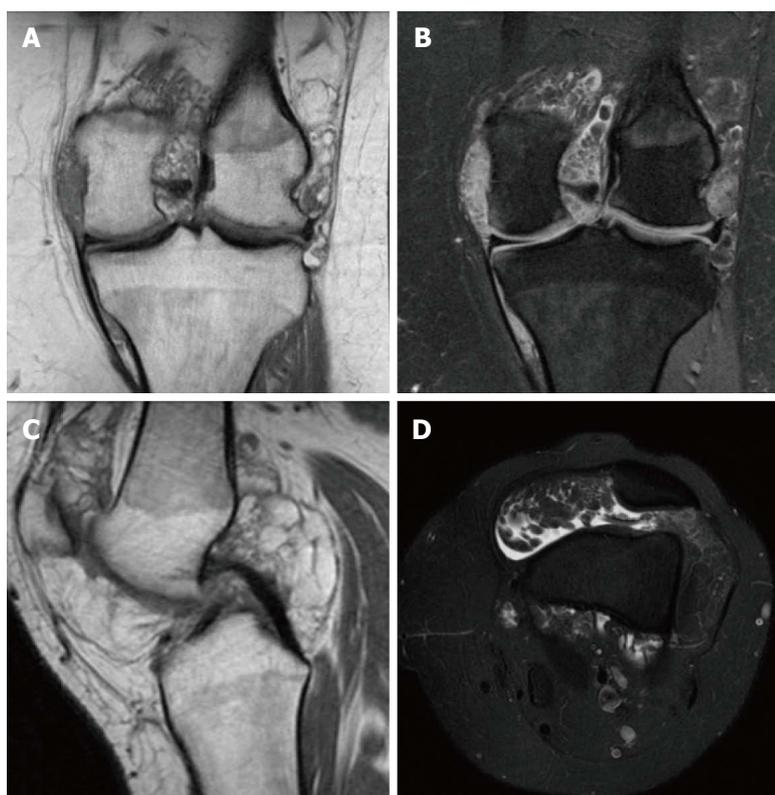


Figure 2 Left knee magnetic resonance imaging demonstrating effusion in the suprapatellar bursa and hypertrophic synovium with leaf-like projections of tissue which has the same signal intensity as fat. A: Coronal proton density (PD); B: coronal PD fat saturation; C: Sagittal PD; D: Axial T2 fat saturation.

to pigmented villonodular synovitis (PVNS), synovial lipomatosis can be differentiated by lack of hemorrhage and hemosiderin on histology^[4]. Hoffa disease is limited to the infrapatellar fat pad and is typically post-traumatic^[12]. Thorough knowledge of the differential is imperative in attaining the correct diagnosis.

In the setting of joint effusion on exam and synovitis

on MRI the differential diagnosis includes PVNS, focal adipose tissue accumulation in osteoarthritis, rheumatoid arthritis, and post-traumatic hypertrophy of the infrapatellar fat pad (Hoffa disease)^[4]. A clinician should have a heightened awareness and consideration for synovial lipomatosis when the patient has joint pain and swelling, mechanical symptoms, refractory to

