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REVIEW

Management of metal-on-metal hip implant patients: Who, when and how to revise?

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Abstract

The debate on how best to manage patients with metal-on-metal (MOM) hip implants continues. With over 1 million patients affected worldwide, the impact is far reaching. The majority of the aggressive failures of MOM hip implants have been dealt with by revision hip surgery, leaving patients with a much more indolent pattern of failure of devices that have been *in situ* for more than 10 years. The longer-term outcome for such patients remains unknown, and much debate exists on how best to manage these patients. Regulatory guidance is available but remains open to interpretation due to the lack of current evidence and long-term studies. Metal ion thresholds for concern have been suggested at 7 ppb for hip resurfacing arthroplasty and below this level for large diameter total hip arthroplasties. Soft tissue changes including pseudotumours and muscle atrophy have been shown to progress, but this is not consistent. New advanced imaging techniques are helping to diagnose complications with metal hips and the reasons for failure, however these are not widely available. This has led to some centres to tackle difficult cases through multidisciplinary collaboration, for both surgical management decisions and also follow-up decisions. We summarise current evidence and consider who is at risk, when revision should be undertaken and how patients should be managed.

Key words: Metal on metal hip; Management; Multidisciplinary; Revision; Decision

Core tip: Evidence supporting the management of metal on metal hips is lacking, and guidance is open to interpretation. Until supporting evidence is available, an evidence based multi-disciplinary approach on a case-by-case basis is considered a safe method to help surgeons make decisions and potentially improve patient outcomes.

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INTRODUCTION

Considerable debate continues to surround the use and management of patients with failing metal-on-metal (MOM) hip implants. Over a million patients worldwide have been implanted with a MOM device[1], and according to the United Kingdom National Joint Registry (NJR), their use peaked in 2006 [hip resurfacing arthroplasty (HRA)] and 2008 [large diameter total hip replacement (LDTHR)][2]. However, due to several concerns of catastrophic soft tissue reactions leading to early failures and associated complications, medical device alerts were published[3], and MOM hips were subsequently withdrawn from use by the British Hip Society in 2012.

It is clear that there are evolving and changing patterns of behaviour in the failure of MOM hips[4]. Many of the early, aggressive failures have been dealt with by revision hip surgery, and we now see a much more indolent pattern of failure in patients who have had devices *in situ* for more than 10 years.

This spectrum of patients from the well functioning, that require only monitoring, to the poorly functioning, which require revision continues to evoke debate among surgeons, especially since the bulk of patients fall between these two extremes Figures 1 and 2. Uncertainties surround thresholds for investigation, revision surgery and methods for surveillance[5]. Guidance from international regulatory agencies exists, but tend to reflect the needs of local health authorities, which accounts for some of the variation seen in the guidance[3,6,7].

This review examines the literature on current clinical dilemmas facing surgeons and their patients with MOM hip replacements, and summarises current clinical guidance for how and when patients should be managed.

MOM hip implants

MOM hip implants consist of two broad types, the HRA and the LDTHR. Since their inception in 1937[4], they have gone through several key design changes and modifications, with the expected fluctuations in their use. Their use flourished in the 1990s with the introduction of the modern HRA and subsequently accounted for approximately a third of all hip replacements being implanted in the United States in 2008[1].

The proposed benefits for using MOM bearings were to reduce the occurrence of polyethylene disease (aseptic loosening) and to allow the use of large diameter femoral head components to reduce the occurrence of hip dislocation[4]. However, the inception of highly cross-linked polyethylene and improved ceramic bearing design, have diminished the perceived advantages of MOM over other bearing surfaces[8,9].

Besides this, metal debris and corrosion products have led to inflammatory reactions within the soft tissues surrounding MOM hip implants and subsequently their early failure and need for revision[10-13]. This has led to the subsequent fall in use of MOM hips and intervention from regulators[3].

Metal debris - A cause for concern?

Metal implants are considered biologically inert, however wear debris is not and is thought to evoke an immune response[14]. The release of material from metallic implants occurs by wear, corrosion and mechanical factors such as fretting and third body wear. Cobalt and chromium are the major constituents of alloy metal implants, and are the main cause for concern.

Metal particulate and ionic wear debris from the hip is released into the peri-prosthetic tissues and transported systemically throughout the body[15,16]. Studies have demonstrated a peak in blood cobalt levels at 6-mo post implantation and chromium levels at 9-mo, followed by a steady decline over time[17,18]. Following revision of a MOM implant to an alternative bearing, blood ion levels reduce but do not normalise in the post-operative period[19,20].

Component design and positioning has been shown to be associated with increased wear and as a result raised metal ion levels[21-25]. Blood cobalt and chromium ion levels in patients with unexplained painful MOM hips are double those of well-functioning MOM hips[13].

Wear debris can accumulate locally as seen by studies of joint fluid surrounding MOM hip implants[26-28]. The level of chromium is greater in joint fluid compared to cobalt, whereas the converse is true for blood analysis[28]. However it is believed that cobalt is the species with greatest reactivity causing local tissue inflammatory reactions due to its ready solubility[29-31].

WHO IS AT RISK?

Local soft tissue reactions

Pseudotumours are well described in patients with MOM hip implants, and can be either solid or cystic. Reported prevalence in both symptomatic and asymptomatic patients ranges from 0.1% to 69%[10,11,32-37]. The precise aetiology is not known, however the term aseptic lymphocytic vasculitis-associated lesion (ALVAL) is used to describe the histological features associated with metal hips[38]. It has been suggested that a delayed type Ⅳ hypersensitivity reaction to metal ions is the potential cause, however this has been challenged[12]. Pseudotumours were, however, shown to correlate with elevated blood and hip aspirate metal ion levels suggesting a relation to excessive implant wear[12,39].

Recent evidence regarding the natural history of soft tissues abnormalities is conflicting. Studies report varying degrees of progression in size and grade of pseudotumours, however limitations in sample size,

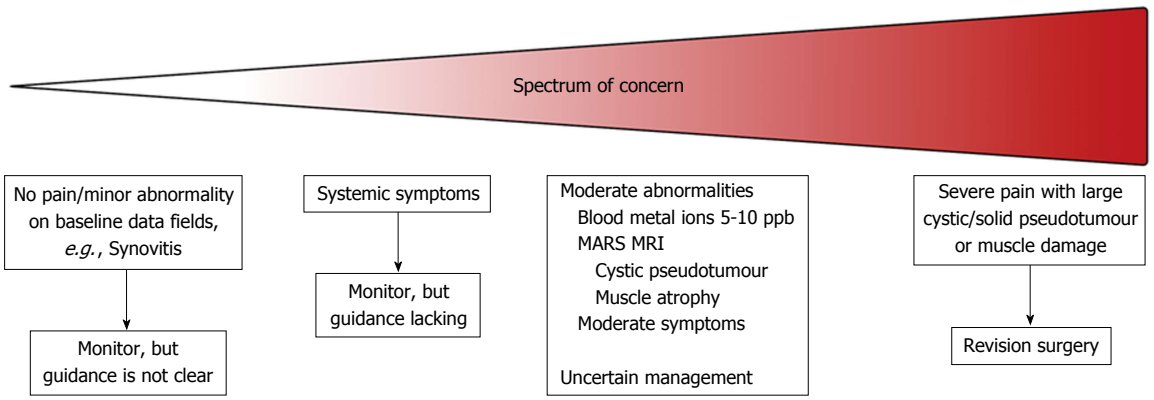

Figure 1 Diagram demonstrating the spectrum of concern for patients with metal-on-meta hip implants. The decision on how to manage patients at the extremes of the spectrum is relatively straightforward. However the majority of patients fall into to the middle category, where the management is uncertain or difficult. MRI: Magnetic resonance imaging; MARS: Metal artefact reduction sequence.

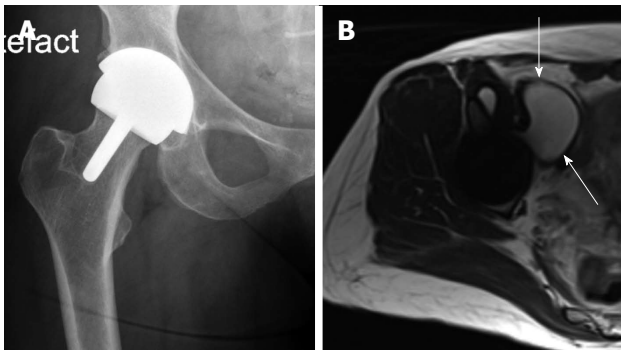

Figure 2 Middle of the spectrum - A typical patient with moderate problems. This 58-year-old very active lady with a right hip resurfacing arthroplasty (A: X-ray AP hip) implanted 8 years ago. She has minimal symptoms and moderately raised blood metal ion levels (Cobalt 13 ppb, Chromium 7 ppb). A magnetic resonance imaging scan (B: Axial T2 weighted image) has revealed a 6 cm cystic pseudotumour anterior to the hip (arrows).

implant type and imaging modality do not readily allow the generalisability of the results[40-42]. It appears that when disease progression does occur, it is slow and therefore serial imaging annually is sufficient to identify change. The potential to cause local pressure effects causing necrosis and compression of nearby structures such as the iliac vessels, femoral vessels and the sciatic nerve is also a concern.

Muscle atrophy is now becoming an increasing concern, and is driving the debate regarding the timing of revision surgery in order to prevent irreversible damage. A recent publication demonstrated progressive muscle atrophy using serial magnetic resonance imaging (MRI) scanning in a mixed cohort of patients[43].

Systemic effects

Several cases of systemic effects from metal hip implants have been reported, including cardiac, endocrine, neurological and dermatological complications, however this remains a relatively rare occurrence[44]. There is a mixture of cases reported in both fractured ceramic hips and in primary MOM hip patients[44]. Removal of the implant led to reduced metal ion levels and symptomatic improvement in several of these cases. Additionally, chronic low dose exposure over several years revealed a negative effect on cardiac function and bone density[45], however these were subtle and sub-clinical. Recent cases of cardiac toxicity have been further highlighted and novel diagnostic techniques are being explored[46,47].

MANAGEMENT - WHEN SHOULD PATIENTS BE REVISED?

The local and systemic effects of metal particulate and ionic debris from MOM hips have led to increased rates of revision hip surgery. It has also led to significant levels of patient anxiety, not to mention the physical and financial burden of a failed metal implant on the patient and the health services.

The British Hip Society was the first to publish their guidance through the Medicines and Healthcare Products Regulatory Agency (MHRA)[3]. The MOM task force (American Association of Hip and Knee Surgeons, the American Academy of Orthopaedic Surgeons, and The Hip Society) in the United States[48], the European Hip Society (EHS) (2012)[6], and most recently the European Commission's Scientific Committee on Emerging and Newly Identified Health Risks, have also published guidance for surgeons[49]. However, uncertainties remain over decision making because of the difficulty - for any guideline - to define or quantify clinical symptoms, imaging findings and clinically important thresholds for blood metal ion results.

Role of metal ions

The MHRA currently recommends 7 ppb as the threshold for concern beyond which further investigations are recommended to diagnose complications associated with MOM hip implants. The Food and Drug Administration (FDA) does not currently set an action level, and SCENIHR acknowledge that the level for concern lies between 2-7 ppb based on questions raised regarding the current available evidence.

The population background level of cobalt in blood

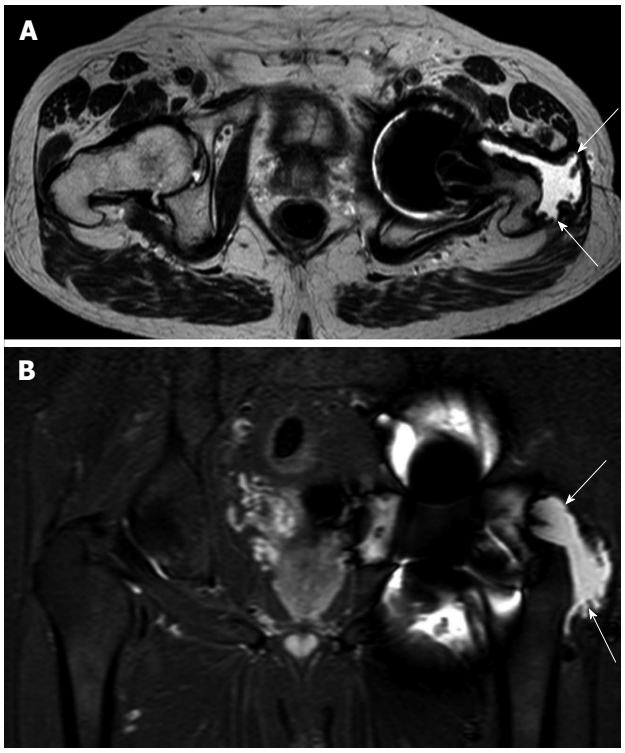

Figure 3 Axial (A) and coronal (B) magnetic resonance imaging. Example of abductor stripping secondary to a pseudotumour (marked by arrows). The pseudotumour can be seen traversing the posterior hip around the greater tuberosity onto its lateral aspect, which is now void of abductor tendon insertion.

has been shown to be 0.5 ppb. There is a correlation seen with wear rates, where 2 ppb can be expected with wear rates of 2 cubic mm per year[50,51].

Since the 7 ppb level was derived from research based on hip resurfacings[51], it has been postulated that this may not apply to stemmed implants. A study including a variety of implant types demonstrated improved sensitivity and specificity with a threshold cobalt level of 4.5 ppb[50].

Various groups have argued for a blood metal ion threshold for revision. The prevalence of patients with blood metal ion levels over 25 ppb was 2.6% in HRA patients, and 3.1% in total Hip Replacement (THR) patients[52]. The sensitivity and specificity of the 7 ppb cut-off level have been reported to be 52% and 89%, respectively, indicating that the 7 ppb has relative poor ability to identify MOM failures. The lowering of the cut-off level to 5 ppb increases the sensitivity to 63% and lowers specificity to 86%[51]. The Finland group demonstrated that 25 ppb was 99% specific compared to 93% specificity at 7 ppb, however more notably revised patients with metal ions over 25 ppb had a significantly lower oxford hip score 12 mo after revision compared to those with ions less than 25 ppb. The re-revision rate was also higher in those patients with metal ions over 25 ppb[52].

Based on current literature 7 ppb remains a safe level for concern in patients with a HRA implant, whereas the presence of a taper (LDTHR) would prompt a lower threshold for concern.

Role of diagnostic imaging

The MHRA advise metal artefact reduction sequence MRI (MARS MRI) or ultrasound scan as part of the investigation algorithm[3]. MARS MRI appears more appropriate, due to excellent sensitivity and specificity for detection of both superficial and deep lesions[53-55], and also muscle atrophy. Ultrasound is a satisfactory modality for identifying tendon abnormalities[54]. Current MARS MRI techniques do suffer from metal artefact that limits the diagnosis of osteolysis, however, improved techniques are being developed[56]. Currently computed tomography (CT) scanning is ideal for visualising osteolysis if it is suspected on plain radiographs[57].

In patients where the cause of pain is unexplained, single-photon emission CT (SPECT-CT) has been recommended[58]. SPECT-CT was shown to be clinically valuable in diagnosing the cause of pain and influenced management decisions in over half of patients with unexplained pain following a MOM hip arthroplasty despite inconclusive conventional investigations.

Pseudotumours

There is a lack of evidence surrounding the need for revision secondary to pseudotumours, particularly regarding the outcome following revision surgery and the long-term natural history of pseudotumours. This is reflected in the current guidance by the limited detail in how to interpret MRI findings.

It has been shown that revision for pseudotumour is associated with significant post-operative complications[59]. In addition, recurrence after revision with excision is possible and may be as high as 30%. If pseudotumours, cystic or solid, are large enough to cause pressure necrosis or stretch of soft tissues, then this is usually an indication for revision surgery (Figure 3).

Large pseudotumours with intra-pelvic extensions along the psoas sheath or arising wholly within the pelvis are of particular concern. These have the potential for compression of neurovascular structures including the iliac vessels. In addition, surgical excision becomes more difficult and often a multi-disciplinary surgical approach with vascular surgeons is required (Figure 4).

Osteolysis

Osteolysis surrounding MOM hip implants is a further concern that needs to be addressed[60], and one should be vigilant in the presence of very high metal ions. Progressive osteolysis may be an indication for early intervention if the potential for peri-prosthetic fracture is apparent.

Muscle atrophy

There is growing evidence supporting early revision to a non-MOM hip implant to prevent irreversible damage[38,61]. Campbell *et al*[62] observed that patients can expect a good outcome if their soft tissues remain

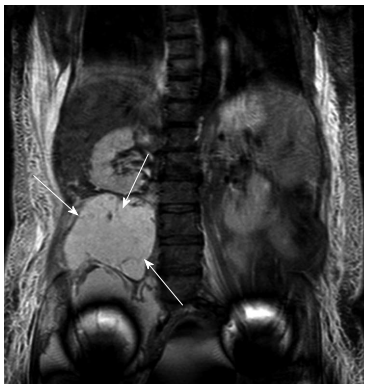

Figure 4 A 58-year-old patient with bilateral large diameter total hip replacement metal-on-meta implanted 9-years ago, moderate hip symptoms and raised metal ion levels (Cobalt 17 ppb, Chromium 13 ppb). She presented to the general surgeons with abdominal pain and distension. Coronal magnetic resonance imaging scan (above) demonstrated a large cystic pseudotumour extending into the pelvis up to the level of the L2 vertebra and abutting the right kidney in the retroperitoneal space (arrows). The cystic pseudotumour was drained prior to surgical excision with both orthopaedic and vascular surgeons present.

intact. A recent study demonstrated progressive muscle atrophy over a period of 12 mo using serial MRI, and noted an association with high metal ion levels[43]. Liddle *et al*[63] highlight the degree of misdiagnosis possible when planning for revision of MOM hip implants. They describe that pre-operative imaging can underestimate the degree of soft tissue abnormalities seen at revision surgery including a high rate of severe abductor muscle atrophy and stripping of the tendinous attachment[63]. If progressive and destructive soft tissue change is possible, predicting those patients that are likely to fail is paramount so that revision can be undertaken early to ensure a better outcome (Figure 3).

Broadly however, a decision to revise should not be based on a single investigation, instead the decision should take into account patient symptoms, activity level, implant type, metal ion levels and imaging findings.

WHEN SHOULD PATIENTS BE FOLLOWED UP?

Current guidance stratifies patients by risk depending on the type of implant they have *in situ*. Small diameter THR and hip resurfacing arthroplasty is considered low risk, where as the large diameter THR and the DePuy ASR implants are considered high risk[3]. A recent publication went one step further and stratified all current generation MOM hip implants into low, medium and high risk categories[5], based on registry and regulatory advice. More recently however the Regulators state that low risk implants that are functioning well should be monitored according to local hospital protocols, whereas high-risk implants require follow-up for the life of the implant. The Birmingham Hip Resurfacing (Smith and Nephew, London, United Kingdom) has been the best performing hip resurfacing, however concerns have always existed regarding their use in female patients, and patients with small diameter femoral heads (< 48 mm). As a result of these concerns the MHRA have released further guidance advising against their use in this population and additional advice on the management of patients with these implants *in situ*[64].

However the majority of guidelines do not offer detail on what constitutes follow up, and more importantly which patients require more frequent monitoring. A pragmatic approach would be to take this on a case-by-case basis where the frequency of follow up needs to be tailored to the individual based on the implant risk stratification and the patients clinical status.

Based on the literature, with particular reference to the natural history of soft tissue changes, annual follow up would suffice for those with a medium to high risk implant. Follow up should consist of a history, clinical examination, functional scoring, blood metal ions measurement and X-ray. If clinical concern exists then cross sectional imaging with MARS MRI would be indicated. For low risk implants in individuals with a low risk profile, then less intensive follow-up would be indicated, such as annual questionnaires and 5-yearly clinical review.

One must be mindful of applying a simplistic approach based on implant risk stratification alone, since certain aspects of the patients clinical and surgical history would suggest a heightened risk even in the best performing hip implants. Low risk implants in patients with hip symptoms, evidence of soft tissue abnormality or high metal ions would require closer monitoring. In addition, excessive acetabular cup inclination can lead to edge loading and early failure[65,66], and also female patients with small femoral head size hip resurfacing arthroplasties and females with primary hip dysplasia have worse long term outcomes[48].