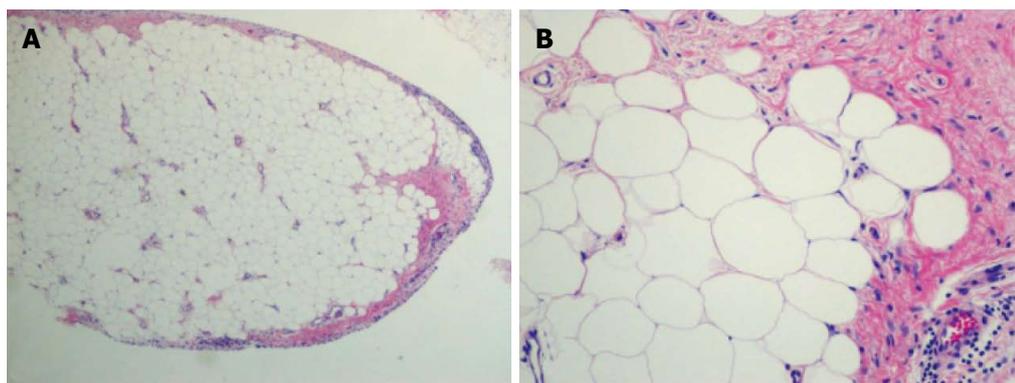


Figure 3 Descriptions of benign synovial tissue and fragments of adipose present beneath the synovial surface. A: Villous and nodular fatty projections common in synovial lipomatosis (Hematoxylin/eosin, 20 x); B: Synovial tissue with papillary architecture replaced by mature adipocytes with infiltration of lymphocytes and plasma cells. (Hematoxylin/eosin, 200 x).

nonoperative management, no evidence of ligamentous or meniscal pathology, and the appropriate MRI findings. Commonly the laboratory testing is negative in this setting and optimal evaluation to diagnose this rare disease is MR imaging. The MRI findings are diagnostic and help differentiate from a number of other pathologies. Common MRI findings for synovial lipomatosis are villous or “leaf-like” projections into the knee joint diffusely. The signals for the projections will match that of fat on both T1 and T2 weighted images^[5]. This is different from PVNS because it lacks hemosiderin deposits which are low signal areas best seen on the fast field echo sequence. Rheumatoid arthritis typically presents with MRI findings of joint space narrowing, synovitis, bony erosion and positive laboratory studies for anti-cyclic citrullinated protein and rheumatoid factor. Hoffa’s disease is post traumatic in origin and will be isolated to hypertrophy of the infrapatellar fat pad.

Our patient had been initially diagnosed with JIA which commonly is a diagnosis of exclusion. Symptoms should last more than six weeks and the patient should be less than sixteen years old^[13]. Rheumatoid factor is only positive in about 15% of cases. She was treated with high dose non-steroidal anti-inflammatory medication and injections; however she had continued symptoms of pain and locking, specifically in her knees. In these cases, a clinician may consider utility of MRI imaging especially given the mechanical symptoms to further evaluate intra-articular pathology. MRI findings helped distinguish this patient’s JIA symptoms with more specific intra-articular pathology. Although there is limited literature providing treatment recommendations for synovial lipomatosis, our patient’s clinical improvement and patient satisfaction support surgical treatment recommendations. Success with arthroscopic synovectomy in this case is consistent with previous reported results for both open and arthroscopic treatment. Although long term outcomes and reoccurrence rates have yet to be reported, review of the literature suggests that it is low.

Synovial lipomatosis is a rare diagnosis, but should be considered in the setting of refractory chronic joint

effusions and knee pain. The etiology is currently unknown, although it has been hypothesized that trauma, inflammation, rheumatism, developmental, neoplastic, or obesity can be implicated. It has been suggested that perhaps increased BMI may be a risk factor in this disease as was seen in our patient, however there is no evidence supporting this correlation^[1,6]. This is often diagnosed in patients with inflammatory diseases. This may be due to higher index of suspicion, a biased diagnostic workup, or it may be a true relationship. Either way, more research is needed to better understand the cause of this disorder, the optimal diagnostic evaluation and treatment.

This case increases awareness of this rare disease. This entity may be missed if the clinician does not have a high index of suspicion, especially in the setting of a young patient with chronic refractory knee pain and an otherwise negative work up. If MRI findings are consistent with diagnosis of synovial lipomatosis, we recommend obtaining a biopsy to verify the diagnosis and to consider arthroscopic debridement. Patients can expect improved pain relief and decreased mechanical symptoms, with good short term results. Our case presentation is limited to one individual; however, it demonstrates the need for further studies as this is an identifiable entity with successful treatment options.

COMMENTS

Case characteristics

An 18 years old female, with a history of juvenile rheumatoid arthritis, presents with bilateral knee pain.