HOW - MULTI-DISCIPLINARY TEAM APPROACH

Some clinical cases are straightforward and decision-making is relatively easy. However, in many instances surgeons experience considerable uncertainty in decision-making because of the lack of guidelines or the difficulty in applying guidelines in complex cases. This gap has led to the use of a multidisciplinary teams (MDT) approach to help interpret the guidance published by the regulatory agencies, with the aim of using surgical experience, tacit knowledge, and evidence-based current best practice to reduce the uncertainty surrounding the management of patients with MOM hip implants[5].

This highlights the need for a more collaborative approach between surgeons, regulators and industry representatives to improve the available evidence and the guidance offered to aid the management of patients with MOM hip implants.

Role of retrievals

In a recent commentary by Jacobs *et al*[67], the im-

portance of implant retrieval analysis by centres with access to large retrieval cohorts was emphasized as significant in understanding mechanisms of failure and also for developing future preclinical testing models. This reflects the number of developments established through retrieval analysis and includes the relationship with cup position and edge loading[68], the correlation of wear rates with blood metal ion levels[66] and the role of frictional torque and fretting currents in LDTHR[69].

CONCLUSION

The management of patients with MOM hip implants continues to cause concern and difficulties for patients and surgeons alike. The evidence is lacking in certain scenarios, and regulatory guidance can be interpreted differently. When considering which patient requires revision, no single investigation or aspect of the history should be taken in isolation. Decisions should be taken on a case-by-case basis, with consideration given to all aspects of the patient's clinical history and investigation results. A multi-disciplinary approach with shared decision-making, tacit knowledge and surgical experience appears to be a safe and practical approach to improving patient's outcomes.

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Bernese periacetabular osteotomy for hip dysplasia: Surgical technique and indications

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Abstract

For young, active patients with healthy hip cartilage, pelvic osteotomy is a surgical option in to address hip pain and to improve mechanical loading conditions related to dysplasia. Hip dysplasia may lead to arthrosis at an early age due to poor coverage of the femoral head and abnormal loading of the joint articulation. In patients with symptomatic dysplasia and closed triradiate cartilage (generally over age 10), including adolescents and young adults (generally up to around age 40), the Bernese periacetabular osteotomy (PAO) is a durable technique for addressing underlying structural deformity. The PAO involves a modified Smith-Petersen approach. Advantages of the Bernese osteotomy include preservation of the weight-bearing posterior column of the hemi-pelvis, preservation of the acetabular blood supply, maintenance of the hip abductor musculature, and the ability to effect powerful deformity correction about an ideal center of rotation. There is an increasing body of evidence that preservation of the native hip can be improved through pelvic osteotomy. In contrast to hip osteotomy and joint preservation, the role of total hip arthroplasty in young, active patients with correctable hip deformity remains controversial. Moreover, the durability of hip replacement in young patients is inherently limited. Pelvic osteotomy should be considered the preferred method to address correctable structural deformity of the hip in the young, active patient with developmental dysplasia. The Bernese PAO is technically demanding, yet offers reproducible results with good long-term survivorship in carefully selected patients with preserved cartilage and the ability to meet the demands of rehabilitation.

Key words: Periacetabular osteotomy; Hip dysplasia; Pelvis

Core tip: The periacetabular osteotomy has been used to address structural deformity in young patients with acetabular dysplasia. The technique through a modified Smith-Petersen approach offers advantages: Preservation of the posterior column adds to the stability of the hemipelvis and protection of the sciatic nerve, preservation of the acetabular blood supply, and

maintenance of hip abductor musculature. The juxta-articular osteotomy planes offer the ability to effect powerful deformity correction about an ideal center of rotation. While maximizing joint stability, coverage and congruency, the acetabular reorientation must also be assessed in light of the impingement-free range of motion.

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INTRODUCTION

The goal of pelvic osteotomy in the setting of hip dysplasia is to address the biomechanical and structural abnormalities that lead to secondary osteoarthrosis under improper loading conditions. Poor coverage and/or incongruity due to developmental hip dysplasia may be corrected through reorientation of the acetabulum into an ideal position[1]. By improving these loading conditions, the static and dynamic instability patterns seen with hip dysplasia can be appropriately countered. While reorienting the osteotomy fragment and increasing the femoral head coverage improve load distributions across the joint, the amount and direction of correction required depends on the individual patient. This correction remains the critical - and certainly the most challenging - part of the procedure.

Prior to surgery, a thorough history and physical examination is required, including a careful assessment of gait, leg lengths, joint stability, and range of motion. High-quality radiographs should be obtained. These studies include an anteroposterior pelvis projection in proper rotation and tilt, a Dunn lateral view of the hip (*e.g.,* 45-degree projection), and a false profile (faux profile) view of the affected hemipelvis[2]. To estimate the ability for containment and the amount of correction and resulting congruency possible with reorientation of the acetabulum, a functional abduction and internal rotation radiograph should be obtained as well. The patient's age, body mass index, level of activity, and functional goals must also be incorporated into a decision to pursue surgical intervention.

The Bernese, or Ganz, periacetabular osteotomy (PAO) is the author's preferred method for correcting acetabular dysplasia. Other pelvic osteotomies (*e.g.,* triple, rotational) vary in the nature of the osteotomy planes, the ability to address open *vs* closed triradiate cartilage, and ability to correct acetabular orientation in multiple planes. The most frequent indication for performing the Bernese PAO is symptomatic acetabular dysplasia in an adolescent or young adult[3] with correctable deformity and preserved range of motion. The procedure is generally performed after closure of the triradiate cartilage (generally after age 10). Older patients (into the fourth decade) may be suitable candidates for the procedure based on the degree of arthrosis, as well as other factors such as ability to cope with rehabilitation period, activity level, expectations, obesity, and systemic conditions.

Contraindications to the Bernese PAO include advanced arthrosis (*e.g.,* Tönnis Grade 2 or 3), subluxation resulting in a femoral head within a neoacetabulum, and a mismatch between a smaller acetabular radius and that of the femoral head which may cause worsening of joint congruity after reorientation. Patients with severe restrictions in range of motion are also poor surgical candidates.

SURGICAL TECHNIQUE

Equipment

An epidural catheter is placed pre-operatively and is continued post-operatively for pain control. Either regional anesthesia (*e.g.,* spinal/epidural) *vs* general anesthesia with selective muscle relaxation may be used. General anesthesia may be performed with total intravenous anesthesia to maintain the ability to perform neuromonitoring during key exposure and reduction maneuvers that might put neurologic structures at highest risk. A Foley urinary catheter is also placed at the time of surgery. The patient is positioned supine on a radiolucent operating room table.

A fluoroscopy machine with a wide field of view may be used during the case for accurate and safe osteotomy cuts. A portable X-ray machine for obtaining intra-operative radiographs of the entire pelvis after acetabular correction is essential. Neuromonitoring during the case[4] is optional but advised to ensure safe dissection and osteotomy maneuvers. A cell-salvage system is used to collect intra-operative blood loss, and tranexamic acid is routinely dosed prior to incision and during wound closure. A foot rest for stabilizing the limb in a position of hip flexion is attached to the operating table, or, alternatively, a radiolucent triangle or specialized sterile leg holder may be used to achieve hip flexion throughout the majority of the procedure.

Specialized PAO retractors, osteotomes (including Ganz-type osteotomes), and surgical instruments may be obtained through commercial sets (*e.g.,* manufactured by Subtilis/Smith and Nephew). Steinman pins and Kirschner wires (including 1/8th, 5/64th, 3/32nd diameters), as well as Schanz screws (5.0 mm, 6.0 mm) with appropriate T-handle adaptors for intra-operative reduction maneuvers should be available. Likewise, a ball-spike pusher and bone-holding forceps/clamps, including Weber-type (*e.g.,* as found on Synthes Pelvic Reduction instrument tray) are important for fragment reduction and fixation. Long 3.5 mm/4.5 mm screws and appropriate length depth gauge, drill bits, bone taps (as found on a Synthes Large Fragment and/or Pelvic Reconstruction set) are needed for fixation. Reconstruction plates may be used if poor bone quality

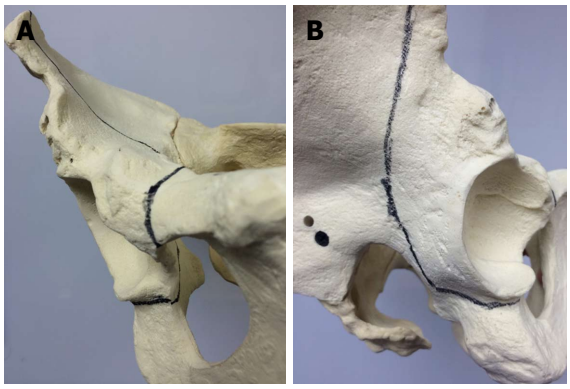

Figure 1 Location of osteotomy planes in the bernese periacetabular osteotomy. Frontal (A) and lateral (B) views of the pelvis demonstrating placement of juxta-acetabular osteotome cuts (dark lines).

is encountered or if there is a very large correction performed. Wide and narrow oscillating saw blades are used for osteotomy cuts, and a high-speed bur is used for acetabuloplasty and/or osteochondroplasty. Bone wax, drains (*e.g.,* medium Hemovac), and heavy non-absorbable suture for tendinous repair are other miscellaneous equipment needed during the procedure.

Other equipment that should be available, but necessarily open for the start of the case, includes appropriate femoral osteotomy plating system, if performing concurrent femoral osteotomy; and acetabular labral suture anchors, with appropriate drilling system, for labral repair if indicated. Similarly, hip arthroscopy equipment and viewing tower should be available if a concomitant hip arthroscopy procedure is preferred over capsulotomy.

Patient positioning and draping

The patient is placed in the supine position on a radiolucent table. The ipsilateral upper limb may be placed across the chest, and all bony prominences are well-padded. Fluoroscopic views (antero-posterior pelvis and roll-over oblique) should be confirmed prior to definitive prep and draping of the limb. Access to above the level of the iliac crest of the operative hemipelvis and down to the ipsilateral foot must be included within the prepped field. Neuromonitoring leads may be secured to the involved extremity before final sterile draping.

Surgical exposure

The modified Smith-Petersen approach, with preservation of the abductor musculature, is utilized. A curvilinear skin incision, centered about the anterior superior iliac spine (ASIS) is used. This incision extends proximally along the iliac crest and distally along the internervous interval of the tensor fascia lata and sartorius muscles. The fascia over the tensor is incised along the orientation of the muscle fibers. The lateral femoral cutaneous nerve is protected proximally about the ASIS, as well as during distal superficial exposure. The tensor fascial muscle belly is separated from the fascial envelope bluntly and retracted laterally; slight abduction may make this separation easier. Maintenance of this fascial sleeve also helps to protect the cutaneous nerve.

The ASIS is then osteotomized (block or wafer). This osteotomy maintains the origins of the sartorius and ilioinguinal ligament in continuity with the mobile fragment. The external oblique is dissected off the iliac wing in a subperiosteal plane for access to the inner pelvis down to the pelvic brim. The periosteum is elevated along with the iliacus muscle using straight and angled long Cobb-type elevators. If bleeding is encountered from the iliolumbar artery as it penetrates the iliac crest, the arterial orifice may be enlarged and then filled with bone wax.

The deep distal exposure is competed by reflecting the rectus tendon from the anterior inferior iliac spine, preserving a bed of tendon for later repair. As the deep fascia is opened distally, the pedicle to the tensor is exposed. This pedicle is freed, mobilized, and preserved. By dissecting the iliocapsularis muscle off the anterior hip capsule, an interval is developed medially under the iliopsoas tendon. The hip should be flexed up on a radiolucent triangle (or rested upon a foot bump) at this time to relax the anterior soft tissues. Completion of the dissection between the iliocapsularis, especially at its inferolateral border, allows the surgeon to palpate the calcar femoris through the capsule as well as the anterior surface of the ischium using closed scissors. Medial dissection exposes the iliopectineal bursa. Further subperiosteal exposure of the quadrilateral surface and pubic root allows for placement of a sharp Hohmann into the pubis, medial to the iliopectineal eminence.

Periacetabular osteotomies

The location of the various periacetabular osteotomy cuts are shown in Figure 1. Exposing the hip capsule inferiorly, the ischium is palpated with scissors. The ischium is triangular in shape with the base posterior. The infracotyloid groove, along with the obturator foramen medially and hamstrings origin laterally, is appreciated. The tips of the long curved dissecting scissors should be kept proximal to the obturator externus muscle. This scissor trajectory then guides the placement of a specialized curved osteotome to create the osteotomy just distal to the infracotyloid groove. The osteotome may be slid behind the scissors to ensure no entrapment of soft tissues. The position of the osteotome may be verified in anteroposterior and oblique fluoroscopic projections.

The inferior retro-acetabular osteotomy begins at the infracotyloid groove and progresses toward the midpoint of the ischial spine. The osteotomy is done in both medial and lateral limbs: The osteotomy is begun on the medial side. During the lateral osteotomy, the sciatic nerve should be relaxed with the limb abducted, the hip extended, and the knee in slight flexion. Both tactile and aural feedback is critical in assuring the osteotome is within bone, as well as to prevent violation

of the posterior column. The ischial osteotomy is an incomplete osteotomy, with depth to about 2.5 cm. It is important to cut the thicker medial cortex, while the thinner lateral cortex may break in a controlled fashion during the final osteotomy expansion maneuvers.

An assistant may then adduct the hip (maintaining flexion) to aid in access to the pubic ramus. The ramus periosteum is sharply cut on the superior cortical surface, and square-tip retractors are placed around the postero-inferior and postero-superior aspects of the pubic ramus. These retractors encircle the bone and protect the obturator nerve. Adequate circumferential release of the periosteum must be ensured to allow later fragment mobility, especially in younger patients with thick periosteum. A spiked Hohmann is secured into the superior cortex of the ramus a couple centimeters medial to the medial border of the iliopectineal eminence. This safely retracts the iliopsoas and the femoral neurovascular bundle medially, while maintaining a safe distance from the joint. A thin-kerf narrow saw (may alternatively use an osteotome) is used to start the osteotomy at an angle away from the joint; the osteotomy is completed with an osteotome. Removing a thin wafer of bone from the anterior cortex may help with sounding the far posterior cortex. The posterior cortex cut should exit medial to the obturator nerve. An osteotome may be used to gently splay the osteotomy ends to ensure that the cut is complete.

The ischial spine is identified with a reverse Eva retractor placed on the inside of the ischial spine after subperiosteal presentation of the quadrilateral surface. A muscular window along the lateral surface of the iliac wing is created, and a second reverse Eva is placed laterally. This tunnel along the outer table protects the gluteal muscles. The level of this iliac osteotomy is at a sufficient distance from the acetabulum to minimize risk of injury to the superior gluteal artery (supra-acetabular branch) and vascular arcade supplying the acetabulum. Furthermore, a larger bone bridge allows for better purchase of the Schanz screw during reduction, as well as to minimize the chance of joint surface violation while performing the second limb of the retro-acetabular cuts. A burr is used to make a target hole approximately 1 cm superolateral to the brim of the true pelvis. Alternatively, an osteotome may be used to mark this eventual vertex of the 120-degree osteotomy limbs. The osteotomy of the ilium is started with an oscillating saw: The first cut is along the medial cortex; subsequently, with the leg held in abduction, the lateral portion of the cortex is cut. Osteotomy of the posterior column is performed at an angle of 120 degrees to the previous iliac cut. Fluoroscopy may be used to confirm safe depth and trajectory. As with the iliac osteotomy, the posterior column cut begin within the medial cortex. The cut may be initiated using a straight or angled osteotome depending on the body habitus and angle of the osteotomy plane. To ensure that the retro-acetabular portion is complete, a straight osteotome is passed in a distal-ward direction; likewise, a Ganz-type osteotome is passed from the inside of the pelvis aiming laterally in sequential steps. Tactile and aural feedback is important at this step, and the bone may displace subtlety during progressive osteotomy maneuvers. Maintaining a safe distance from the subchondral bone prevents iatrogenic intra-articular fracture propagation.

A laminar spreader is placed into the iliac osteotomy site; a second laminar spreader may be placed in the second limb of the retro-acetabular osteotomy to effect the final displacement. Residual tethering of the posterior column osteotomy, if present, may be freed under direct vision with an angled bifid osteotome from the inside. During this maneuver the hip is again extended and abducted to relax the sciatic nerve.

Acetabular correction

A Schanz screw (5.0 mm) is inserted into the superior aspect of the mobile fragment, and rotatory motions test the osteotomy segment mobility. Combined movement of the Schanz screw and an inwards turn of the laminar spreader placed at the vertex of the supra-retro-acetabular osteotomy may help to free the fragment and maintain an adequate reorientation. A small bone hook or Weber clamp may be applied to the pubic segment to aid in reduction. The lack of complete mobility prompts the surgeon to review three problematic sites: The pubic osteotomy and accompanying periosteum, the posterior cortex at the vertex (junction of iliac and posterior column segments), and the inferior ischial cut. Mobility is again verified with the ability to flip the fragment.

The reorientation is then performed, keeping in mind that there is one ideal position of the fragment that optimizes joint loading conditions, while maintaining range of motion about an ideal center of hip rotation. For the more common hip dysplasia morphology, the acetabulum is usually repositioned with a combination of internal rotation, forward tilt/extension, and medial translation. As before, adjunctive reorientation tools may include a ball-spike pusher, Weber clamp, small bone hook, or a second Schanz pin. Provisional fixation is maintained with several terminally threaded or smooth Kirschner wires; the surgeon may choose to place two antegrade and one retrograde wires.

A properly projected and rotated pelvic radiograph is then obtained intra-operatively. This X-ray must be critically evaluated for the final acetabular orientation: The lateral center-edge angle, Tönnis angle/inclination, adequate medialization of the hip center of rotation, teardrop position, restoration of Shenton's line, and version of the acetabulum. It is essential to not retrovert the acetabulum in addressing classic dysplasia. An example of an acetabular correction performed for hip dysplasia is presented in Figure 2.

On-table range of motion is then performed to assess for potential secondary impingement or residual instability after the acetabular correction. The hip flexion should be at least 100 degrees. The mobile segment is secured with several 3.5 mm/4.5 mm fully

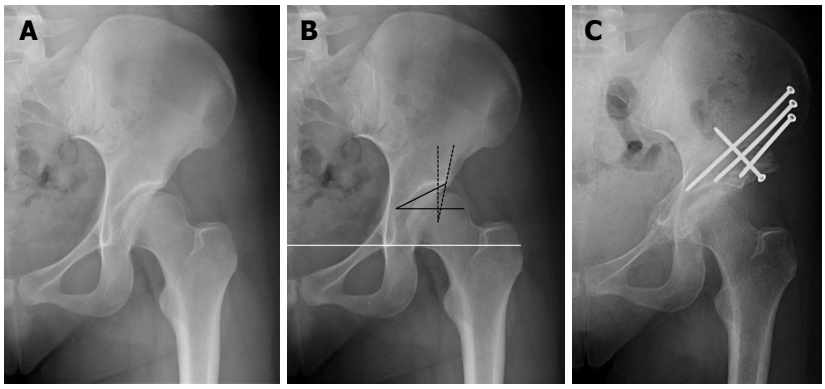

Figure 2 Acetabular radiographic measurements and correction. Pre-operative (A) antero-posterior radiograph of a hip with classic dysplastic. Basic radiographic measurements of dysplasia (B) include the lateral center edge angle (dashed black line; measure of lateral acetabular coverage), Tönnis angle (solid black line; measure of sourcil angle); the solid white line is the inter-teardrop line, which is the reference for pelvic tilt in the coronal plane; an anterior center edge angle on a false profile view completes the basic radiographic work-up. The post-operative (C) antero-posterior radiographic view of the same hip demonstrating satisfactory acetabular reorientation to correct bony dysplasia.

threaded screws in antegrade and/or retrograde fashion. Fluoroscopic images may confirm that the acetabular reduction is maintained, along with position of fixation hardware.

After fragment fixation, an arthrotomy may be performed. This offers the opportunity to examine the acetabular labrum for repair if needed, as well as to address any offset abnormalities of the femoral neck region. Labral debridement *vs* repair (with possible augmentation) is performed, depending on the characteristics of the labral tear and quality of tissue. Osteochondroplasty using a curved osteotome and a burr may be performed at this time at the sites of femoroacetabular impingement.