Clinical diagnosis

The patient’s main complaints were chronic swelling with recent onset of mechanical symptoms, specifically popping, catching, and locking while performing daily activities.

Differential diagnosis

Synovial chondromatosis, pigmented villonodular synovitis, synovial hemangiomas.

Imaging diagnosis

Bilateral knee magnetic resonance imaging demonstrated effusion in the suprapatellar bursa and hypertrophic synovium in the right knee worse than left with leaf-like projections of tissue which has the same signal intensity as fat.

Pathological diagnosis

Microscopic description demonstrated benign synovial tissue and fragments of adipose present beneath the synovial surface.

Treatment

The patient was treated with arthroscopic synovectomy.

Related reports

Synovial lipomatosis is a rare disease of unknown etiology. Cases in children and adolescents have been infrequently reported.

Experiences and lessons

This case increases awareness of this rare disease. This entity may be missed if the clinician does not have a high index of suspicion, especially in the setting of a young patient with chronic refractory knee pain and an otherwise negative work up.

Peer-review

The authors have performed a good study, the manuscript is interesting.

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Subtalar dislocation without associated fractures: Case report and review of literature

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are frequently associated with fractures of the malleoli, the talus, the calcaneus or the fifth metatarsal. Four types of subtalar dislocation have been described according to the direction of the foot in relation to the talus: medial, lateral posterior and anterior. It has been shown that some of these dislocations may spontaneously reduce. A rare case of a 36-year-old male patient who sustained a closed medial subtalar dislocation without any associated fractures of the ankle is reported. The patient suffered a pure closed medial subtalar dislocation that is hardly reported in the literature. Six months after injury the patient did not report any pain, had a satisfactory range of motion, and no signs of residual instability or early posttraumatic osteoarthritis. The traumatic mechanism, the treatment options, and the importance of a stable and prompt closed reduction and early mobilization are discussed.

Key words: Subtalar; Dislocation; Talus; Calcaneus; Isolated; Medial

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Core tip: Isolated subtalar dislocations are rare injuries. Subtalar dislocations occur typically in combination with fractures of the adjacent bones such as malleoli, talus, and calcaneus. In this case report of an isolated subtalar dislocation, a successful outcome was achieved after immediate reduction and a 4-wk period of immobilization. This manuscript highlights the importance of prompt reduction and short period of immobilization in order to avoid complications, such as stiffness and arthritis.

Abstract

Isolated subtalar dislocations are unusual injuries due to the inherent instability of the talus. Subtalar dislocations

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INTRODUCTION

There are only few cases of patients with isolated dislocation of subtalar joint in English literature. This type of injury is extremely rare and usually there are associated fractures of the fifth metatarsal, the talus or the malleoli^[1]. Rarity of this injury can be attributed to the presence of strong ligament connecting the talus and the calcaneus, the strong biomechanical properties of the ankle and the tight joint capsule^[2].

Calcaneus and the rest foot can dislocate medially, laterally, posteriorly or anteriorly in relation to the talus. The dislocation results in substantial distortion of the foot shape. Fractures of the fifth metatarsal, the talus, and the malleoli are often encountered with subtalar dislocation^[3]. Patients with bone or soft tissue dysplasia or impaired function of the ankle joint are more likely to suffer from isolated Subtalar dislocation^[4]. Aplasia of the ankle ligaments or the calcaneus facets, hypoplasia of the maleolus, recurrent ankle sprains causing posttraumatic ligamentous insufficiency, and atrophy of the peroneal muscles predispose to this specific injury pattern.

Subtalar dislocations without associated fracture are rare because of the inherent instability of these types of injuries (the talus has two articular surfaces which contribute in the formation of talonavicular and talocalcaneus joints)^[5]. It has also been demonstrated that injury in this area can easily dislocate the subtalar joint. In most of the cases the calcaneus and the rest foot is dislocated medially. Dislocation can be reduced spontaneously^[4]. Most of these trauma patterns are missed because radiographs are normal with no evidence of previous injury. The majority of these patients will admit in the emergency department with an open injury, displaced malleolar fractures, and significant soft tissue impairment^[4].