Wound closure

After thorough irrigation of the joint and surgical field, the capsular incision is closed. Any bony prominences of the reoriented fragment may be trimmed with a saw and/or burr; the autograft may be used to fill the iliac osteotomy site. The rectus tendon is repaired with non-absorbable suture back to its footprint. The subspine region may be decompressed if impinging on the femur in deep flexion. The ASIS fragment is repositioned and fixed with a small-fragment screw or heavy suture in trans-osseous fashion. Closed suction drains may be used per surgeon preference. The fascia over the iliac wing, as well as distally over the tensor, is closed. Establishing a watertight seal of the fascia is important. The remainder of the superficial wound is closed in a routine, layered fashion.

POST-OPERATIVE CARE AND REHABILITATION

Mobility and weight-bearing status depends on whether the PAO has been performed alone or in conjunction with other procedures, such as femoral osteotomy and/or surgical hip dislocation. With maintenance of the posterior column and with good bone quality, partial weight-bearing (15 kg) is prescribed for the first 4-6 wk. A period of non-weight-bearing may be used in the setting of large corrections or poor bone quality. A continuous passive motion machine may be employed, especially if intra-articular work is performed. Routine deep venous thrombosis prophylaxis (*e.g.,* low molecular weight heparin or aspirin) is used for the first six weeks. Heterotopic ossification prophylaxis is not routinely used. At four weeks, abduction strengthening exercises (first standing and then laying on opposite hip) is allowed, along with a stationary bike. Active flexion of the hip joint is prohibited for at least six weeks to protect the reattached hip flexor muscles. At eight weeks postoperatively, the patient is assessed clinically and radiographically: Healing is usually sufficient for full weight-bearing, and full muscular strengthening can be started. Flexion strength may take up to six months to return, and complete bony union will take several months to achieve. The majority of patients have pain-free range of motion at 2-3 mo, depending on how significant of a correction has been performed. Patients may generally return to sports activity between 6-12 mo, but patients with severe preexisting abductor and other functional weakness may take up to a year for complete rehabilitation.

CONCLUSION

The Bernese PAO is one of several acetabular osteotomies to address structural deformity in patients with closed triradiate cartilage, including adolescents and young adults with symptomatic dysplasia. The PAO technique involves a modified Smith-Petersen approach. Advantages of the Bernese PAO include preservation of the weight-bearing posterior column of the acetabulum, preservation of the acetabular blood supply, maintenance of the hip abductor musculature, and powerful deformity correction about an ideal center of rotation.

The Bernese PAO has been applied to complex acetabular dysplasia cases for over 30 years[5]. While it remains a technically demanding procedure[6-8], the potential to improve the natural history of hip dysplasia is well-demonstrated in mid- and long-term clinical studies[9-11]. Refinements in surgical technique and patient indications, in combination with the application of key femoroacetabular impingement concepts, have increased the understanding of hip pathomorphology and the parameters for acetabular reorientation[12].

Compared with a number of other pelvic osteotomy techniques, the Bernese PAO maintains the posterior column. By not violating the posterior column, prolonged immobilization and/or extensive pelvic fixation methods are obviated, and there remains inherent stability and good potential for union of the mobile fragment to the residual pelvis. The juxta-articular osteotomy planes also maintain the dimensions of the true pelvis and effects a powerful correction about an ideal center of hip rotation. With medialization of the hip joint, the abductor lever arm is maximized, and joint reaction forces are dampened.

Since its initial description, the PAO surgical technique has undergone various modifications[13]. The original approach involved stripping of the abductors from the iliac crest during the iliac and supra-acetabular osteotomy segment. Protecting the abductors not only preserves muscle function but also decreases the risk of osteonecrosis due to compromised acetabular vascular supply. Associated vessels include branches of the obturator, superior and inferior gluteal arteries, and capsular contributions to acetabular perfusion. Initially, the bone cuts were performed from both sides of the iliac wing; the bone cuts are now predominantly performed from the inner aspect of the pelvis to further preserve the abductors. More recently, it has become apparent that hip flexion strength is decreased post-operatively, and thus a rectus-sparing approach has been supported by some centers. This technique variation leaves the direct and indirect heads of the rectus femoris attached. It is unclear whether this will solve the problem of flexion strength deficits, or whether injury to the most proximal branches of the femoral nerve during osteotomy of the pubis may be increased.

Other modifications to the original surgical technique include a two-incision technique. In this manner, the ischial osteotomy has been performed under direct visualization. The primary disadvantage of this technique involves dissection of the external rotators posteriorly, with risk to the medial femoral circumflex artery and blood supply to the femoral head. Additional variations to the technique include various minimally invasive incisions, including a trans-sartorial approach. Other investigators have presented the use of hip arthroscopy at the time of PAO to evaluate the articular cartilage and to address labral pathology, which obviates the need for capsulotomy and more distal exposure.

The femoral head in a dysplastic hip may have a decreased head-neck offset and lateral flattening from a hypertrophic gluteus minimus. When the acetabulum is reoriented in a position of excess lateral and/or anterior coverage, secondary femoroacetabular impingement may occur. Impingement has been recognized as a potential cause for continued pain after PAO. As a result, an arthrotomy (or hip arthroscopy as above) has been incorporated for evaluation and correction of intra-articular impingement. Careful recognition of acetabular version (*e.g.,* avoidance of iatrogenic retroversion) during the correction also helps to minimize secondary impingement.

The osteotomy technique is technically demanding, yet offers reproducible results with good long-term survivorship in carefully selected patients with preserved cartilage and the ability to meet rehabilitation demands. Pelvic osteotomy should be considered as a preferred alternative to arthroplasty in the young, active patient with correctable structural deformity of the hip.

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MINIREVIEWS

Controversial role of arthroscopic meniscectomy of the knee: A review

Austin Y Ha, Robert M Shalvoy, Anne Voisinet, Jennifer Racine, Roy K Aaron

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Abstract

The role of arthroscopic partial meniscectomy (APM) in reducing pain and improving function in patients with meniscal tears remains controversial. Five recent high-quality randomized controlled trials (RCTs) compared non-operative management of meniscal tears to APM, with four showing no difference and one demonstrating superiority of APM. In this review, we examined the strengths and weaknesses of each of these RCTs, with particular attention to the occurrence of inadvertent biases. We also completed a quantitative analysis that compares treatment successes in each treatment arm, considering crossovers as treatment failures. Our analysis revealed that each study was an excellent attempt to compare APM with non-surgical treatment but suffered from selection, performance, detection, and/or transfer biases that reduce confidence in its conclusions. While the RCT remains the methodological gold standard for establishing treatment efficacy, the use of an RCT design does not in itself ensure internal or external validity. Furthermore, under our alternative analysis of treatment successes, two studies had significantly more treatment successes in the APM arm than the non-operative arm although original intention-to-treat analyses showed no difference between these two groups. Crossovers remain an important problem in surgical trials with no perfect analytical solution. With the studies available at present, no conclusion can be drawn concerning the optimal treatment modality for meniscal tears. Further work that minimizes significant biases and crossovers and incorporates sub-group and cost-benefit analyses may clarify therapeutic indications.

Key words: Arthroscopic partial meniscectomy; Meniscal tear; Knee osteoarthritis; Physical therapy; Randomized controlled trial; Crossover; Bias

Core tip: Despite several recent high-quality randomized controlled trials, the efficacy of arthroscopic partial meniscectomy (APM) for meniscal tears remains controversial. In this review, we analyzed the five most important trials for potential inadvertent biases. Each study was found to have some combination of selection, performance, detection, and transfer biases that compromise its conclusion. We also completed an alternative analysis of their results that took into account the observed high crossover rates. This analysis suggested that two studies whose original conclusions showed no superiority of APM may in fact support APM.

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INTRODUCTION

Observational studies, including longitudinal cohort studies, have suggested that arthroscopic partial meniscectomy (APM) is an effective treatment for meniscal tears[1-5]. More recent randomized controlled trials (RCTs) have suggested that non-operative regimens may provide equivalent symptom relief and functional improvement[6-10]. We have previously analyzed RCTs comparing APM with non-operative therapy specifically in the clinical setting of meniscal tears with concomitant osteoarthritis of the knee (MT-OAK) (Ha *et al*, submitted). That approach maximized internal validity but limited generalizability of the analysis. Therefore, there is value in analyzing reports of APM in a variety of clinical settings, understanding that the variable settings may increase variability but are more broadly generalizable. Occasionally, direct comparisons between outcome assessments cannot be made because of varying assessment instruments but outcomes can still be compared.

Our previous analysis of APM for MT-OAK identified two types of problems in the studies reviewed that compromised confidence in the study conclusions: (1) inadvertent biases within the structure of the RCTs; and (2) the large numbers of patients who crossed over from the non-operative to the operative groups. While the RCT is the methodological gold standard for establishing efficacy of treatments, bias may still occur within their structure that compromise their conclusions[11-15]. The second problem encountered is the evaluation of outcomes of patients who cross over from one treatment group to another, when they comprise a substantial portion of the study population[16]. Crossovers can be major confounders especially to an intention to treat (ITT) analysis and can obscure differences in the outcomes of two treatments[16,17]. Other methods of data analysis, each with their own limitations, may be useful as supplementary, but potentially more precise, analytical approaches[14].

In the present analysis, we review five RCTs reporting the efficacy of APM for meniscal tears in a variety of clinical settings. Particular attention is paid to the occurrence of biases within the RCT structure and the fidelity to the treatment assignment. Second, we employ an alternative quantitative analysis that examines the effects of crossovers upon the efficacy of APM.

Five RCTs comparing APM to non-operative treatment for meniscal tears with at least 6 mo follow-up were included in this analysis[6-10,18]. One study was excluded because it had not reported results beyond 3 mo[19]. Another study was excluded because it dealt with arthroscopic surgery for OAK rather than meniscal tears[20]. A third study was excluded whose results are not generally accepted because of methodological flaws making the data uninterpretable[21].

The five RCTs were first assessed for the presence of inadvertent bias within their structure. We used the framework proposed by Rudicel *et al*[15] to detect existing selection, performance, detection, or transfer biases. Furthermore, each RCT was individually assessed for the percentage of patients meeting the criterion for treatment success in both non-operative and APM groups. For this analysis, we used the definition of treatment success put forward by Katz *et al*[8]: Achieving improvement that is equal to or greater than the minimal clinically important difference (MCID) at the primary outcome time point compared to baseline without crossing over or requiring additional procedures. Data from either the original report or supplementary information provided directly by the authors was used to complete this analysis.

The Fisher exact test was used to test for statistical significance between the numbers of treatment successes in operative and nonoperative groups. SPSS, version 23.0 (IBM), was used for all statistical analyses. A biomedical statistician performed the statistical analyses.

The citations, meniscal pathology and associated conditions of the five RCTs reviewed are summarized in Table 1.

Herrlin *et al*[6,7] reported 96 patients with medial meniscal tears and Ahlback grade 0-1 osteoarthritis (comparable to Kellgren-Lawrence grade 0-2) between the ages of 45-64 followed for 5 years. The primary outcome was the change in knee injury and osteoarthritis outcome (KOOS) scores at 6-mo follow-up. Forty-seven were randomized to APM and exercise; 49 were randomized to exercise therapy alone. Thirteen/forty-nine (27%) of patients managed by exercise therapy were ultimately treated by APM. ITT analysis showed a 9-point difference on the KOOS Pain scale compared to baseline favoring APM, which was not statistically significant. Forty-two/forty-seven (89%) of operative group met the definition for treatment

Table 1 Characteristics of included studies

Ref.	Meniscal pathology	Associated osteoarthritis	Operative group treatment	Non-operative group treatment
Herrlin *et al*[6,7]	Medial meniscal tear	Ahlback grades 0-1	Exercise + APM	Exercise
Katz *et al*[8]	Meniscal tear	Kellgren-Lawrence grades 0-3	Exercise + APM	Exercise
Yim *et al*[10]	Horizontal medial meniscal tear	Kellgren-Lawrence grades 0-1	APM	Strength exercises
Sihvonen *et al*[9]	Meniscal tear	Kellgren-Lawrence grades 0-1	APM	Sham surgery
Gauffin *et al*[18]	Meniscal tear	Kellgren-Lawrence grades 0-2	Exercise + APM	Exercise

APM: Arthroscopic partial meniscectomy.

success compared to 34/49 (69%) of non-operative group (P = 0.023) (personal communication, May 18, 2015). The study had significant strengths including a homogeneous population and well standardized surgical and physical therapy protocols. However, the APM cohort had significantly poorer baseline characteristics, leading to possible selection bias. The study also experienced low enrollment of eligible patients (80/177, or 55%), high crossover rate, and was non-blinded.

Katz *et al*[8,16] followed for 12 mo 351 patients with meniscal tears and concomitant osteoarthritis of grades 0-3 by Kellgren-Lawrence criteria aged 45 years or older. The primary outcome was the change in the Western Ontario and McMaster Osteoarthritis Index (WOMAC) scores at 6-mo follow-up. One hundred and seventy-four were assigned to APM and physical therapy; 177 were assigned to physical therapy alone. 51/177 (29%) and 59/177 (33%) of patients initially managed by physical therapy underwent APM by 6 mo and 12 mo, respectively. ITT analysis showed a 2.4-point difference in on the WOMAC score compared to baseline favoring APM, which was not statistically significant. However, as noted in the original paper, a greater proportion of APM patients had successful treatment outcomes than that of physical therapy patients (108/161, or 67.1% *vs* 74/169, or 43.8%, P < 0.0001). This was a landmark study with a strong study design and large cohort size. However, this study suffers from low enrollment rate (351/1330, or 26%), inconsistent referral patterns from participating surgeons, and lack of blinding, leading to potential selection and detection biases. High crossover rate and large variability in the percentage of crossovers among participating centers (range 0%-60%) question protocol adherence and suggest potential performance and transfer biases.

Yim *et al*[10] reported 102 patients aged 43-62 years with degenerative horizontal tears of the posterior horn of the medial meniscus with OA of grades 0-1 by Kellgren-Lawrence criteria followed for 24 mo. The primary outcome was by Lysholm scores at 2 years follow-up. Fifty patients were treated with APM and strengthening exercises; 52 were treated with strengthening exercises alone. Only 1/52 (2%) of patients assigned to nonoperative management crossed over to surgery. The results as analyzed in the original report showed no difference in the Lysholm scores between the two groups at 2 years follow-up. Forty-five/fifty (90%) of surgical patients met the definition for treatment success compared to 48/52 (92%) of non-surgical patients (P = 0.739) (personal communication, June 27, 2015). The strengths of this study include low loss to follow-up rate (2/108, or 2%), low crossover rate (1/52, or 2%), and relatively long follow-up period. Its weaknesses include: disproportionately large female study population (81/102, or 79.4%); sample size falling just short of the 54 patients per group required for 80% power; and low enrollment rate (108/162, or 66.7%). Finally, Lysholm scores are best suited for measuring outcomes after ligament surgery and may not have sufficient validity, sensitivity, and reliability for assessing degenerative tears of the meniscus[22].

Sihvonen *et al*[9] reported 146 patients aged 35-65 years with degenerative meniscal tears with OA of grades 0-1 by Kellgren-Lawrence criteria followed for 12 mo. The primary outcome measures were changes in the Lysholm and Western Ontario Meniscal Evaluation Tool (WOMET) scores at 12 mo post-op. Seventy patients were treated with APM; 76 underwent sham surgery. Five/seventy-six (6.6%) of patients assigned to sham surgery were ultimately treated with APM (4 patients) or high tibial osteotomy (1 patient). Two/seventy (2.9%) of patients assigned to APM were ultimately treated with additional arthroscopy (1 patient) or total knee replacement (1 patient). The results as analyzed in the report showed no differences in the changes in WOMET and Lysholm scores at 12 mo compared to baseline. A priori and post-hoc subgroup analyses did not show between-group differences. Forty-nine/seventy (70%) of the APM cohort met the definition for treatment success compared to 51/76 (67.1%) of the exercise cohort (P = 0.725) (personal communication, May 11, 2015). This study had many strengths, including its rigorous double-blinded, sham-controlled design, low loss to follow-up and crossover rates, and high enrollment rate (146/205, or 71.2%). This study's weakness is its relatively narrow generalizability, having included only nontraumatic degenerative medial meniscal tears with no or very mild OA.

Gauffin *et al*[18] reported 150 patients aged 45-64 years with minimum 3 mo of meniscal symptoms and OA of grades 0-2 by Kellgren-Lawrence criteria, who had undergone 3 mo of prior physiotherapy, followed for 12 mo. The primary outcome measure was the change in KOOS Pain scores at 12 mo compared to baseline. Seventy-five patients were treated with arthroscopic surgery, and 75 patients were treated

by 3 mo of physical exercises alone. Sixteen/seventy-five (21.3%) of patients assigned to physical therapy ultimately underwent surgery, whereas 9/75 (12%) originally assigned to surgery only completed physical exercises. This is the first RCT to report superiority of surgical management to physical therapy, by both ITT and as-treated analyses. In ITT analysis, the between-group difference in the changes in KOOS Pain scores from baseline was both statistically and clinically significant (10.6 points, $P = 0.004$). As-treated analysis accentuated this difference to 13.9 points ($P < 0.001$). However, the surgery group had more females and poorer baseline KOOS scores than the non-surgery group - a breakdown of randomization. Sixty-two/seventy-four (84%) of the surgical patients, whereas 36/56 (64%) of the non-surgical patients, met the definition for treatment success ($P = 0.010$). This study's strengths include a high enrollment rate (150/179, or 83.8%), relatively long planned follow-up period of 3 years. The study's weaknesses include heterogeneity in the surgeries performed, poor compliance to physiotherapy, and high loss to follow-up rate (20/150, or 13.3%) and crossover.

DISCUSSION

While RCTs are the best way to minimize bias in clinical trials, there are nonetheless opportunities for bias within the structure of an RCT and the use of this study design in itself does not ensure either internally or externally valid data[12]. Analysis of five RCTs reveals that they were excellent attempts to compare APM with non-surgical treatment but all suffered from potential inadvertent biases that reduce confidence in their conclusions.

Selection bias was the most frequently encountered bias in the five RCTs. This was often due to a low enrollment rate from the patients' explicit preference for one treatment option to the other. Two studies suffered from unequal baseline characteristics between the surgical and non-surgical arms despite randomization. Performance bias was observed when intraoperative procedures and/or physiotherapy protocols were not standardized or determined a priori. Variability in supplemental therapy, such as unspecified use of non-steroidal anti-inflammatory drugs, and inconsistency among different participating medical centers can also lead to performance bias. Detection bias was also common, as only one RCT employed the double-blind methodology. We acknowledge that double blinding in surgical trials is challenging. However, a placebo effect may account for a significant part of response to surgery - up to 35% in some trials[23,24] - and therefore needs to be addressed[25]. Placebo also contributes to the effect of physical therapy and may need to be controlled[26,27]. Lastly, transfer bias occurs when there is a significant proportion of patients lost to follow-up or crossing over to the opposite study arm. One RCT had a high loss to follow-up rate, and three RCTs suffered from high crossover rates.

The American Academy of Orthopedic Surgeons has recommended using the MCID to evaluate the clinical significance of treatment outcomes[28]. The MCID is the smallest change in an outcome score that corresponds to a change in a patient's condition and thereby derives its clinical relevance. The MCIDs of two of the patient report outcome measures used in these studies, the WOMAC and the KOOS, have been determined to be 9-12 points and 8-10 points respectively[22]. We analyzed each study according to the number of patients in each group reaching this clinically meaningful end point.

Using the definition of treatment success suggested by Katz *et al*[8], which occurs when the improvement in a patient's outcome score is greater than or equal to the MCID without crossing over or requiring additional procedures, and the data reported in the original papers or communicated to us directly by the authors, we compared the percentage of patients meeting the definition of treatment success in each group for statistical significance. Two RCTs had significantly more patients treated successfully with APM, although their original ITT analyses showed no between-group differences. By this analysis method, three RCTs favor APM and two RCTs show no difference (Table 2).