The purpose of this study is to report a rare case of an isolated subtalar dislocation. We also describe the mechanical patterns resulting in subtalar dislocation and give prominence of the improved outcomes after immediate closed reduction and fast rehabilitation program.

CASE REPORT

A 36-year-old male patient was admitted to the emergency room after a fall while climbing on a mountain. The patient was complaining for significant pain in his left ankle. Deformity and swelling in the left ankle were noticed. More specifically, the ankle was found in medial plantar flexion, had a diffuse swelling, abrasions, and local ecchymosis (Figure 1). The patient was hemodynamically stable without any associated injuries.



Figure 1 Photograph showing the calcaneus and the rest foot is displaced medially while tibiotalar joint maintain normal angulation.

In the lateral aspect of the joint a bony prominence was noticeable. Due to the soft tissue swelling there were no palpable arteries. However nail capillary refill test indicated undamaged circulation. Sensation of light touch was intact and the two point discrimination test within normal limits.

Radiographic evaluation showed displacement of the calcaneus and of the rest foot in relation to the talus. Calcaneus was dislocated medially in the anteroposterior view. Calcaneus was located in neutral position in the lateral view. Plain films did not reveal any associated fracture (Figure 2). A computed tomography (CT) scan with 3D reconstruction confirmed the isolated dislocation of the talonavicular and talocalcaneal joints (Figures 3-5).

A closed reduction under sedation was attempted in the emergency room. Despite the copious manual traction of the foot with the knee flexed and the application of eversion force on the foot with simultaneous plantar flexion of the ankle initially and dorsiflexion finally, no reduction could be obtained.

The patient was then brought to the operating room and an attempt for reduction was performed under general anesthesia. The reduction was confirmed fluoroscopically (Figure 6).

After reduction, the dorsalis pedis and posterior tibialis pulse were palpable. The leg was immobilized in a posterior splint initially for 3 d and in a short-leg cast after that for 4 wk. The patient underwent a CT after the reduction that revealed no osteochondral fractures or intraarticular free bodies (Figure 7). Soft tissue swelling was resolved 3 d after reduction.

The patient started a mobilization protocol with progressive passive and active range of motion exercises 4 wk after reduction. At that time, partial weight bearing was initiated. The patient was instructed to bear his full weight at about 10 wk after the injury.

DISCUSSION

Subtalar dislocation is a rare injury, which accounts approximately 1% of all dislocations. It involves

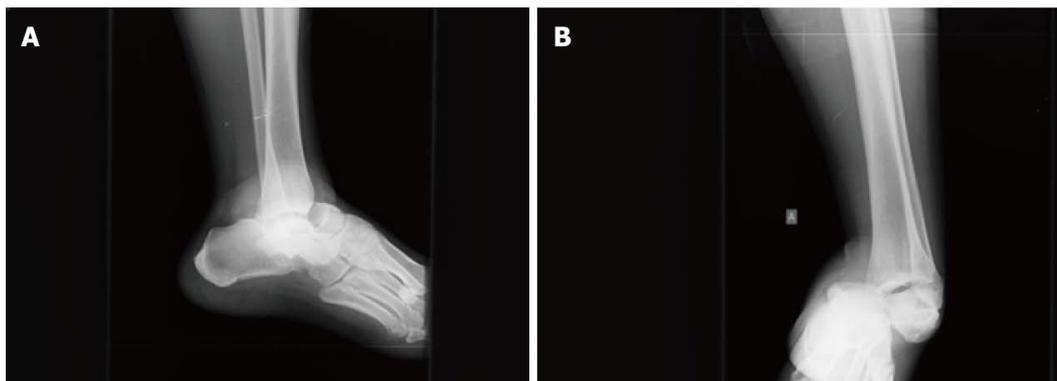


Figure 2 X-rays of the left ankle. Dislocation of the talonavicular and talocalcaneal joints with no obvious fracture is shown. The calcaneus is displaced in medial position in the anteroposterior view. A: Lateral view; B: Anterior posterior view.