ITT analysis remains the current gold standard for data analysis in RCTs. It has the advantages of preserving randomization and minimizing false positive (type Ⅰ) errors; however, in the setting of high cross over rates, the ITT analysis does not reflect the treatment actually received and, therefore, may not accurately reflect the efficacy of treatment, leading to false negative (type Ⅱ) errors[29,30]. The risk for a type Ⅱ error is especially high when there is a significant number of patients who perform poorly with one treatment method and then show rapid improvement after crossing over. Noncompliance with assigned therapy may also exaggerate this feature and lead the ITT analysis to underestimate the potential benefit of a treatment. Additional analyses may therefore be useful[31,32]. An "as treated" analysis is an alternative, but it has been criticized for compromising initial randomization. Our analysis of treatment success can be considered a form of "as treated" analysis as it separates those patients who remained in their originally assigned groups from those who did not. However, we acknowledge that this analysis is not a generic solution to the crossover problem.

CONCLUSION

This review sought to approach the question of efficacy of APM and non-operative management for meniscal tears by examining five important RCTs. Special attention was paid to inadvertent biases they may harbor despite their RCT design. Many potential biases were identified. An alternative analysis to the conventional ITT analysis was completed, which showed that the data from three RCTs favor APM while two others show

Table 2 Outcomes of analysis

Ref.	Potential bias	Results as reported	Crossovers *n* (%)	Treatment success by group
Herrlin *et al*[6,7]	Selection Detection Transfer	APM group showed 9-point greater improvement in KOOS pain scores (NS)	13/49 (27%) from PT to APM	APM - 42/47 (89%) PT - 34/49 (69%) (P = 0.023)
Katz *et al*[8]	Selection Performance Detection Transfer	APM group showed 2.4-point greater improvement in WOMAC scores (NS)	51/177 (29%) from PT to APM at 6 mo post-op	APM - 108/161 (67%) PT - 74/169 (44%) (P < 0.0001)
Yim *et al*[10]	Selection Detection	APM group showed 0.1-point greater improvement in Lysholm scores (NS)	1/52 (2%) from PT to APM	APM - 45/50 (90%) PT - 48/52 (92%) (P = 0.739)
Sihvonen *et al*[9]	Narrow generalizability	Sham surgery group showed 2.5-point greater improvement in WOMET scores (NS)	5/76 (6.6%) from sham to APM	APM - 49/70 (70%) Sham - 51/76 (67%) (P = 0.725)
Gauffin *et al*[18]	Performance Detection Transfer	APM group showed 10.6-point greater improvement on KOOS Pain scores (P = 0.004)	16/75 (21%) from PT to APM 9/75 (12%) from APM to PT	APM - 62/74 (84%) PT - 36/56 (64%) (P = 0.010)

APM: Arthroscopic partial meniscectomy; NS: Not statistically significant; KOOS: Knee injury and osteoarthritis outcome; WOMAC: Western Ontario and McMaster Osteoarthritis Index; WOMET: Western Ontario Meniscal Evaluation Tool; PT: Physical therapy.

no difference between APM and non-operative management. Use of the RCT design in itself ensures neither internal nor external validity of study data. Crossovers remain a significant problem in surgical RCTs, but there are currently no suitable analytical methods that both preserve randomization and minimize type Ⅱ errors. With the studies available at present, no conclusion can be drawn concerning the optimal treatment modality for meniscal tears. Further work on sub-group analysis and cost-benefit analysis may clarify therapeutic indications.

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MINIREVIEWS

Resection and reconstruction of pelvic and extremity soft tissue sarcomas with major vascular involvement: Current concepts

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Abstract

Soft tissue sarcoma accounts for approximately 1% of all cancers diagnosed annually in the United States. When these rare malignant mesodermal tumours arise in the pelvis and extremities, they may potentially encase or invade large calibre vascular structures. This presents a major challenge in terms of safe excision while also leaving acceptable surgical margins. In recent times, the trend has been towards limb salvage with vascular reconstruction in preference to amputation. Newer orthopaedic and vascular reconstructive techniques including both synthetic and autogenous graft reconstruction have made complex limb-salvage surgery feasible. Despite this, limb-salvage surgery with concomitant vascular reconstruction remains associated with higher rates of post-operative complications including infection and amputation. In this review we describe the initial presentation and investigation of patients presenting with soft tissue sarcomas in the pelvis and extremities, which involve vascular structures. We further discuss the key surgical reconstructive principles and techniques available for the management of these complex tumours, drawn from our institution's experience as a national tertiary referral sarcoma service.

Key words: Sarcoma; Extremities; Vascular surgical procedures; Limb salvage; Reconstruction

Core tip: This paper describes the investigation and management of patients presenting with a complex soft tissue pelvic and extremity sarcomas that also

compromise local vascular structures. The principles of surgical management of these cases are described in light of the most recent evidence, with examples drawn from our experience to illustrate these principles. We emphasize the importance of a multidisciplinary approach in the care of this complex patient cohort.

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INTRODUCTION

Soft tissue sarcomas are rare malignant tumours that are invariably fatal if not treated aggressively. Surgical excision of these lesions offers the only hope of potential cure. Sarcomas located in the pelvis and extremities may potentially encase or invade large caliber vascular structures. This presents the orthopaedic surgeon with a major challenge in balancing safe excision while still maintaining acceptable surgical margins. Moreover, involvement of major vascular structures was historically assumed to carry grave prognosis, since it was thought the vessels would provide a route of haematogenous spread of the tumour[1]. It was for this reason that early, more conservative attempts at limb preservation surgery, which frequently left inadequate margins, invariably resulted in unacceptably high rates of local recurrence.

The philosophical turning point in the management of these complex cases came with a report by Fortner *et al*[2] describing the earliest initial series of *en bloc* resection of tumour with involved vascular structures. Although preservation of the limb was achieved, high rates of post-operative oedema were observed in patients where no vascular reconstruction was performed. Improved rates of oedema and function were observed in the subsequent three patients who underwent concomitant arterial reconstruction at the time of tumour resection by the same author.

Unsurprisingly given the nature and relative rarity of these aggressive tumours, no large randomized control trials investigating optimal treatment strategies have been reported in the literature. Issues surrounding the role of venous reconstruction, the choice of autologous *vs* synthetic graft, and appropriate anticoagulation have meant controversy remains concerning optimal treatment of this complex patient cohort. Despite this, technical advances in the fields of both orthopaedic and vascular surgery have resulted in a trend towards aggressive limb salvage with vascular reconstruction in preference to amputation. The addition of both pre- and post-operative radiotherapy and chemotherapy has resulted in a truly multimodal treatment strategy for these complex cases.

The primary focus of this review will be to discuss the broad principles concerning the appropriate investigation and treatment of these complex tumours, with illustrative cases drawn from our institution's experience as a national tertiary referral center for sarcoma in Ireland. Particular attention will be paid to the strategy for management of the vascular component of these difficult resections.

EPIDEMIOLOGY AND PREVALENCE

Soft tissue sarcomas represent a heterogenous group of rare malignant tumours of mesenchymal origin with an estimated 9000 new cases diagnosed each year in the United States[3]. Currently, more than 50 histological subtypes of soft tissue sarcoma have been characterized. More than half (59%) of these tumours are found in the extremities, although they may be found anywhere in the body[4]. Despite improved treatment strategies, the overall survival rate for all stages of soft tissue sarcoma remains relatively disappointing at a level between 50% and 60%[4]. Reports in the literature suggest involvement of adjacent blood vessels in approximately 5% of cases, although Schwarzbach *et al*[5] report an incidence of 10%[5,6].

INVESTIGATION

Clinical examination of the patient on initial presentation will often elicit the possibility of vascular involvement of a sarcomatous lesion. Reduced or absent palpable arterial pulsation distal to the level of a mass should raise concern in the clinician's mind about vascular compromise.

Magnetic resonance imaging (MRI) has now become the gold standard of work-up for soft tissue sarcoma and should be performed to evaluate any suspicious lesions. However, colour duplex sonography, computed tomography (CT) and formal angiography have all been reported modalities used in the diagnosis of a soft tissue sarcoma invading vascular structures[5,7-9]. The addition of radiographic contrast to the study helps delineate vascular structures. The location of the mass, its depth in relation to fascia, heterogeneity and signal characteristics should be determined. More specifically, the relationship of the lesion to adjacent blood vessels, and other important structures, must carefully be considered. Vascular involvement may be diagnosed when MRI or CT demonstrates absence of normal tissue in the tumour-to-vessel plane[5]. MRI and magnetic resonance imaging angiography (MRA) can be useful in guiding the surgeon as to the length of vessel that is likely to be resected, as well as identifying potential donor vessels for reconstruction. Pre-operatively, lower limb venous duplex and vein marking of the contralateral limb may also be useful to map patent vein graft available for harvest at the time of resection.

All of these factors should be weighed-up by the

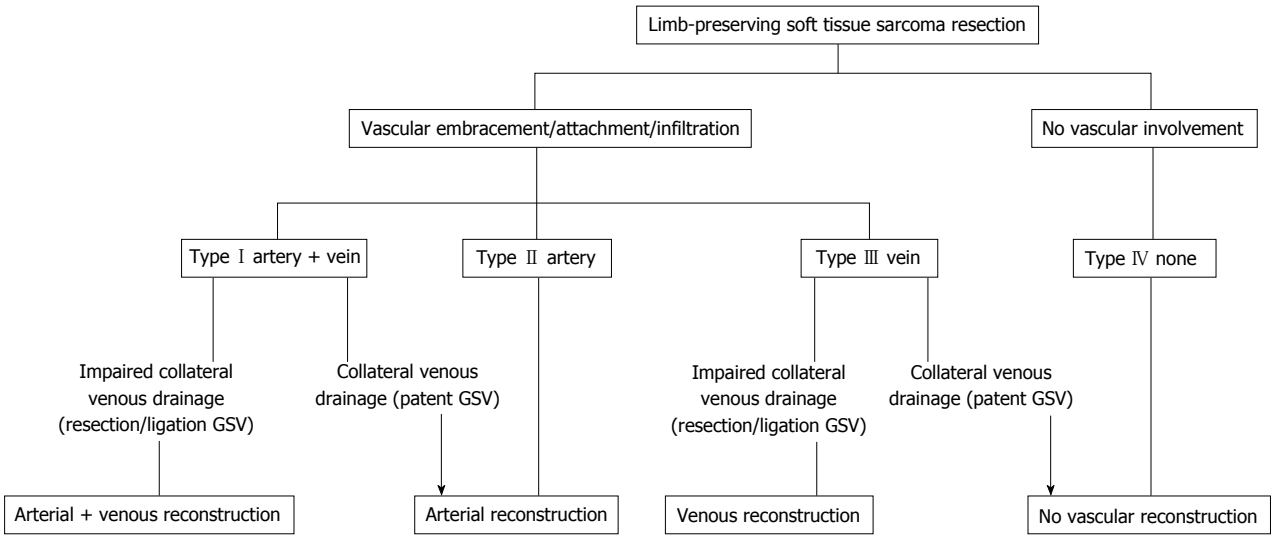

Figure 1 Types of vascular involvement by soft tissue sarcomas of the extremity and algorithm for reconstructive options (adapted from, with permission of Elsevier from Schwarzbach *et al*[5]). GSV: Great saphenous vein.

operating surgeon in planning any proposed attempt at surgical resection. Involvement of a vascular surgeon at this point, where there exists the possibility of major vessel reconstruction, is crucial.

CLASSIFICATION OF VASCULAR INVOLVEMENT

Schwarzbach *et al*[5] have classified the pattern of vascular involvement, which may be useful in guiding surgical management (Figure 1). Type Ⅰ soft tissue sarcomas involve both major arteries and veins, while Type Ⅱ lesions involve the artery in isolation. Type Ⅲ lesions were characterized as those with purely venous involvement, leaving an intact artery. Type Ⅳ lesions have no involvement of either artery or vein, and require no vascular reconstruction.

In cases of type Ⅰ involvement, Schwarzbach *et al*[5] propose both arterial and venous reconstruction where there is impaired collateral venous drainage. In type Ⅰ cases with adequate venous drainage, arterial reconstruction alone may be sufficient.

In type Ⅱ cases, the artery may be resected, and reconstructed using either venous autograft or alternatively prosthetic material, depending on surgeon preference and available autogenous graft. Some authors have advocated the use of isolated limb perfusion in these cases[10,11]. The rationale for this is to isolate the limb from circulation to facilitate direct administration of high dose cytotoxic agents, with the aim of down-staging the tumour, and ultimately preserving the native vascular structures. The role of this modality of treatment, however, remains controversial.

In type Ⅲ cases, venous reconstruction has been advocated where there is impaired venous drainage. If sufficient venous drainage does exist, then type Ⅲ cases may be treated as type Ⅳ cases, with resection of the lesion alone.

GENERAL PRINCIPLES OF SURGICAL TECHNIQUE

A number of general principles governing resection of these complex lesions may be elicited from the literature. A multidisciplinary team should be considered mandatory for successful limb salvage in these cases. This involves not only the orthopaedic and vascular surgeons but also allied health professionals including physiotherapists, dieticians and occupational therapists. Resections should only be performed in a specialized tertiary-level institution with both orthopaedic and vascular surgical services familiar with the management of complex soft tissue sarcomas. Radiological and theatre departments should have angiographic capabilities on site. Additionally, plastic and reconstructive surgery may be necessitated by the nature and size of tissue resected, and thus access to this specialty should be easily available if required.

The required volume of tissue that the operating surgeon must resect to ensure an adequate and wide margin can be determined by the tissue surrounding the lesion. Fascia is considered impenetrable to tumour cells, and thus may act as a margin in its own right. However, skin, fat and muscle are easily penetrated and thus 2-3 cm of these tissues must be excised[12].

Difficulty arises when determining safe margins where major vessels are in the surgical field. Inevitably, a major vessel must be sacrificed if tumour originates within the lumen of the vessel itself[5]. Where tumour surrounds a vessel, or infiltrates its wall, resection of the vessel may also become necessary[5,13].

The adventitial layer of the vessel may be considered an acceptable margin. Some authors have advocated longitudinal division of the adventitia on the side oppo-

site to the tumour[5,14-16]. The layer is opened like a book, allowing the vessel to be mobilized and released. Moreover, patch-type reconstructions may be an option where tumour is in very limited contact with the vessel wall[12]. Cipriano *et al*[12] note that the pseudocapsule that typically surrounds soft tissue sarcomas should not be considered equivalent to fascia, and should be treated as a contaminated plane.

The initial strategy in these procedures is to mobilise the tumour, while controlling and preserving vascular structures proximal and distal to the lesion[15]. As with all tumour surgery, one of the primary goals is to prevent contamination of the surgical bed by tumour cells. For this reason, Matsumoto *et al*[17] introduced the concept of complete isolation of the tumour mass once mobilized using a vinyl sheet, drape or gauze. Attention must then turn to the careful dissection of adjacent or involved vascular structures.

Ischaemic time of the limb must be a consideration throughout the procedure. Vessel clamping and division should be performed just prior to complete excision of the tumour. Baxter *et al*[18] suggest the administration of 50 units/kg of heparin 5 min prior to the application of clamps. Emori *et al*[8] administered 1 mg/kg of heparin immediately prior to clamping. In their series, Muramatsu *et al*[19] preferred the administration of 2000-5000 U of intravenous heparin immediately following vascular anastomosis. Following complete division of the vessels and final excision of the tumour mass, arterial and venous shunts may also be placed to reduce ischaemic time. The routine lowering of ambient room temperature in the operating theatre at the time of vascular reconstruction has also been reported[19].

Once the tumour mass has been excised, with control of compromised vessels, attention must then turn to vascular reconstruction. A number of vascular reconstructive options are available to the surgeon, and the choice of specific graft depends on the length and caliber of vessel required, the availability of suitable venous graft in the contralateral limb, and surgeon experience and preference. Options variously described in the literature include contralateral superficial femoral vein graft, reversed long saphenous vein graft, or synthetic grafts such as polytetrafluoroethylene or polyethylene terephthalate[5,7,8,15,18-22].

Routinely patients should receive prophylactic antibiotic treatment, and a closed suction drain may also be placed at time of closure. In the post-operative setting, follow-up should be as standard for soft tissue sarcoma resections. However, additionally the patency of vascular anastomoses should be followed at regular intervals.

CONTROVERSIES IN MANAGEMENT

It should be noted that while limb salvage is possible, the precise manner in which this is achieved has been variously described. Given the nature of the pathology, large randomized control trials would be both difficult to construct and ethically inappropriate. As such, there is some controversy in the literature regarding some aspects of treatment of this patient cohort. In particular, the optimal choice of substitute vessel graft is not well established, and whether venous reconstruction is necessary also remains unclear.

Arterial reconstruction following resection is clearly indicated since the limb is unlikely to survive due to the high risk of ischaemia. Evidence in the literature favouring similarly aggressive venous reconstruction is less robust. Fortner *et al*[2] and Imparato *et al*[23] report some of the earliest experiences of venous reconstruction. In general terms, however, reports of venous reconstruction in the literature are less frequently encountered. Moreover, in those reports where venous reconstruction was performed, follow-up data is occasionally absent and difficult to interpret[6,23,24].

Patients undergoing venous resection without reconstruction have been observed to experience post-operative oedema, discoloration of the limb and venous eczema[22,25]. Some authors have described successful management of oedema through use of simple elevation and elastic support[6,23]. Additionally, it has been argued that limb oedema may be more reflective of lymphatic disruption than venous deficiency[26]. Furthermore, both Tsukushi *et al*[27] and Adelani *et al*[28] have found no reduction in post-operative oedema when venous reconstruction was performed.

Despite these observations, a majority of reports describe attempts made by surgeons to reconstruct the venous system in every case, or at least in those cases where sufficient concern exists for collateral flow[5,7,8,18,19,21]. It may well be that the rate of post-operative oedema correlates closely with the degree of disruption of venous collaterals at the time of surgical resection.

Concerning the specific choice of material for vascular reconstructions, there appears to be no clear evidence supporting one material over another. Both autologous vein and prosthetic material have been used successfully (Table 1). Some authors have preferred the use of autologous material in preference to prosthetic graft[5,22,29].

The great saphenous vein remains a common and popular choice of graft for both arterial and venous reconstructions. Its length and diameter is generally amenable to use as a vascular conduit, and it is easily accessible for harvest at the time of operation. Further, saphenous vein graft has been reported to afford superior patency rates at four years when compared with prosthetic graft (68% *vs* 38%)[30]. There is not universal agreement on this point, and other reports suggest that there is no superior advantage to autologous graft over synthetic graft in terms of patency in the longer term[2,23,31].

Against these observations, it has been argued that saphenous graft may be of inadequate length for reconstructive purposes, and harvest carries additional

Table 1 Venous grafts and patency rates

Ref.	Number (*n*)	Graft material (*n*)	Patency
Imparato *et al*[23]	3	Saphenous	
Nambisan *et al*[35]	6	PTFE	33%
Steed *et al*[36]	1	Saphenous	
Karakousis *et al*[37]	9	PTFE	0%
Kawai *et al*[26]	7	PTFE (5), saphenous (2)	14%
Koperna *et al*[29]	13	Saphenous (8), PTFE (4), PETE (1)	77%
Karakousis *et al*[6]	15	PTFE (14), saphenous (1)	
Hohenberger *et al*[13]	10	Saphenous (6), PTFE (4)	72%
Bonardelli *et al*[14]	5	Saphenous (3), transposition (2)	100%
Leggon *et al*[24]	8	Saphenous (5), femoral (2), PETE (1)	
Schwarzbach *et al*[5]	12	PTFE (10), saphenous (2)	58%
Nishinari *et al*[22]	17	Saphenous (12), PTFE (3), PETE (2)	82%
Song *et al*[21]	9	Saphenous (4), femoral vein (2), Allograft (3)	78%
López-Anglada Fernández *et al*[15]	1	PTFE (1)	100%
Muramatsu *et al*[19]	12	Saphenous (10), PTFE (2)	
Emori *et al*[8]	9	PTFE (9)	
Viñals Viñals *et al*[38]	1	Saphenous (1)	100%
Umezawa *et al*[7]	13	Saphenous (13)	

PTFE: Polytetrafluoroethylene; PETE: Polyethylene terephthalate.

morbidity in terms of longer operative time, and additional surgical exposure and wounds. Regardless of the material chosen, it should be of sufficient length and caliber to appropriately and securely reconstruct the resected vessel.

POST-OPERATIVE FUNCTION

Limb salvage surgery should seek to leave the patient with a limb which functions superiorly when compared with amputation and prosthetic replacement. This should not be at the expense of oncological outcome[12]. The literature has relatively few reports concerning the functional outcomes of those patients undergoing limb-salvage surgery with concomitant vascular reconstruction. In one report of pooled data, 76% of a cohort of 58 patients for whom functional outcome measures were available reported having a "functional limb"[24].

Wound complications, tumour size and motor nerve sacrifice have been identified as determinants of overall functional outcome after limb-salvage surgery and radiotherapy for soft tissue sarcoma[32,33]. Ghert *et al*[20] matched each of a cohort of patients undergoing limb salvage and vascular reconstruction with two other patients not undergoing vascular reconstruction, on the basis of tumour size, wound complications and pre-operative toronto extremity salvage score (TESS) score. The TESS score is a functional measure of physical disability, specifically designed for patients with extremity sarcoma[34]. At one year post-operatively, those patients undergoing vascular reconstruction had only slightly lower post-operative TESS scores.

Schwarzbach *et al*[5] found that of nine patients interviewed regarding limb function, five reported their outcome as excellent, three felt their outcome was good, while one patient reported a poor outcome due to contracture.

SURVIVAL AND RECURRENCE

It is possible to obtain reasonably good survival rates with careful pre-operative planning and appropriate and timely intervention. Recurrence of tumour remains an issue however. Schwarzbach *et al*[5] report recurrence in 15.8% (n = 3) of 19 patients in their study. A slightly higher figure of 21% has been reported by Song *et al*[21].

Two-year survival has been variously reported in the literature, ranging from 58.6% to 70.4%[5,8,22]. At five years post surgery, approximately one in two patients will have died from their disease, with reported figures ranging from 42.4% to 70%[5,8,21,22].

ILLUSTRATIVE CASES

Case 1

A 73-year-old woman presented with a high grade, stage Ⅲ leiomyosarcoma in her left inguinal region. The lesion was present for approximately one year prior to presentation and measured 11 centimeters in maximum diameter. CT and MRI demonstrated a large tumour mass invading the left common femoral vein, and surrounded the anterior aspect of the common femoral artery for greater than 180 degrees of the vessel surface. The tumour mass was intimately related to adjacent vessels and was found to interdigitate the common femoral bifurcation (Figure 2). The lesion was resected *en-bloc* with concomitant vascular reconstruction (Figure 3). Arterial reconstruction involved an end-to-end anastomosis from the external iliac artery to superficial femoral artery using an 8-milimetre Gortex synthetic graft. The contralateral long saphenous vein was harvested for venous reconstruction. An end-to-end anastomosis between the superficial femoral vein and external iliac vein was performed.

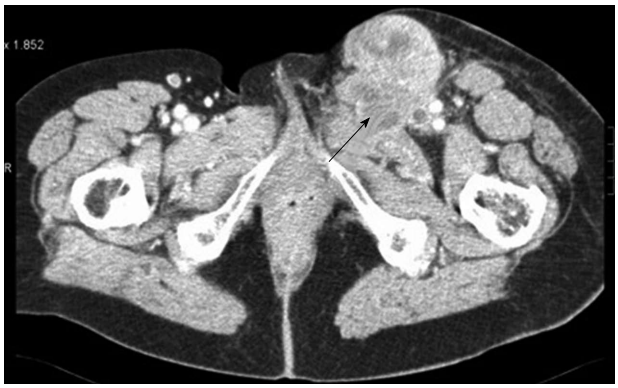

Figure 2 Axial cut computed tomography angiogram demonstrating proximity of a soft tissue sarcoma to the adjacent femoral vessels (arrow).

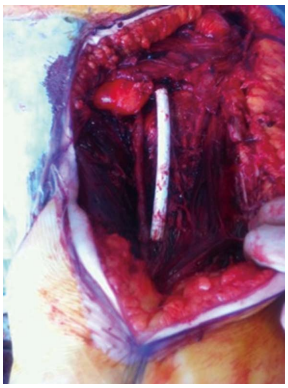

Figure 3 Completed vascular reconstruction following excision of lesion.

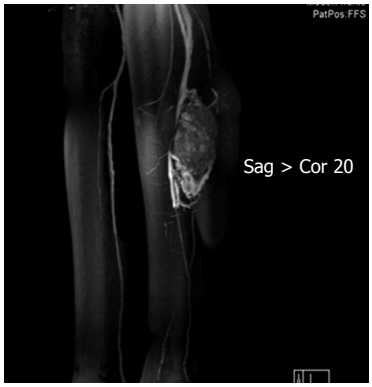

Figure 4 Antero-lateral projection of reconstructed magnetic resonance angiogram of left proximal calf demonstrating the tumour mass in relation to adjacent vascular structures.

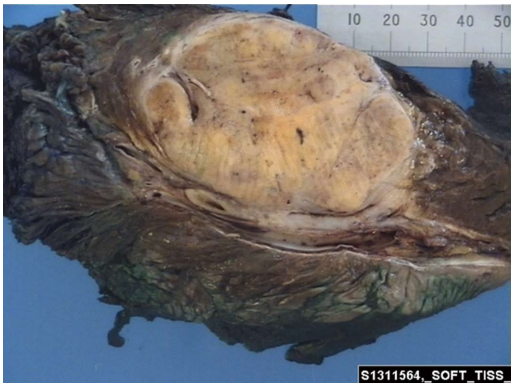

Figure 5 Histopathological specimen of tumour adjacent to vessel.

Post-operatively, the patient's wound healed without complication. In view of the necessary vascular reconstruction, anti-coagulation with warfarin was commenced. At one month post-operatively however, she required ileo-femoral-popliteal thrombectomy for graft thrombosis. The patient completed a course of adjuvant radiotherapy to the tumour bed (66 Gy in 33 fractions).

Case 2

A 16-year-old young woman presented to clinic with a 5-year history of progressive swelling in her left calf. Multi-modality investigations including CT angiogram, MRI and MRA, and tissue biopsy confirmed a 4.2 cm × 5.6 cm × 7.2 cm hypervascular and heterogenous mass, with features of central necrosis, in the posterior compartment of the upper calf (Figure 4). The tumour mass was found to lie in the neurovascular plain, with multiple vessels feeding from the peroneal and posterior tibial arteries. The anterior tibial artery was uninvolved. Microscopy confirmed an alveolar soft part sarcoma.

The surgical strategy involved pre-operative embolization of the feeder vessels as described. The following day, the tumour mass was resected *en-bloc* with concomitant vascular reconstruction. Popliteal and anterior tibial vessels were preserved. Peroneal and posterior tibial vessels were resected with tumour. The posterior tibial artery was revascularized from approximately 5 cm beyond its origin mid-calf using a reversed long saphenous vein graft harvested from the contralateral leg. Anastomosis was performed in an end-to-end fashion.

At the time of diagnosis, the patient was found to have lung metastases. She underwent adjuvant chemotherapy and radiotherapy to both lungs (19.5 Gy in 13 fractions) and to the tumour bed (50.4 Gy in 28 fractions). At 48 mo follow-up, the patient was well without further complications.

Case 3

A 56-year-old man presented with a 2-mo history of painless swelling in the right popliteal fossa. He had a history of having lentigo maligna excised from his ear some 5 mo earlier, but was otherwise healthy. MRI and MRA revealed a large soft tissue mass in the superior popliteal fossa measuring 8.5 cm × 7.8 cm × 4.5 cm in dimension. The tumour encased the popliteal artery for at least 270 degrees of its circumference over a distance of 8 cm (Figure 5). Subsequent biopsy revealed grade Ⅱ stage Ⅰ B leiomyosarcoma.

The patient received pre-operative radiotherapy (50 Gy in 25 fractions) before definitive surgical resection. Arterial reconstruction required reverse long saphenous vein graft with end-to-end anastomosis. Venous recon-

struction was not necessary. Post-operatively, there were no major vascular complications.

CONCLUSION

Patients presenting with soft tissue sarcomas that involve major vascular structures represent a unique and complex cohort of patients. Advances in both orthopaedic and vascular surgery have made it possible to successfully resect these lesions and achieve limb-salvage while also maintaining reasonable function. A multidisciplinary approach with careful pre-operative evaluation is essential to improve outcome.

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Valgus osteotomy for nonunion and neglected neck of femur fractures

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Abstract

Nonunion neck of femur can be a difficult problem to treat, particularly in the young, and is associated with high complication rates of avascular necrosis due to the precarious blood supply and poor biomechanics. The various treatment options that have been described can be broadly divided according to the aim of improving either biology or biomechanics. Surgeries aimed at improving the biology, such as vascularized fibula grafting, have good success rates but require high levels of expertise and substantial resources. A popular surgical treatment aimed at improving the biomechanics-valgus intertrochanteric osteotomy-optimizes conditions for fracture healing by converting shear forces across the fracture site into compressive forces. Numerous variations of this surgical procedure have been developed and successfully applied in clinical practice. As a result, the proximal femoral orientation for obtaining a good functional outcome has evolved over the years, and the present concept of altering the proximal femoral anatomy as little as possible has arisen. This technical objective supports attaining union as well as a good functional outcome, since excessive valgus can lead to increased joint reaction forces. This review summarizes the historical and current literature on valgus intertrochanteric osteotomy treatment of nonunion neck of femur, with a focus on factors predictive of good functional outcome and potential pitfalls to be avoided as well as controversies surrounding this procedure.

Key words: Neck of femur; Valgus intertrochanteric osteotomy; Head shaft angle; Neck resorption ratio; Nonunion

Core tip: Valgus intertrochanteric osteotomy is a viable treatment option for nonunion neck of femur. Size of the proximal fragment appears to be a significant predictive factor of fracture union. While valgus orientation of the proximal femur is important for fracture union, excessive valgus can lead to a poor functional outcome. The neck resorption ratio may be useful for measuring the proximal fragment and the head shaft angle may be

useful for studying proximal femoral alignment in the presence of neck resorption.

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INTRODUCTION

Nonunion neck of femur (NOF) fracture remains a significant challenge to treating orthopedists in the 21st century. Indeed, some studies have shown the nonunion rate to be as high as 30%[1-3]. Nonunion following surgical fixation can result from initial fracture displacement, poor fracture reduction, or fixation in fractures with posterior comminution[4-6]. Neglected NOF fractures are more commonly seen in the developing world[7] and are associated with a particular profile of complications that includes osteopenia, resorption of neck, and avascular necrosis (AVN)[4-6]; unfortunately, these complications are also further detrimental to head salvage. The methods of treating nonunion aim either at improving the biology and bone stock (*i.e.,* non vascularized and vascularized bone grafts[7,8], muscle pedicle graft)[9] or improving the biomechanics (*i.e.,* valgus osteotomy)[10,11].

The concept of valgus osteotomy was refined by Pauwels[6] in 1927, according to his findings showing that nonunion NOF was due to the high shear forces that increased with the vertical orientation of the fracture. The proposed biomechanical solution was to redirect these forces into compression forces *via* an angulation osteotomy and fixation with a blade plate device. Valgus intertrochanteric osteotomy as described by Pauwels[6] and subsequently modified by Muller[12] is still in use today, and remains a popular treatment option as it has a high success rate and corrects the common symptoms of coxa vara and associated limb length discrepancy[11-14]. Marti *et al*[10] helped to popularize the valgus intertrochanteric osteotomy for nonunion NOF by reporting good outcome in a long-term follow-up study.

This review provides a summary of the historical and most up-to-date literature on the valgus intertrochanteric osteotomy for nonunion NOF, detailing the underlying philosophy and technical principles of the procedure and discussing its most common and potential complications, with the aim of helping practicing orthopedists to understand the most relevant concepts that may improve rates of good functional outcome.

OPERATIVE PROCEDURE

The operative procedure is a modification of the method described by Muller[12].

Step 1: Preoperative templating

Templating, performed on the normal hip, provides information for the position of the implant and size of the wedge (Figure 1A). The angle that the fracture line makes with the horizontal should be measured. The angle of wedge measured for removal in the intertrochanteric region is necessary to ensure the vertical fracture plane achieves a near-physiological orientation. However, this angle may be difficult to calculate in patients with long-standing nonunion and can only be confirmed when a closed reduction is obtained on the fracture table[14]. Another complicating factor is that the neck in these patients is often resorbed on the inferior and posterior aspect, which can cause retroversion when impacting the fracture during fixation.

Step 2: Reduction and stabilization

Closed reduction in case of nonunion or neglected fracture would be difficult and should be attempted on the fracture table. Excessive traction to attempt a closed reduction should be avoided as this may stretch and injure the retinaculum, which is less mobile because of surrounding scar tissue. In our experience, the proximal fragment will occasionally have an inferior spike that prevents reduction and requires osteotomization to achieve acceptable alignment. Open reduction should be attempted only if deemed essential as further dissection could damage the precarious blood supply to the femoral head. Once the reduction is maintained with K-wire, the fracture is stabilized with a screw plate or a blade plate device (Figure 1B).

Step 3: Osteotomy and fixation

A lateral closing wedge is taken from the intertrochanteric region, after which the osteotomy is closed by clamping the plate to the bone. While the calculated wedge may be as high as 40 degrees, most authors in the recent literature have reported that a wedge of 25-30 degrees is often sufficient to produce the desired effect[11,14,15]. Even in cases where an osteotomy is not required to obtain a valgus orientation, its advisable to do so as, this may help improve the blood supply to the femoral head. Compression across the fracture site can be achieved with a sliding hip screw, according to the intrinsic nature of the screw itself. However, when a double-angled blade plate device is applied, it is recommended that the length of the blade be 5-10 mm shorter than the measurement value. Firm impaction when inserting the blade plate helps to ensure that compression is obtained across the fracture site (Figure 1C and D). It is our opinion that this impaction is the most important factor in attaining union.

POTENTIAL PITFALLS

Excessive valgus orientation

Often the calculated angle to convert a Pauwels 3 to Pauwels 1 may be as high as 40-50 degrees. Removal

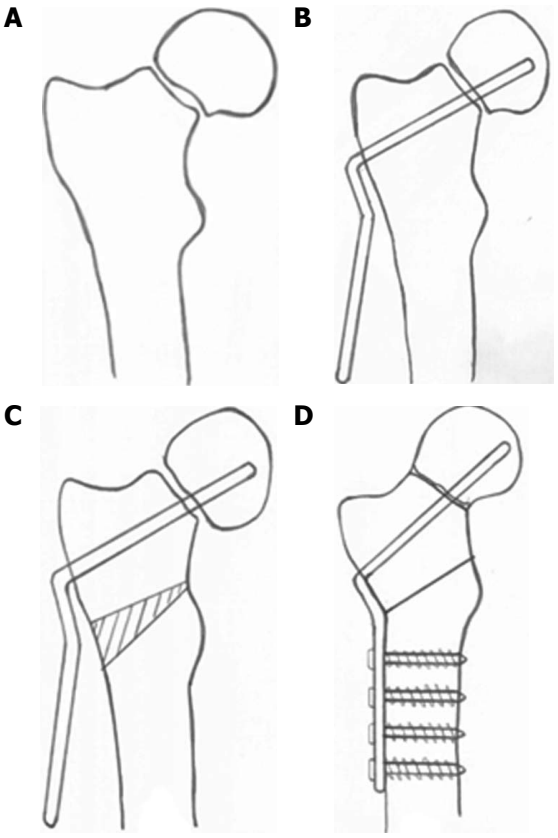

Figure 1 Diagram showing stages of valgus osteotomy. A: Closed reduction; B: Insertion of blade plate device; C: Excision of lateral wedge; D: Final correction after plate fixation.

of such a large wedge will cause the osteotomy to inevitably extend from the intertrochanteric region into the subtrochanteric, which may cause further distortion of the femoral anatomy and abduction as well as external rotation deformity[16]. In addition, valgus of > 30 degrees can compromise the blood supply and increase the risk of AVN[17]. Excessive valgus could also make a salvage total hip replacement extremely difficult.

Severely osteoporotic and short head fragments

These features complicate application of the fixation device, as they may not provide enough hold. Cases with these features should be treated with a replacement rather than a fixative device.

Too long or too short a blade length in a blade plate device

A too long blade length may hold the fracture site in distraction, while a too short blade length may not provide adequate hold in the proximal fragment. The 110 degree and 120 degree AO double angled blade plate is available at lengths of 65, 75 and 85 mm sizes. These lengths are sufficient for most patients. However it is our practice to keep an additional set of blade plates by cutting the blades in a lathe so that blade lengths of 55 mm upwards are available in 5 mm increments. This would take care of the occasional case where it maybe required. The correct blade length cannot be over emphasized as in our opinion the impaction obtained is the single most factor to achieve union.

Position of blade plate in the femoral head

Previous fixation devices can create bone defects in the femoral head. Position of the blade plate in the head should be therefore in the strongest portion of the bone. Care should be taken to be not too superior or anterior, in the femoral head as this can lead to a potential cutout.

CONTROVERSIES

Valgus osteotomies and total hip arthroplasty

The advantages of valgus osteotomy are manifold and include preserving bone stock and avoiding total hip arthroplasty (THA) in young patients. THA in young patients is associated with higher complication rates, such as prosthesis loosening and infection, as well as higher revision rates[18]. Though recent studies have shown increased survival rates in the young[19], head salvage remains the preferable treatment, especially in a patient population which routinely sits cross-legged or squats. Therefore, while THA is the option of choice in patients who are physiologically older, head salvage *via* a valgus osteotomy is preferred for the younger patient population (Figure 2).

When performing an uncemented hip arthroplasty for a failed valgus osteotomy, care should be taken with the entry point so as to avoid reaming a false passage. While broaching care should be taken to negotiate over the tracts cut by the previous implants where a bridge of bone tends to form. An uncemented stem should have a distal fit and extend distal to the previous screw holes. The trochanteric fragment may remain as a nonunion and may have to be separately reattached to the femur. If the proximal femoral anatomy is grossly altered, due to a subtrochanteric osteotomy, a corrective osteotomy may be required. When there is a defect of the posteromedial cortex, use of special modular or calcar replacing stems may be required[20].

If cemented arthroplasty is performed instead, care should be taken during cementation to pressurise the screw holes externally, as the cement can track out and cause devascularisation of the sandwiched bone. It is important to note that cemented THA has been shown to be successful in revising a failed valgus osteotomy. However they have been shown to have increased complication rates in terms of survival and infection rates as compared to primary total hip replacements[21,22].

AVN and valgus osteotomy

Though the presence of radiological AVN preoperatively is not a contraindication for head salvage, the reported post-valgus osteotomy AVN rates range from 10% to 40%[10,14,23]. Not all patients who develop AVN are symptomatic, and conversion rates to THA for treating

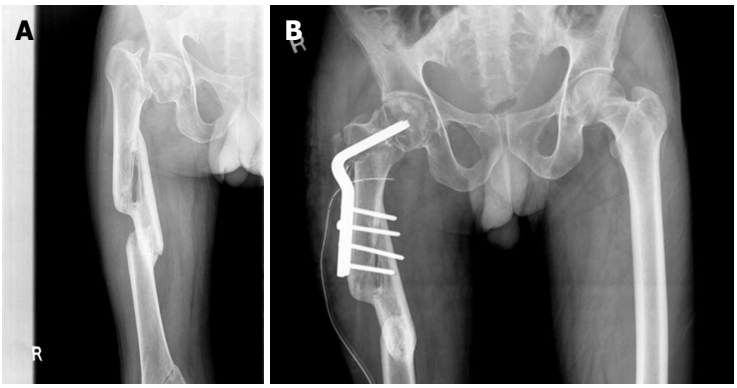

Figure 2 Problems with neglected fractures. A: Anteroposterior radiograph of pelvis of a 41-year-old male with a 3-mo-old nonunion neck of femur fracture and associated malunited femur fracture; B: At 4-year follow-up showing union, when the Harris hip score was 88.

post-valgus osteotomy AVN range from 5% to 10%[10,14]. For patients with the aim of hip salvage, assessing the vascularity of the head may only be of academic value. However, a report of a small series of patients with nonunion and documented AVN who underwent valgus osteotomy with vascularized fibular graft demonstrated that arrest of AVN was achieved in 3 out of the 5 patients[24].

Femoral neck shortening

Femoral neck shortening has been reported as associated with a poorer functional outcome in cases of acute NOF fractures[25]. As most nonunion NOF have resorbed necks, this may be a predictive factor for outcome; however, no such correlation has been shown in a series reported recently[14]. The intrinsic problem of nonunion femoral neck is the shortened neck fragment and, therefore, other options of head salvage, which can reconstruct the femoral neck length, may be effective[8,26].