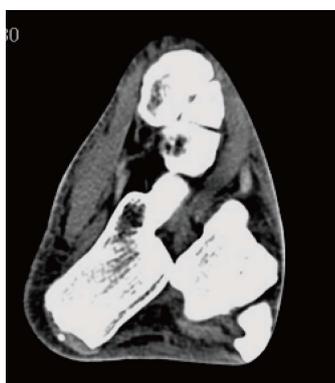


Figure 3 Transverse plane computed tomography image of the patient's left ankle demonstrating the subtalar dislocation without any associated fracture.

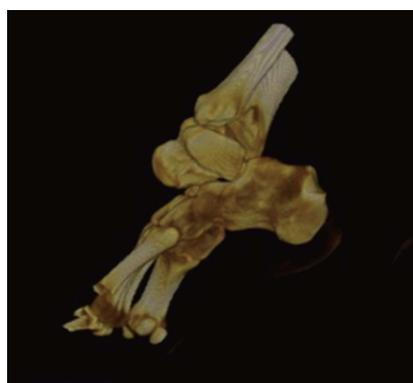


Figure 5 Computed tomography scan with 3D reconstruction image of the patient's ankle joint that demonstrates the dislocation of the talocalcaneus joint and the absence of a fracture.



Figure 4 Computed tomography scan with 3D reconstruction image in the coronal plane showing the medial subtalar displacement of the calcaneus with the rest foot.

displacement of both the navicular and the calcaneus in relation to the talus^[1]. The most widely used classification has been described by Broca who distinguished 3 types of subtalar dislocation: (1) the medial dislocation; (2) the lateral; and (3) the posterior dislocation. Direction of the rest foot in relation to the talus was the determinant element to classify dislocation as medial, lateral or posterior^[4].

Malaigne and Burger described an additional type of subtalar dislocation, the anterior dislocation^[4]. With an estimated rate of 65%-85% medial dislocation, is the most frequent type. Medial dislocation, also known as "acquired clubfoot", is the result of forceful inversion of the forefoot which applies stress on the lateral collateral ligament when the foot is in plantarflexion. The talus pivots on sustentaculum tali. If the strong talocalcaneal and talonavicular ligaments rupture, talus remains in his normal position at the ankle joint and subtalar joint dislocation occurs. The second most frequent type is lateral dislocation, also known as "acquired flat foot", which account for 15%-35% of all subtalar dislocations^[3]. The mechanical pattern of injury leading to lateral dislocation is similar to the medial pattern but instead of inversion, applied forces on the medial side cause eversion of the foot. The talus pivots on the anterior calcaneus process. The anterior type of injury is very rare, accounting for less than 1% of all subtalar dislocations^[4]. The incidence of posterior dislocation which was first described by Luxembourg in 1907, ranges from 0.8% to 2.5% in different studies^[5]. Posterior dislocation occurs when forces applied on the dorsum of the foot result in forceful extreme plantarflexion of the forefoot. Most

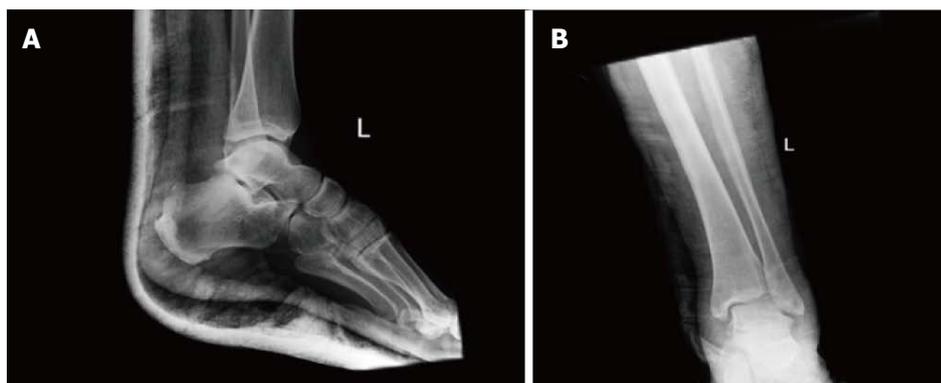


Figure 6 Radiographs of the left ankle after reduction and immobilization with a posterior splint. A: Lateral view; B: Anterior posterior view.