Choice of implant

The 110 and 120 degree angled blade plate, the 95 degree angled blade plate, a bent 95 degree blade plate, the sliding hip screw device, and a modified prebent dynamic condylar screw device have all been used as fixation devices for this surgery[13,27-29]. However, surgeon's preference of implant remains largely subjective, as very little to no evidence from comparative, systematic analyses has been reported in the literature. Thus, the choice of implant may be based on the surgeon's familiarity, as long as the principles of implantation are adhered to.

PROGNOSTIC FACTORS AFFECTING OUTCOME

Evolution of philosophy

Most studies reporting valgus osteotomy emphasize union rates (Table 1) but are hampered by a lack of long-term follow-up and less than optimal functional outcome. Valgus intertrochanteric osteotomy primarily aims to convert shear forces. Earlier studies attempted to convert a Pauwels 3 to a Pauwels 1 and attained union but with excessive valgus.

Marti *et al*[10] and Raaymakers *et al*[27] have shown that excessive valgus is detrimental to function (Figure 3). A more recent study showed that > 15 degrees of excess valgus, compared to the normal hip, results in poorer functional outcome[14]. Thus, the philosophy has evolved over the years to promoting the reproduction of as normal a proximal femoral anatomy as possible (Figure 4). Imaging and radiographic analyses are complicated in cases presenting neck resorption; the recently-described head shaft angle measurement could be a useful tool for analyzing postoperative radiographs and prognosticating functional outcome.

It would be preferable to have clear indications and contraindications for attempting head salvage in patients with femoral neck nonunion. When considering union treatment, the size of the proximal fragment seems to be an important factor. However, measurement of the proximal fragment is a complicated issue. Sandhu *et al*[30] reported a study in which the patients were graded according to sizes of the proximal fragment and fracture gap; it was found that patients with a head size of < 2.5 cm had the worst outcome. This classification system has its own drawbacks[11]. Magu *et al*[31] showed that the absolute head volume size of 43 mm^3 or less, as measured by computed tomography scan, is associated with higher failure rates; however, the average volume of females in that series was 40.8 mm^3, emphasizing the need for further studies in this area.

As femoral head size varies with patient height, sex and ethnicity, a ratio may be a better index than absolute size. Hence, a simple radiographic measurement called the neck resorption ratio (NRR) may be useful[14]. The NRR is a measure of the remnant of the femoral head to the neck length on the sound side, and thus does not vary with traction or magnification of the plate X-ray and can be read on a simple anteroposterior pelvis radiograph. The three nonunion cases, which occurred in this study, were included in the group with an NRR of < 0.5. Thus, head salvage would be indicated in a physiologically young, active patient with sufficient bone

Table 1 Case series of valgus osteotomy for nonunion

Ref.	*n*	Average follow-up (yr)	Union rate, *n*/total (%)	AVN, *n*/total (%)	Implant	Functional outcome
Marti *et al*[10]	50	7.1	43/50 (86)	22/50 (44)	DABP	HHS: 91
Anglen *et al*[15]	13	2	13/13 (100)	2/13 (15)	DABP	HHS: 93
Wu *et al*[33]	32		32/32 (100)	2/32 (6)	SHS +/- (subtrochanteric osteotomy)	NA
Kalra *et al*[23] (neglected fractures)	22	2.5	20/22 (85)	2/22 (9)	DABP	75%; excellent to good results
Sringari *et al*[34]	20	2	18/20 (90)	Nil	DABP	NA
Magu *et al*[11]	48	6	44/48 (94)	2/48 (4)	DABP	HHS: 86.7
Khan *et al*[35]	16	2.5	14/16 (87)	Nil	SHS (120 degree plate)	HHS: 88
Said *et al*[29]	36	3.5	35/36 (97)	5/36 (13)	Angled blade plate (prebent 130 degree)	NA
Sen *et al*[26]	22	3.2	21/22 (91)	5/55 (22)	DABP + non-vasc fibula	66%; excellent to good results
Gadegone *et al*[7]	41	2.75	39/41 (95)	7/41 (17)	SHS (110-130 prebent plate + non-vasc fibula)	HHS: 90.9
Gavaskar *et al*[28]	11	1	11/11 (100)	Nil	SHS + subtrochanteric osteotomy, no wedge taken	Oxford score: 40
Gupta *et al*[36]	60	3.5	56/60 (93)	4/60 (6)	SHS (135 degree subtrochanteric osteotomy)	HHS: 87.5
Varghese *et al*[14]	32	5	29/32 (91)	13/32 (44)	DABP	HHS: 82

DABP: Double-angled blade plate; HHS: Harris hip score; NA: Not available; SHS: Sliding hip screw.

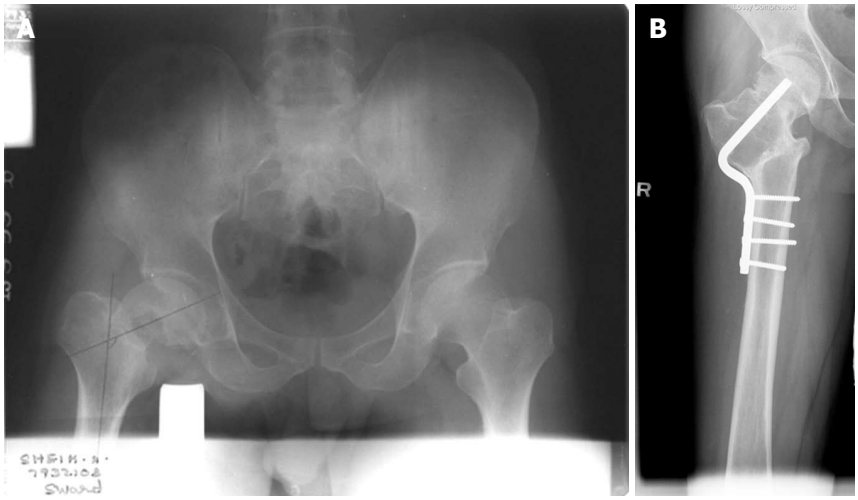

Figure 3 Problems with excess valgus. A: Anteroposterior radiograph of pelvis of a 33-year-old male with a 3-mo-old nonunion neck of femur fracture; B: At 10-year follow-up, showing excess valgus, when the Harris hip score was 68.

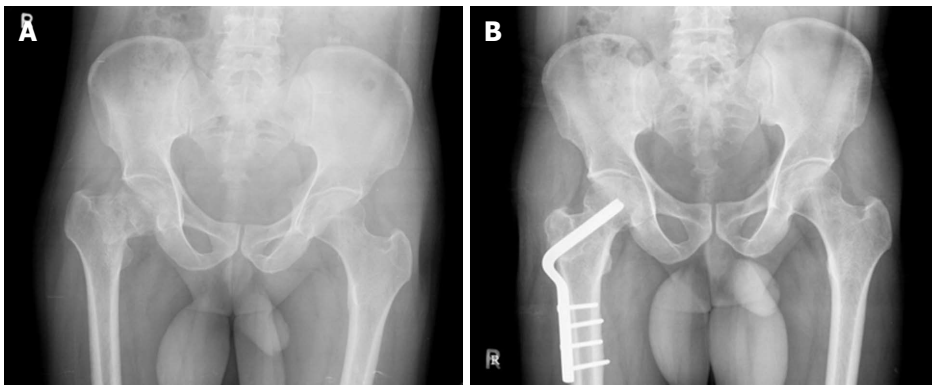

Figure 4 Ideal valgus correction. A: Anteroposterior radiograph of pelvis of a 45-year-old male with a 1-mo-old nonunion neck of femur fracture; B: At 5-year follow-up showing similar valgus orientation as the opposite hip, when the Harris hip score was 85.

stock and would be contraindicated in an older patient with an NRR of < 0.5.

CONCLUSION

There is a significant percentage of nonunion NOF in the young. Moreover in developing countries there is an additional problem of neglected fractures[32]. It would appear that nonunions are increasingly being treated with arthroplasty, even in the young, with an additional need for revision. In this group of patients the valgus osteotomy would remain a viable alternative, especially in places where social and religious activities require squatting and sitting cross legged. Valgus osteotomy remains a successful method of head salvage in cases of nonunion and neglected NOF fractures. Excessive valgus may impair the final functional outcome; in cases presenting with resorbed neck (> 50%), arthroplasty would be a better option.

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ORIGINAL ARTICLE

Prospective Study

From Cape Town to Cambridge: Orthopaedic trauma in contrasting environments

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Author contributions: Lawrence JE and Khanduja V contributed equally to this work; Lawrence JE gathered the data, performed data analysis and drafted the manuscript; Khanduja V devised the study, assisted with data analysis and edited the manuscript.

Institutional review board statement: This study was approved by both Addenbrooke's Hospital, Cambridge and New Somerset Hospital, Cape Town.

Informed consent statement: All patients gave verbal informed consent for their anonymised data to be used in this study.

Conflict-of-interest statement: The authors of this manuscript having no conflicts of interest to disclose.

Data sharing statement: Extended dataset available from the corresponding author at vk279@cam.ac.uk.

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Abstract

AIM: To compare the trauma experience gained by a trainee at a United Kingdom major trauma centre and a secondary level hospital in South Africa.

METHODS: A profile of inpatient trauma cases during a five-week period in Addenbrooke's Hospital, Cambridge and Somerset Hospital, Cape Town was created. This was achieved by recording various parameters for each patient admitted including age, gender, injury, mechanism of injury and postal/area code. This, together with details of the departments themselves, allows a comparison of the amount and variety of orthopaedic trauma cases experienced by an individual trainee in each setting.

RESULTS: The trauma profiles differed significantly. Patients in Cape Town were younger and more likely to be male. In the young, injury in Cape Town was more likely to occur due to assault or being struck by a vehicle, whilst patients in Cambridge were more likely to be injured whilst in a vehicle or in high energy falls. In older patients, trauma at both centres was almost exclusively due to mechanical falls. In a given age group, injuries at the two centres were similar, however the majority of patients admitted to Addenbrooke's were elderly, resulting in less variation in the overall injury profile.

CONCLUSION: The trauma profile of a major trauma centre in the United Kingdom is less varied than that of a South African secondary centre, with significantly fewer cases per surgeon. This suggests a more varied

training experience in the developing world with a greater caseload.

Key words: Comparative; Epidemiology; Developing world; Trauma; Training

Core tip: The caseload of a hospital directly impacts the training experience of a surgeon. Centres in the developing world are widely thought to offer a superior exposure to traumatic injury and consequently a rich training environment for the orthopaedic trainee. This study directly compares the caseload at two centres over a fixed period, and shows that the department in the developing world experienced greater volume and variation in trauma cases thereby offering a better experience for training in trauma.

Lawrence JE, Khanduja V. From Cape Town to Cambridge: Orthopaedic trauma in contrasting environments. *World J Orthop* 2016; 7(5): 308-314 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i5/308.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i5.308

INTRODUCTION

Injury secondary to trauma is a major public health issue. It is a leading cause of death world wide, with road traffic accidents alone accounting for 1.2 million deaths per year[1]. By 2020, musculoskeletal injury will account for 20% of all the world's disability-adjusted life years. The vast majority of this burden lies with the developing world with low and middle-income countries entering the third phase of epidemiologic transition. This entails an increase in the average life expectancy and a consequent exposure of the population to the so-called man-made diseases[2-4]. Despite this growing burden, orthopaedic care in the developing world remains scarce when compared with developed countries, with only one in three people provided for[5].

This disparity in demand and supply of orthopaedic care has implications for orthopaedic training across the globe. This study profiled the orthopaedic trauma admissions at two centres in contrasting settings; one a major trauma centre in Cambridge, United Kingdom, the other a secondary level centre in Cape Town, South Africa. These two counties exemplify the difference in disease burden, with injury accounting for 2.7% and 9% of deaths respectively[6,7]. A comparison would therefore make it possible to quantify how this increased burden in the developing world influences the experience of the orthopaedic trainee in South Africa in comparison with the trainee in the United Kingdom.

The aim of the study, therefore, was to compare, contrast and objectively quantify the trauma admissions that a trainee would be exposed to whilst based in Cambridge, United Kingdom and in Cape Town, South Africa. This in turn would have implications for those intending to train in trauma surgery.

MATERIALS AND METHODS

Study hospitals

New Somerset Hospital is a secondary level state hospital situated in Green Point, a district in the north-west of Cape Town. It serves the central health district of the city, which holds a population of 800000. The orthopaedic department is staffed by one full-time Consultant, one part-time consultant and two medical officers (equivalent to the core surgical trainee in the United Kingdom). Two internship doctors (equivalent to foundation programme year one doctors) staff the ward, which consists of twenty-three beds; three bays of six patients and one bay of five patients. Each bay is staffed by a staff nurse, with a ward sister overseeing care on the ward. The department admits all patients aged 13 or over, with paediatric cases referred to the regional paediatric hospital.

By contrast, Addenbrooke's Hospital is the major trauma centre for the East of England, providing tertiary trauma care to a population of 5.4 million. It has seventy-two orthopaedic beds and is staffed by sixteen Consultants, ten specialist registrars and eight senior house officers (a mix of foundation year two doctors, core surgical trainees and junior clinical fellows). The wards consist of several bays and side rooms with one trained nurse for every five patients and senior and junior sisters for each ward. In addition, the department is staffed by a team of three trauma specialist nurses who co-ordinate admissions and administer specialist nursing care on the wards. The Department has a recently expanded and now houses an Orthopaedic Trauma Unit that is run by 5 Consultants specialising in Trauma and essentially manages all the multiply injured patients admitted to the Hospital. The unit admits patients of all ages.

The period of the study at New Somerset Hospital ran during from June to July 2012, and the study at Addenbrooke's Hospital in Cambridge ran from August to September 2012.

Data collection

This was a prospective study that included all the orthopaedic trauma admissions during a five-week period at each hospital. For each admitted patient, a multitude of parameters were recorded in order to form an overall profile of the orthopaedic trauma. These were age, sex, injury by anatomical site, mechanism of injury [mechanical fall, high energy fall, sporting, interpersonal, pedestrian motor vehicle accident and in - car motor vehicle accident (cMVA)] and postal/area code.

Statistical analysis

Statistical analysis was carried out using SPSS Version

Table 1 The numbers of the more common injuries at each centre

Injury site	Mean patient age - Cambridge (*n*)	Mean patient age - Cape Town (*n*)
Proximal radius and ulna	45.8 (6)	35.6 (5)
Distal radius and ulna	25.3 (12)	42.3 (4)
Intracapsular neck of femur	81.9 (16)	74.5 (6)
Extracapsular neck of femur	80.8 (27)	78.2 (5)
Proximal tibia	47.5 (4)	26.4 (5)
Tibial/fibular diaphysis	37.1 (7)	42.1 (8)
Tibia/fibula	44.8 (12)	49.8 (7)

Table 2 The frequency of each mechanism of injury at each centre

Mechanism	Patients - Cambridge (%)	Mean age (yr) - Cambridge	Patients - Cape Town (%)	Mean age (yr) - Cape Town
Mechanical fall	76 (52.8)	71.5	30 (47.6)	57.7
High energy fall	31 (21.5)	36.9	5 (7.9)	28.2
cMVA	16 (11.1)	45.4	4 (6.3)	41.5
pMVA	6 (4.2)	39.2	6 (9.5)	39.3
Interpersonal	1 (0.7)	68	10 (15.9)	34
Sporting	15 (10.4)	22.2	8 (12.7)	26.8

pMVA: Pedestrian motor vehicle accident; cMVA: Car motor vehicle accident.

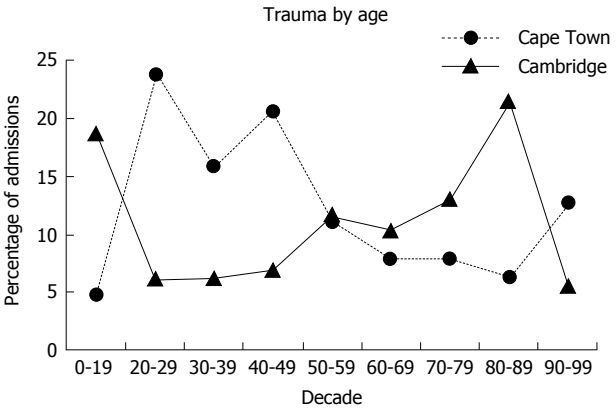

Figure 1 A graph showing age of patients admitted to both centres.

13 for all the variables.

RESULTS

Trauma by age and gender

There were 63 orthopaedic trauma admissions to the New Somerset Hospital during the study period; 40 males and 23 females with a mean age of 44.9 years. The youngest patient admitted was 14 and the oldest 96. The highest rate of admissions was observed in the 20-29 years age group.

Addenbrooke's Hospital admitted 144 patients during the study period with equal numbers of male and female patients and a mean age of 54.8 years (range 1 to 97 years), with the highest admission rate in the 80-89 age group. Of these patients, 125 were aged 13 or older, and the average age in this group was 62.4 years. The age distribution of trauma at the two centres is shown in Figure 1.

Trauma by injury and mechanism

Injury was catagorised by anatomical region using the AO fracture classification. At New Somerset, tibial fractures were the most common (n = 22, 34.9%), particularly those involving the diaphysis and malleoli, followed by fractures of the proximal femur (n = 11, 17.5%) and fractures of the radius and ulna (n = 10, 15.9%).

At Addenbrooke's hospital, fractures of the proximal femur were the most common injury (n = 50, 34.7%), followed by fractures of the tibia (n = 24, 16.7%) and fractures of the radius and ulna (n = 23, 16%). The common fracture sites for both centres are compared in Figure 2. Table 1 shows the mean age for the common injury sites at both centres.

Mechanism of injury was divided into six categories. The frequency of each of these categories, together with the mean age for each mechanism, is summarised in Table 2.

Mechanical fall was the most common mechanism of injury for both centres, accounting for 52.8% of injuries at Addenbrooke's and 47.6% of injuries at New Somerset. High-energy falls were the second most common mechanism at Addenbrooke's (21.5%), followed by in - cMVAs (11.1%). Interpersonal mechanisms were the second most common at New Somerset (15.9%), followed by sporting incidents (12.7%). Mechanisms of injury in the under-45 and 45 and over age groups at both centres are shown in Figure 3. Mechanical falls (25.7%) and interpersonal actions (22.9%) were the most common cause of injury in the under-45 s in Cape Town, with high-energy falls (40%) and in - cMVAs (26.7%) the most common in this age group in Cambridge.

In the over-45 age group, mechanical falls were the

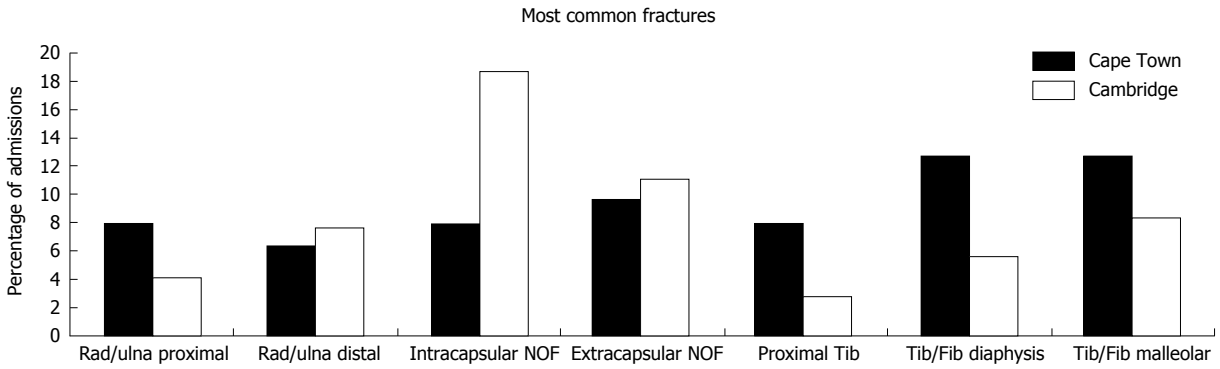

Figure 2 A bar chart showing the most common fracture sites at each centre by anatomical distribution. Rad: Radius; Tib: Tibia; Fib: Fibula; NOF: Neck of femur.

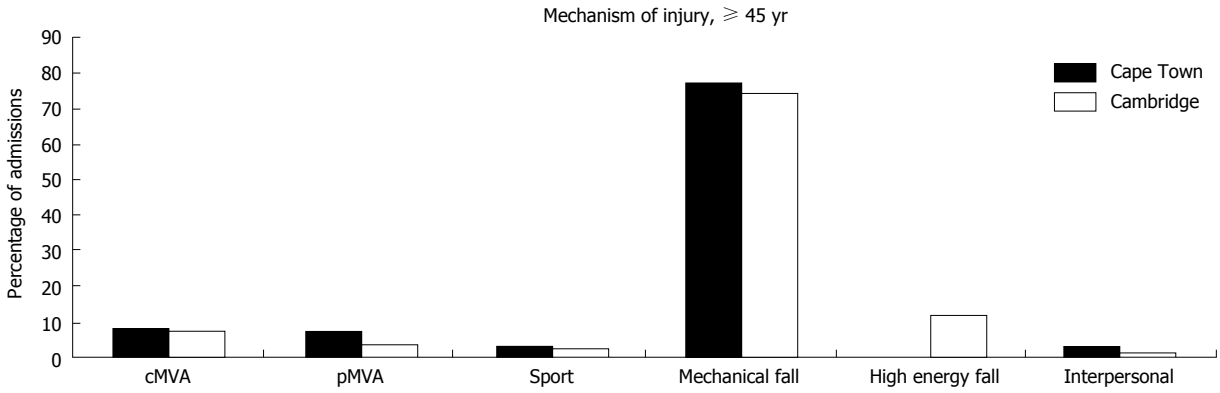

Figure 3 A bar chart showing mechanism of injury in patients aged 45 and over. pMVA: Pedestrian motor vehicle accident; cMVA: Car motor vehicle accident.

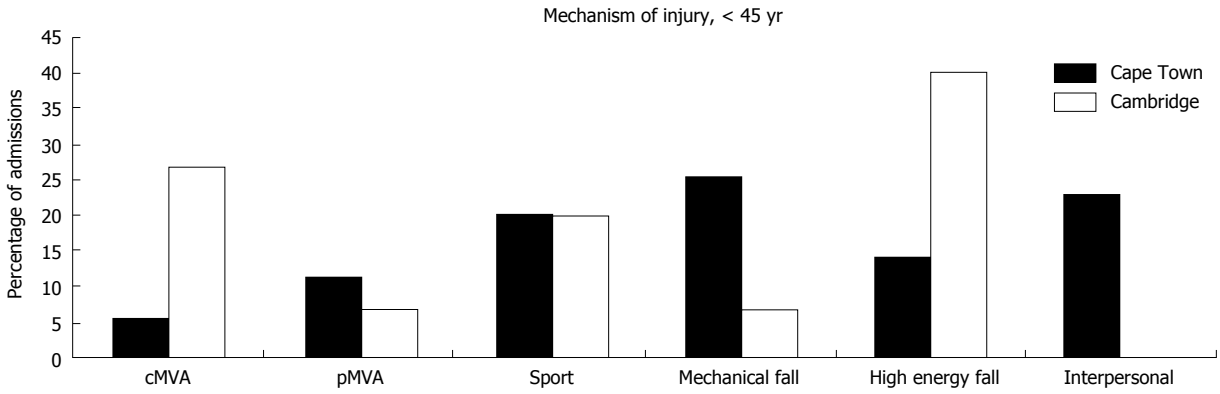

Figure 4 A bar chart showing mechanism of injury in patients aged under 45. pMVA: Pedestrian motor vehicle accident; cMVA: Car motor vehicle accident.

main mechanism, accounting for 74.5% and 77.8% of injuries in Cambridge and Cape Town respectively. These trends are summarized in Figure 3.

Trauma by location

Location was recorded at each admission using patient postal code. At New Somerset, the mean distance from patient address to hospital was 21.1 miles, with the median distance 11 miles. Distances ranged from 1 mile to 93 miles. The mean distance between patient address and Addenbrooke's hospital was 18.6 miles and the median distance was 13.5 miles. Distances ranged from 2 miles to 98 miles.

Geographical distribution of trauma cases is summarized in Figure 4. The distances at Addenbrooke's Hospital were more normally distributed, whereas the distances at New Somerset Hospital were more positively skewed with a second group of admissions corresponding to outreach services provided by the hospital.

DISCUSSION

The trauma profile at Addenbrooke's hospital, Cambridge was markedly different to that of New Somerset Hospital, Cape Town. Patients at New Somerset were younger and more likely to be male. In both centres,

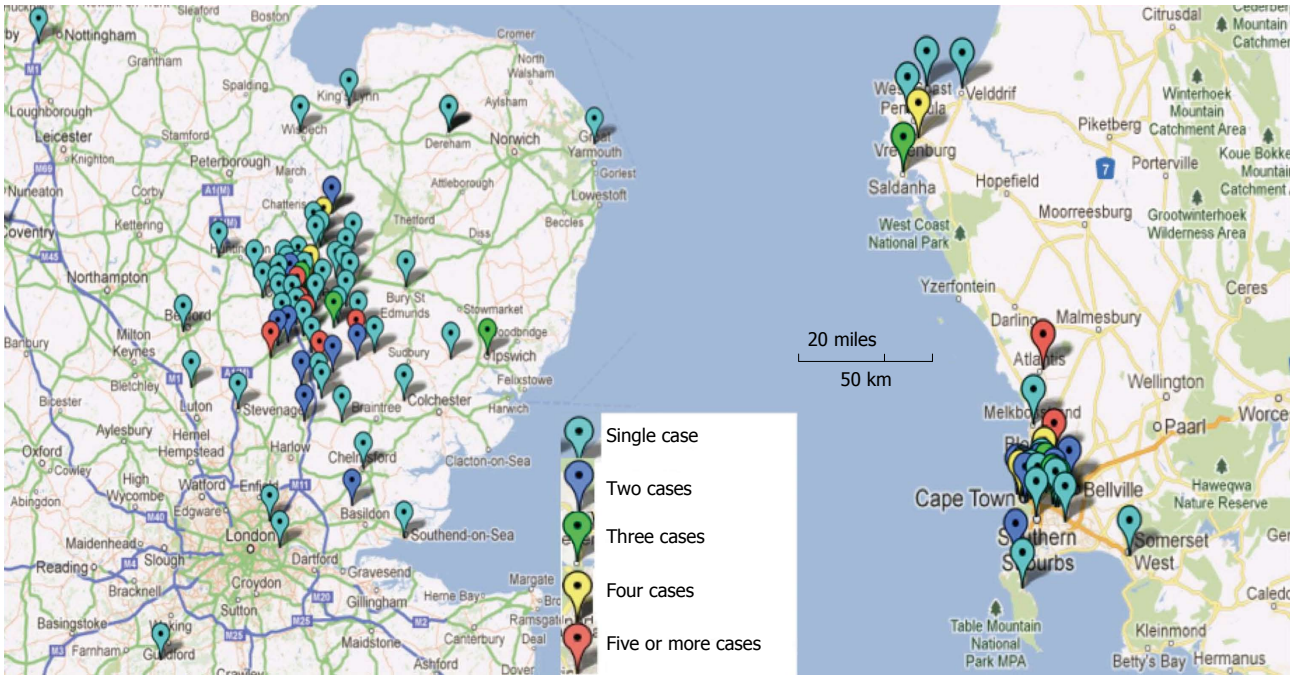

Figure 5 A composite map, to scale, showing the geographical location of trauma in Cambridge (left) and Cape Town (right).

there was a similar injury pattern in any given age group, with a notably broader range of injury in younger patients. However, the patients admitted to New Somerset Hospital were of lower average age, resulting in a much more varied overall injury profile at this centre.

Patients in the younger age groups admitted to New Somerset Hospital were more likely to be injured by interpersonal means or following pedestrian motor vehicle accidents than patients in the same age group admitted to Addenbrooke's Hospital, who were more likely to be injured following an in - cMVA or a high energy fall. These differences reflect the hospitals and their settings; Addenbrooke's Hospital is a level one trauma centre and is therefore specifically tasked with treating more high energy trauma injuries such as those sustained during in-car motor vehicle accidents or high energy falls. Conversely, new Somerset Hospital serves an area with high rates of interpersonal crime, leading to more injuries sustained by these mechanisms. In the elderly, trauma at both centres was almost exclusively due to mechanical falls with the majority of injuries being fragility fractures.

The geographical distribution of cases at the two centres was comparable, with a similar average distance and range of distances between patient address and hospital. The distances between patient address and Addenbrooke's Hospital were more normally distributed than those at New Somerset Hospital. This is in keeping with the role of Addenbrooke's Hospital as a major trauma centre, taking referrals from all parts of the East of England. The distribution of distances between patient address and New Somerset Hospital showed a clear bimodal distribution. These two groups reflect the two distinct areas served by the hospital; the first being western and central Cape Town and the second corresponding to patients admitted from outreach clinics in rural communities far from the hospital (Figure 5).

In order to fully analyse the experience of a trainee, these trauma profiles must be placed in the context of the two centres. Although Addenbrooke's Hospital admitted more than twice the number of patients than New Somerset Hospital, it employs a significantly larger workforce, with a total of thirty-four surgeons (eighteen trainees, sixteen consultants) to New Somerset's four (two trainees, one full-time consultant and one part-time consultant). This imbalance in the number of surgeons results in a much greater trauma caseload for the trainee in Cape Town, South Africa. This, together with the more varied injury profile at New Somerset Hospital, enables the trainee to gain wider experience in the management of orthopaedic trauma.

Whilst caseload is an important aspect of surgical training, it is not the sole determinant of its quality. The training programmes in both countries follow the traditional apprenticeship model and are largely comparable, with some subtle differences which should be understood when comparing the experience gained by a trainee. In South Africa, orthopaedic training is undertaken following a two year internship and community service year. Training takes place at one of nine accredited universities, two of which are accredited for the first two years of the training programme only. This is similar to the structure of training in the United Kingdom which takes place in one of twelve regions in England, Wales and Northern Ireland (Scotland has a separate training structure). Each region contains at least one teaching hospital linked to a university. United

Kingdom medical graduates undertake a two-year foundation training programme analogous to that of the South African internship, however there is no equivalent to the community service year in the United Kingdom. Instead, trainees must complete the two-year core surgical training programme before applying for specialty training in orthopaedics.

Both South African and United Kingdom orthopaedic specialty training programmes typically last for five years, and require the completion of various examinations in order to progress. In South Africa, training works on the basis of three levels of study. The first level is assessed with the primary examination, which focuses on basic surgical sciences such as pathology and anatomy. The second level of study concludes with the orthopaedic intermediate examination, which focuses on the clinical aspects of surgery, with a focus on orthopaedics. Enrollment in the intermediate examination requires candidates to have eighteen months of experience in one of the aforementioned university hospitals, including intensive care and trauma experience. The final part of training involves six month rotations through the various orthopaedic sub-specialties with attachment to a consultant for each rotation. During this part of training, trainees must publish at least one research article. Upon completion of three years of rotations, trainees may register for the final examinations, the fellowship of the college of orthopaedic surgeons of South Africa, meaning a surgeon can be fully qualified eight years after graduation from medical school.

Orthopaedic specialty training in the United Kingdom follows a similar pattern, though trainees must attain Membership of the Royal College of Surgeons (MRCS) prior to the commencement of specialist training. This involves passing two examinations; the first a written exam with a focus on basic surgical sciences and principles of surgery in general and the second an objective structured clinical examination which focuses on applied surgical sciences with practical and communication skills. In this regard, the MRCS is comparable to a combination of the primary and intermediate examinations in South Africa, though it lacks specificity to orthopaedics. In a similar fashion to South Africa, the training programme lasts for five years and involves six month rotations through sub-specialties with attachment to a consultant. Like South Africa, trainees take the Fellowship of the Royal College of Surgeons after three or four years of specialty training. Trainees are expected to regularly partake in research and quality improvement. Overall, trainees can be expected to complete training nine to ten years post-graduation[8,9].

Both training programmes have a set of competencies which are expected to be achieved at the completion of training. This essentially requires trainees to be competent in a range of orthopaedic procedures, with competency defined as the completion of a defined number of cases.

The apprenticeship nature of surgical training means much depends on the quality of the mentor, meaning there will always be natural variation in the quality of training. However, the similarity of the training programmes in these two countries places emphasis on the quantity and type of orthopaedic trauma experienced by a trainee. This study shows trainees at Addenbrooke's Hospital experience fewer cases than their counterparts at New Somerset Hospital, and the cases they do experience are less varied.

To this end, the study highlights the potential benefits of establishing training programmes that combines the structure of a United Kingdom major trauma centre with the volume and variation provided by hospitals in the developing world. Currently, trainees in the United Kingdom are able to apply to their regional training body for out of programme clinical experience (OOPE), which can take the form of work in the developing world. Whilst studies such as ours highlight the potential benefits this would hold for the trainee, time out of programme does not often gain approval for clinical training and thus can delay career progression, making it an unpopular choice amongst trainees.

An alternative to OOPE is an approved fellowship abroad. Several studies have shown the benefits of establishing synergistic partnerships between hospitals in the developing and developed worlds, whereby trainees from each centre swap roles in order to broaden their surgical experience[10,11]. We believe that expanding the number and variety of such fellowships will help surgeons worldwide to establish best practices and increase the standard of trauma care in a time when traumatic injury is increasing at an alarming rate.

COMMENTS

Background

Traumatic injury is rapidly increasing in the developing world as many countries enter the third phase of epidemiological transition. This has wide-ranging implications for surgical training, with trainees in the developing world thought to gain greater experience in the management of orthopaedic trauma. The study aimed to compare the experience gained in orthopaedic trauma at United Kingdom major trauma centre and a secondary level South African centre.

Research frontiers

Restrictions on working hours have placed additional strain on the training of surgeons, and this study suggests a potential mutual benefit lies in training periods spent in the developing world.

Innovations and breakthroughs

This is the first study to directly compare the orthopaedic trauma experience gained in South African and United Kingdom hospitals, showing a greater caseload with more variation in South Africa. The study adds to the literature on the utility of out of programme experience and exchange fellowships.

Applications

This study supports the expansion of both out of programme experience and exchange fellowships in trauma and orthopaedic training.

Terminology

Out of programme experience: Time spent by a United Kingdom trainee away from their training institution.

Peer-review

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

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Management of lumbar zygapophysial (facet) joint pain

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Abstract

AIM: To investigate the diagnostic validity and therapeutic value of lumbar facet joint interventions in managing chronic low back pain.

METHODS: The review process applied systematic evidence-based assessment methodology of controlled trials of diagnostic validity and randomized controlled trials of therapeutic efficacy. Inclusion criteria encompassed all facet joint interventions performed in a controlled fashion. The pain relief of greater than 50% was the outcome measure for diagnostic accuracy assessment of the controlled studies with ability to perform previously painful movements, whereas, for randomized controlled therapeutic efficacy studies, the primary outcome was significant pain relief and the secondary outcome was a positive change in functional status. For the inclusion of the diagnostic controlled studies, all studies must have utilized either placebo controlled facet joint blocks or comparative local anesthetic blocks. In assessing therapeutic interventions, short-term and long-term reliefs were defined as either up to 6 mo or greater than 6 mo of relief. The literature search was extensive utilizing various types of electronic search media including PubMed from 1966 onwards, Cochrane library, National Guideline Clearinghouse, clinicaltrials.gov, along with other sources including

previous systematic reviews, non-indexed journals, and abstracts until March 2015. Each manuscript included in the assessment was assessed for methodologic quality or risk of bias assessment utilizing the Quality Appraisal of Reliability Studies checklist for diagnostic interventions, and Cochrane review criteria and the Interventional Pain Management Techniques - Quality Appraisal of Reliability and Risk of Bias Assessment tool for therapeutic interventions. Evidence based on the review of the systematic assessment of controlled studies was graded utilizing a modified schema of qualitative evidence with best evidence synthesis, variable from level Ⅰ to level Ⅴ.

RESULTS: Across all databases, 16 high quality diagnostic accuracy studies were identified. In addition, multiple studies assessed the influence of multiple factors on diagnostic validity. In contrast to diagnostic validity studies, therapeutic efficacy trials were limited to a total of 14 randomized controlled trials, assessing the efficacy of intraarticular injections, facet or zygapophysial joint nerve blocks, and radiofrequency neurotomy of the innervation of the facet joints. The evidence for the diagnostic validity of lumbar facet joint nerve blocks with at least 75% pain relief with ability to perform previously painful movements was level Ⅰ, based on a range of level Ⅰ to Ⅴ derived from a best evidence synthesis. For therapeutic interventions, the evidence was variable from level Ⅱ to Ⅲ, with level Ⅱ evidence for lumbar facet joint nerve blocks and radiofrequency neurotomy for long-term improvement (greater than 6 mo), and level Ⅲ evidence for lumbosacral zygapophysial joint injections for short-term improvement only.

CONCLUSION: This review provides significant evidence for the diagnostic validity of facet joint nerve blocks, and moderate evidence for therapeutic radiofrequency neurotomy and therapeutic facet joint nerve blocks in managing chronic low back pain.

Key words: Chronic low back pain; Lumbar facet joint pain; Lumbar discogenic pain; Intraarticular injections; Lumbar facet joint nerve blocks; Lumbar facet joint radiofrequency; Controlled diagnostic blocks; Lumbar facet joint

Core tip: This review summarizes diagnostic and therapeutic aspects of chronic low back pain of facet joint origin. Even though multiple high quality diagnostic accuracy studies are available, there is room for further studies to confirm accuracy. These studies are key for the universal acceptance of facet joint nerve blocks of the lumbosacral spine as the gold standard. Deficiencies continue with therapeutic interventions. Lumbar radiofrequency neurotomy studies have shown contradicting results with short-term follow-ups. There is limited high quality literature for lumbar facet joint nerve blocks, and the available literature contains contradictory findings in multiple trials of intraarticular injections.

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INTRODUCTION

Low back pain is a common health problem with increasing prevalence, health challenges, and economic impact[1-20]. Studies indicate that low back pain is the number one cause contributing to most years lived with disability in 2010 in the United States and globally[1,2]. In addition, work-related low back pain continues to be an important cause of disability[3]. The global burden of low back pain has a point prevalence of 9.4% of the population, with severe chronic low back pain but a lack of lower extremity pain accounting for 17% of cases, and of low back pain with leg pain 25.8%[2]. Low back pain increased 162% in North Carolina, from 3.9% in 1992 to 10.2% in 2006[4]. Treatment of chronic low back pain has yielded mixed results and the substantial economic and health impact has raised concerns among the public-at-large, policy-makers, and physicians[6-19]. The large increase in treatment types and rapid escalation in health care costs may be attributed to multiple factors, including the lack of an accurate diagnosis and various treatments that do not have appropriate evidence of effectiveness.

Numerous structures in the lower back may be responsible for low back and/or lower extremity pain, including lumbar intervertebral discs, facet joints, sacroiliac joints, and nerve root dura, and may be amenable to diagnostic measures such as imaging and controlled diagnostic blocks[10,21-29]. Other structures also capable of transmitting pain, including ligaments, fascia, and muscles, may not be diagnosed with accuracy with any diagnostic techniques[29]. Disc-related pathology with disc herniation, spinal stenosis, and radiculitis are diagnosed with reasonable ease and accuracy leading to definitive treatments[30]. However, low back pain from discs (without disc herniation), lumbar facet joints, and sacroiliac joints is difficult to diagnose accurately by noninvasive measures including imaging[10,21-35]. Consequently, no gold standard is generally acknowledged for diagnosing low back pain, irrespective of the source being facet joint(s), intervertebral disc(s), or sacroiliac joint(s), despite the fact that lumbar facet joints, the paired joints that stabilize and guide motion in the spine, have been frequently implicated.