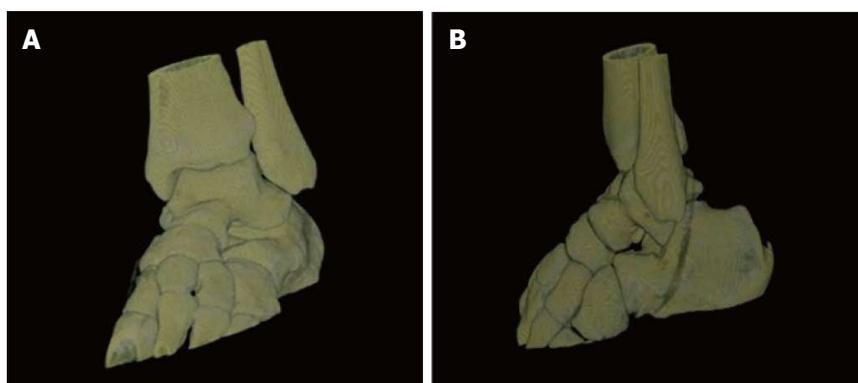


Figure 7 Computed tomography scan with 3D reconstruction images after reduction. There are no intraarticular free bodies. A: Coronal plane; B: Sagittal plane.

commonly, subtalar dislocation is an injury resulting from high energy trauma and, more frequently, it involves active young men. In most of the cases there is an associated fractures, such as fracture of the fifth metatarsal, the talus or the malleoli^[6]. A fact that remains controversial in the literature is that lateral dislocations tend to have worse outcomes than medial dislocations^[7-11], probably because of the higher energy trauma and the associated articular involvement^[1,12].

Only 33 studies describing a total of 439 patients with closed, isolated subtalar dislocation have been reported in literature. Most of the patients (85%) were treated conservatively with closed reduction under general anesthesia and immobilization with a short leg cast for 3-6 wk. The intermediate results were described as good to excellent^[13-17]. Jungbluth *et al.*^[12] reported good results in 21 out of 23 patients with isolated subtalar dislocation and satisfactory results for the rest 2 of the patients after conservative treatment. They also noticed no difference between the outcomes of medial and lateral subtalar dislocations despite the fact that literature suggests that lateral dislocations have poorer prognosis than medial^[1]. Heppenstall *et al.*^[18] reported excellent results in 14 out of 19 patients after closed reduction. In 10%-32% of lateral dislocations treated with conservative treatment, the results were inadequate.

In cases which are non-reducible by closed means

it is recommended to proceed to open reduction^[10]. In a case series of 3 non reducible subtalar dislocations De Palma *et al.* described 2 lateral dislocations which were non reducible due to the interposition of posterior tibialis tendon. In these cases flexor retinaculum was ruptured. The third non reducible dislocation was a medial one with interposition of the extensor retinaculum^[11].

The duration of immobilization remains controversial. In complicated dislocations an initial immobilization by means of posterior splint is recommended. In this way, a more safe way of monitoring the condition of the skin and soft tissue envelope is achieved^[6]. In cases of successful closed reduction, a non-weight bearing short leg cast is applied for four weeks. After this four-week-period, gradual mobilization and return to daily activities is recommended. Even though there are studies supporting that a shorter period of immobilization (*i.e.*, 3 wk) may lead to better results, many authors recommend immobilization for more than 4 wk assuming that 4-wk-period is insufficient time for healing^[2,4,19]. Subtalar joint stiffness in cases of immobilization for less 4 wk is minimal^[2]. Lasanianos *et al.*^[20] suggested that for uncomplicated medial subtalar dislocations, if passive and active range of motion exercises and partial weight bearing are started earlier, the outcomes regarding functionality are better when compared to those of longer immobilization periods. In

the present study, the lower limb was immobilized in a short leg posterior splint. The patient was bedridden for the first days and his foot was in an elevated position. The posterior splint was removed 3-4 d after reduction and after subsidence of the swelling. A short-leg cast was applied and mobilization without weight bearing was started. Three weeks after injury, active range of motion exercises were initiated. Partial weight bearing was started after the third week, and gradually progressed to full weight bearing at five weeks after the reduction. Mobilization after the third week was achieved using a short leg functional boot that allowed ankle motion except from inversion and eversion.

Excellent outcomes can be achieved if 3 conditions are fulfilled: (1) low energy forces are applied on soft tissue envelope during injury; (2) a prompt reduction is performed; and (3) immobilization is applied for a short period of time^[20]. Long-term complications are posttraumatic arthritis (usually of the subtalar, the talonavicular or the tibiotalar joint), osteonecrosis of talus, and subtalar joint stiffness^[21]. Eventually 80% of subtalar dislocations will demonstrate a small reduction of the subtalar and/or ankle range of motion, while in 50%-80% of subtalar dislocations there will be subtalar arthritic changes in X-rays^[18]. The incidence of posttraumatic osteonecrosis of the talus ranges from 10% to 29%^[22]. In this direction, Jarde *et al*^[23] found that 3 out of 35 patients developed talar osteonecrosis one year after injury. Evaluation for possible vascular damage is essential. If there are clinical signs of ischemia, impalpable pulses, negative nail capillary refill test or low oxygen saturation measured by pulse oximetry after reduction, it is recommended to perform further imaging studies. CT angiography or Doppler sonography may demonstrate vascular impairment. The rate of vascular damage after this type of injury has not been studied in literature.

Posttraumatic fibrosis of the periarticular soft tissue envelope due to high energy forces is the main cause of ankle joint stiffness. These forces except from soft tissue fibrosis will not result to degenerative changes^[11]. As many authors^[1,4,7,21] suggest, subtalar joint stiffness in subtalar dislocations can be avoided by reducing the duration of immobilization. Less than 4 wk of immobilization of isolated dislocations, or less than 6 wk in dislocations associated with fractures will result in better functional outcomes.

In summary, isolated subtalar dislocations occurs with an extremely low incidence rate. In cases with successful closed reduction and no signs of remaining instability conservative treatment can prove beneficial. The limb should be immobilized in a short leg splint and early mobilization should be allowed to achieve full range of motion without pain.

COMMENTS

Case characteristics

A 36-year-old male patient presented with significant pain, deformity, swelling in the area, and local ecchymosis in his left ankle after a fall while climbing on a

mountain.

Clinical diagnosis

Tenderness, painful restriction of motion, no palpable pulse of dorsalis pedis and posterior tibialis arteries.

Differential diagnosis

Talar fracture, calcaneal fracture, total dislocation of the talus, midtarsal dislocation.

Imaging diagnosis

Plain X-rays, computed tomography scan with 3D reconstruction showed medial displacement of the calcaneus and of the rest foot in relation to talus.

Treatment

The patient after a failed attempt for reduction in the Emergency room, was brought to the operating room and under general anesthesia the dislocation was reduced closely. A posterior splint was applied for 4 wk.

Related reports

Very few cases of isolated subtalar dislocations have been reported in the literature.

Term explanation

Isolated subtalar dislocation is the dislocation of talonavicular and talocalcaneal joint without any associated fractures. Calcaneus and the rest foot dislocate medially, laterally, posteriorly or anteriorly in relation to talus.

Experiences and lessons

This case report represents an isolated subtalar joint dislocation. Immediate reduction and short immobilization period may result in an excellent outcome for this type of injury.

Peer-review

The study presents an interesting case of isolated subtalar dislocation and it deals with a rare topic with a nice work up of the literature.

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