Based on neuroanatomy, neurophysiologic, biomechanical studies, and controlled diagnostic facet joint nerve blocks, lumbar facet joints have been recognized

as a potential cause of low back pain as well as referred lower extremity pain in patients who have chronic low back pain[10,22-35]. Lumbar facet joints are well innervated by the medial branches of the dorsal rami, with presence of free and encapsulated nerve endings as well as nerves containing substance P and calcitonin gene-related peptide[10,35-38]. While there are many causes for pain in the facet joints, mechanical injury and inflammation of the facet joints have produced persistent pain in experimental settings[39-45]. Further, the high prevalence of facet joint osteoarthritis has been illustrated in numerous studies[46-49]. Nonetheless, attempts to make the diagnosis of lumbar facet joint pain by history, identification of pain patterns, physical examination, and imaging techniques better have shown low accuracy and utility[10,22-29,35]. It has been proposed that controlled diagnostic blocks may be the only means to diagnose lumbar facet joint pain with reasonable accuracy, although controversy continues regarding the diagnostic accuracy of controlled local anesthetic blocks[10,21-29,31,32,35,50-53].

With appropriate diagnosis, accurate and evidence-based treatments may be expected to achieve reasonable outcomes; however, the disadvantages of controlled local anesthetic blocks, apart from discussions on their accuracy, include invasiveness, expenses, and difficulty in interpretation, occasionally making them problematic in routine clinical practice as a primary diagnostic modality. Various systematic reviews have assessed the value and validity of various diagnostic maneuvers including diagnostic facet joint nerve blocks[10,28,29,32,35].

Therapeutic interventions include conservative modalities and interventional techniques and occasionally surgical interventions[10,33,54-73]. Conservative management includes drug therapy, chiropractic manipulation, physical therapy, and biopsychosocial rehabilitation. However, there have not been any trials reported in the literature that studied conservative management[10,54-67] in confirmed lumbar facet joint pain or discogenic pain[74,75]. The literature regarding pain of presumed facet joint origin has involved interventional techniques using intraarticular injections, facet joint nerve blocks, and various neurolytic techniques, including injection of neurolytic solutions, radiofrequency neurotomy, and cryoneurolysis. However, as with diagnostic accuracy studies of facet joint nerve blocks, therapeutic interventions have met with favor, skepticism, and critiques[10,15,50-55,69-74].

The aim of this systematic review is to assess the diagnostic accuracy of lumbar facet joint nerve blocks and the therapeutic effectiveness of multiple interventional techniques based on a best evidence synthesis.

MATERIALS AND METHODS

A systematic review was conducted utilizing the review process derived from evidence-based systematic reviews and meta-analysis of diagnostic accuracy studies and randomized controlled trials (RCTs)[76-83].

Criteria for considering studies for this review

Diagnostic accuracy studies and RCTs evaluating accuracy and efficacy managing lumbar facet joint pain were included. Patients above 18 years of age with chronic lumbar facet joint pain of at least 3 mo duration after failure of previous pharmacotherapy, physical therapy, and exercise therapy were included for interventional pain management. Types of included studies were all RCTs and diagnostic facet joint nerve blocks appropriately performed with proper technique under fluoroscopy or computed tomography guidance.

Outcome measures

The outcome measures included pain relief as the primary criterion for diagnostic accuracy studies concordant with the local anesthetic used and the ability to perform previously painful movements. The primary outcome parameter for RCTs of efficacy was pain relief with short-term defined up to 6 mo and long-term defined as longer than 6 mo with functional improvement as the secondary outcome measure.

Literature search

Literature searches were performed utilizing PubMed from 1966, EMBASE from 1980, Cochrane library, United States National Guideline Clearinghouse, previous systematic reviews and cross references, and any other trials available from any source in all languages from all countries, through March 2015.

Search strategy

The search strategy included a review of the literature through March 2015 and emphasized chronic low back pain, facet or zygapophysial joint pain, cryoneurolysis, neurolytic injections, chronic lumbar facet joint pain, and selected studies meeting inclusion criteria.

The search terminology was as follows: ((((((((((((((((chronic low back pain) OR chronic back pain) OR disc herniation) OR discogenic pain) OR facet joint pain) OR herniated lumbar discs) OR nerve root compression) OR lumbosciatic pain) OR postlaminectomy) OR lumbar surgery syndrome) OR radicular pain) OR radiculitis) OR sciatica) OR spinal fibrosis) OR spinal stenosis) OR zygapophysial)) AND (((((((facet joint[tw]) OR zygapophyseal[tw]) OR zygapophysial[tw]) OR medial branch block[tw]) OR diagnostic block[tw]) OR radiofrequency[tw]) OR intraarticular[tw]).

Data collection and analysis

At least 2 of the review authors independently in an unblinded standardized manner performed each search and assessed outcome measures. The searches were combined to obtain a unified search strategy.

Methodological quality or validity assessment

At least 2 of the review authors independently assessed

Table 1 Modified grading of qualitative evidence with best evidence synthesis for diagnostic accuracy and therapeutic interventions

Level Ⅰ	Evidence obtained from multiple relevant high quality randomized controlled trials or Evidence obtained from multiple high quality diagnostic accuracy studies
Level Ⅱ	Evidence obtained from at least one relevant high quality randomized controlled trial or multiple relevant moderate or low quality randomized controlled trials or Evidence obtained from at least one high quality diagnostic accuracy study or multiple moderate or low quality diagnostic accuracy studies
Level Ⅲ	Evidence obtained from at least one relevant moderate or low quality randomized controlled trial study or Evidence obtained from at least one relevant high quality non-randomized trial or observational study with multiple moderate or low quality observational studies or Evidence obtained from at least one moderate quality diagnostic accuracy study in addition to low quality studies
Level Ⅳ	Evidence obtained from multiple moderate or low quality relevant observational studies or Evidence obtained from multiple relevant low quality diagnostic accuracy studies
Level Ⅴ	Opinion or consensus of large group of clinicians and/or scientists.

Source: Manchikanti *et al*[82].

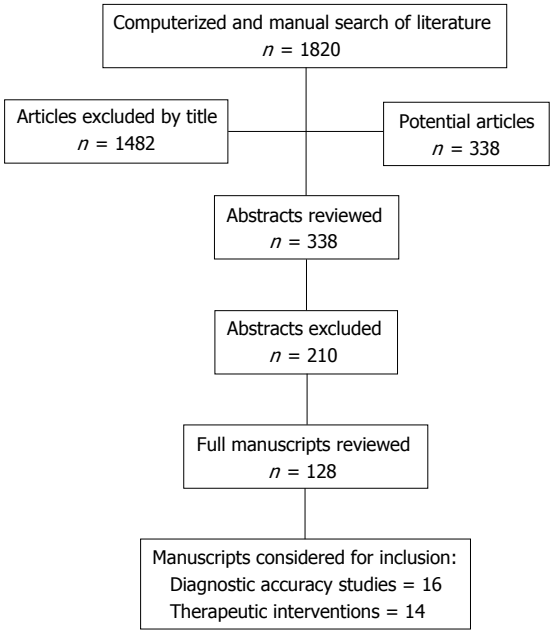

Figure 1 Flow diagram illustrating literature evaluating diagnostic accuracy and therapeutic effectiveness of lumbar facet joint interventions.

the criteria for inclusion for methodological quality assessment and then performed the methodological quality assessment. Authors with a perceived conflict of interest for any manuscript, either with authorship or any other aspect, were recused from reviewing those manuscripts.

For diagnostic accuracy studies, all articles were assessed based on the quality appraisal of reliability studies checklist, which has been validated[80]. All randomized trials were assessed for methodological quality utilizing Cochrane review criteria[78] and Interventional Pain Management Techniques - Quality Appraisal of Reliability and Risk of Bias Assessment (IPM-QRB) criteria[79].

Summary measures

Summary measures for diagnostic accuracy studies included at least 50% pain relief with an ability to perform previously painful movements as the criterion standard, whereas for RCTs, summary measures included a 50% or more reduction of pain in at least 40% of the patients or at least a 3 point decrease in pain scores.

Outcomes and analysis of evidence

Outcomes of the studies of diagnostic accuracy were assessed for prevalence and false-positive rates when available. For therapeutic efficacy, the short- and long-term outcomes were assessed. For diagnostic accuracy and therapeutic efficacy studies, 5 levels of evidence were utilized as shown in Table 1, varying from level Ⅰ with the highest evidence with multiple relevant high quality RCTs, or multiple high quality diagnostic accuracy studies, to level Ⅴ with minimal evidence and results based on consensus. Any disagreement among authors was resolved by a third author or by consensus.

RESULTS

Figure 1 lists the study selection flow diagram of diagnostic accuracy studies and therapeutic intervention trials.

Based on the search criteria, there were multiple diagnostic accuracy and therapeutic efficacy studies; however, utilizing inclusion criteria as described above, there were 16 diagnostic accuracy studies meeting inclusion criteria for methodological quality assessment[22-25,84-95], whereas there were 14 trials meeting inclusion criteria for therapeutic efficacy assessment[96-109]. Among the multiple trials not meeting methodological quality assessment inclusion criteria, Leclaire *et al*[110] was of significant importance. This trial was randomized and placebo controlled. It assessed 70 patients with a 12-wk follow-up. This was a relatively small study but

more importantly, the technique used was inappropriate as was using intraarticular injections for diagnostic evaluation. Subsequently, the authors have agreed that the results may not be applied in clinical practice[111]. Multiple studies assessing the influence of factors of prevalence and accuracy of facet joint pain were also considered[112-123].

Methodological quality assessment

Methodological quality assessment of diagnostic accuracy studies is shown in Table 2 and methodological quality assessment of therapeutic interventions by Cochrane review criteria is shown in Table 3, whereas methodological quality assessment utilizing IPM-QRB criteria is shown in Table 4.

Study characteristics

Diagnostic accuracy study characteristics are shown in Table 5, and therapeutic efficacy trial characteristics are shown in Table 6.

Among the diagnostic accuracy studies, 6 studies were performed utilizing ⩾ 75% pain relief as the criterion standard[24,85-87,93,94]. All told there were 856 patients, a heterogenous population with prevalence ranging from 30% to 45%, including a false-positive rate of 25% to 44%. These results are also similar to 80% pain relief as the criterion standard studied in 5 studies[23,89-91,95] in 1431 patients. The prevalence in a heterogenous population ranged between 27% and 41%. However, utilizing controlled diagnostic blocks, the prevalence was shown somewhat differently in specific populations with 30% in patients younger than 65 years and 52% in patients older than 65[93], 36% in non-obese patients and 40% in obese patients[94], 16% in post surgery patients[92], and 21% with involvement of a single region[88].

Among the therapeutic interventions, a total of 14 trials met inclusion criteria with 9 trials evaluating lumbar radiofrequency neurotomy[96-101,105,108,109], 2 trials evaluating lumbar facet joint nerve blocks[102,108], and 5 trials evaluating the role of intraarticular facet joint injections[101,103,104,106,107]. Among the radiofrequency neurotomy trials, of the 9 trials included, 7 moderate to high quality trials showed long-term effectiveness[96,98-101,105,108], whereas one moderate to high quality trial showed a lack of effectiveness[97] with one trial showing short-term effectiveness[109]. Among the long-term trials with effectiveness assessed at least for one year, Civelek *et al*[108] included 50 patients, Tekin *et al*[96] included 20 patients in the conventional radiofrequency neurotomy groups, and van Kleef *et al*[99] included only 15 patients in the radiofrequency neurotomy group showing positive results with a total number of 85 patients included among the 3 trials. van Wijk *et al*[97], showing a lack of effectiveness, included 40 patients undergoing radiofrequency neurotomy. Among the other studies, Cohen *et al*[109] included 14 patients with controlled diagnostic blocks, Nath *et al*[105] included 20 patients with triple diagnostic blocks, Dobrogowski *et al*[98] included 45 patients with controlled diagnostic blocks, Moon *et al*[100] included 82 patients utilizing 2 different types of techniques with controlled diagnostic blocks, and Lakemeier *et al*[101] included 27 patients with an intraarticular injection of local anesthetic with a single block.

The evidence for therapeutic lumbar facet joint nerve blocks was assessed in 2 RCTs[102,108]. In these trials, Manchikanti *et al*[102] studied 120 patients with chronic lumbar facet joint pain with a confirmed diagnosis with a criterion standard of 80% pain relief using controlled diagnostic blocks after failure of conservative management. At the end of a 2-year study period, significant pain relief was seen in 85% of the patients who received a local anesthetic and 90% of the patients who received a local anesthetic with steroids. The patients received an average of 5 to 6 total treatments. In the second study, Civelek *et al*[108] assessed 100 patients suffering from chronic low back pain. These patients had failed conservative therapy utilizing noninvasive diagnostic criteria; however, without diagnostic blocks. They compared lumbar facet joint nerve blocks with conventional radiofrequency neurotomy. Effectiveness was seen in 69% of the patients who received facet joint nerve blocks. In the radiofrequency neurotomy group, 90% effectiveness was seen. Civelek *et al*[108] showed significant improvement in 90% of the patients at one year follow-up, Cohen *et al*[109] showed 64% of the patients responding at 3 mo selected with controlled diagnostic blocks, Nath *et al*[105] showed at 6 mo follow-up significant reduction in the majority of patients, Tekin *et al*[96] reported a significant percentage of patients with appropriate relief at one year in the conventional radiofrequency neurotomy group, van Wijk *et al*[97] showed a lack of response at 3 mo follow-up, Dobrogowski *et al*[98] showed effectiveness of radiofrequency neurotomy in 66% of the patients at one year follow-up, van Kleef *et al*[99] showed effectiveness of radiofrequency neurotomy at one year in 47% of the patients, Moon *et al*[100] showed significant reduction in pain and disability index scores at the end of one year, and finally Lakemeier *et al*[101] showed significant improvement with conventional radiofrequency neurotomy at the end of 6 mo.

Intraarticular injections were studied in 5 trials[101,103,104,106,107]. Of these, 3 high quality RCTs showed effectiveness with short-term follow-up of less than 6 mo[101,106,107]. However, 2 moderate to high quality RCTs showed opposing results with a lack of effectiveness[103,104]. Ribeiro *et al*[107] showed effectiveness of intraarticular injections at the end of 6 mo with selection criteria not including diagnostic blocks. Lakemeier *et al*[101] showed significant improvement with selection of patients with a single intraarticular injection at 6 mo. Yun *et al*[106] showed positive results at the end of 3 mo with selection of patients without diagnostic blocks. In contrast, Carette *et al*[103] in a large controlled trial showed a lack of effectiveness of intraarticular steroid injections with selection of the patients with a single

Table 2 Quality appraisal of the diagnostic accuracy of lumbar facet joint nerve block diagnostic studies

	Manchikanti *et al*[23]	Pang *et al*[25]	Schwarzer *et al*[22]	Schwarzer *et al*[84]	Manchikanti *et al*[86]	Manchikanti *et al*[79]	Manchikanti *et al*[85]	Manchikanti *et al*[93]	Manchikanti *et al*[94]	Manchikanti *et al*[88]	Manchikanti *et al*[82]	Manchikanti *et al*[90]	Manchukonda *et al*[91]	Manchikanti *et al*[92]	Manchikanti *et al*[95]	DePalma *et al*[24]
(1) Was the test evaluated in a spectrum of subjects representative of patients who would normally receive the test in clinical practice?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(2) Was the test performed by examiners representative of those who would normally perform the test in practice?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(3) Were raters blinded to the reference standard for the target disorder being evaluated?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
(4) Were raters blinded to the findings of other raters during the study?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(5) Were raters blinded to their own prior outcomes of the test under evaluation?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
(6) Were raters blinded to clinical information that may have influenced the test outcome?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
(7) Were raters blinded to additional cues, not intended to form part of the diagnostic test procedure?	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

(8) Was the order in which raters examined subjects varied?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(9) Were appropriate statistical measures of agreement used?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(10) Was the application and interpretation of the test appropriate?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(11) Was the time interval between measurements suitable in relation to the stability of the variable being measured?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(12) If there were dropouts from the study, was this less than 20% of the sample	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Total	9/12	8/12	9/12	9/12	9/12	9/12	9/12	9/12	9/12	9/12	9/12	9/12	9/12	9/12	9/12	9/12

Y: Yes; N: No. Source: Lucas *et al*[80].

block and Fuchs *et al*[104] provided undetermined results with a large number of injections over a period of 6 mo which is not applicable clinically.

Analysis of evidence

Lumbar facet joint nerve blocks in the diagnosis of chronic lumbar facet joint pain have an evidence level of Ⅰ based on 7 controlled diagnostic studies with 80% or more pain relief[23,88-92,95] and 6 studies with a criterion standard of at least 75% pain relief[24,85-87,93,94].

For therapeutic interventions, there is level Ⅱ evidence for the long-term effectiveness of using lumbar facet joint nerve blocks and radiofrequency neurotomy. For short-term improvement of 6 mo or less, lumbosacral intraarticular injections have evidence that is level Ⅲ.

DISCUSSION

This systematic review assessing the diagnostic accuracy and therapeutic efficacy of lumbar facet joint interventions assessed diagnostic facet joint nerve blocks and therapeutic intraarticular injections, facet joint nerve blocks, and radiofrequency neurotomy. There is level Ⅰ evidence for the diagnostic accuracy of lumbar facet joint nerve blocks, and level Ⅱ evidence for radiofrequency neurotomy, level Ⅱ evidence for lumbar facet joint nerve blocks, and level Ⅲ evidence for lumbosacral intraarticular injections for long-term improvement of > 6 mo.

Level Ⅰ evidence is established for diagnostic accuracy studies based on multiple high quality diagnostic accuracy studies that have pain relief of at least 75% as the criterion standard utilizing dual blocks with mild variability in the prevalence and false-positive rates. The therapeutic efficacy of radiofrequency neurotomy, based on multiple

Table 3 Methodological quality assessment of randomized trials of lumbar facet joint interventions utilizing Cochrane review criteria

	Manchikanti *et al*[102]	Carette *et al*[103]	Fuchs *et al*[104]	Nath *et al*[105]	van Wijk *et al*[97]	van Kleef *et al*[99]	Tekin *et al*[96]	Civelek *et al*[108]	Dobrogowski *et al*[98]	Cohen *et al*[109]	Ribeiro *et al*[107]	Moon *et al*[100]	Lakemeier *et al*[101]	Yun *et al*[106]
Randomization adequate	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Concealed treatment allocation	Y	Y	N	Y	Y	Y	Y	Y	U	N	Y	Y	Y	Y
Patient blinded	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N
Care provider blinded	Y	Y	N	Y	Y	Y	Y	N	Y	U	N	Y	N	N
Outcome assessor blinded	N	Y	Y	Y	Y	Y	Y	U	U	U	N	Y	N	N
Drop-out rate described	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
All randomized participants analyzed in the group	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Reports of the study free of suggestion of selective outcome reporting	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Groups similar at baseline regarding most important prognostic indicators	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Co-intervention avoided or similar in all groups	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Compliance acceptable in all groups	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Time of outcome assessment in all groups similar	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Score	11/12	11/12	8/12	12/12	12/12	12/12	12/12	9/12	10/12	8/12	10/12	9/12	9/12	9/12

Y: Yes; N: No; U: Unclear. Source: Furlan *et al*[78].

moderate to high quality randomized trials is level Ⅱ with 7 trials[96,98-101,105,108] showing efficacy for at least 6 mo follow-up, with discordant evidence demonstrating a lack of effectiveness in one moderate to high quality RCT[97]. There is level Ⅱ evidence for lumbar facet joint nerve blocks based on 2 moderate to high quality RCTs[102,108] for long-term improvement. For lumbosacral intraarticular injections, the evidence is level Ⅲ based on 3 RCTs[101,106,107] showing effectiveness with 2 randomized trials showing a lack of effectiveness[103,104].

In recent years, understanding lumbar facet joint pain, not only with pathophysiology, but with diagnostic and treatment strategies, has expanded with numerous publications[10,15,22-25,34-49,53-55,84-123]. Hancock *et al*[53] systematically assessed tests to identify the structures in the low back responsible for chronic pain, including facet joints. Their results demonstrated the lack of diagnostic accuracy for various tests. Thus, controlled diagnostic blocks seem to be the only viable and appropriate diagnostic method, despite discussions about the precision and accuracy of these techniques[10,34]. Although the majority of systematic reviews demonstrate the accuracy of controlled diagnostic blocks when performed by interventional pain physicians[10,28,34], others failed to demonstrate accuracy[50-52] though debate continues[10,28,34].

Rubinstein *et al*[32] of the Cochrane Review Musculoskeletal Group conducted a best-evidence review of neck and low back pain diagnostic procedures. They concluded that surprisingly, many of the orthopedic tests for the low back had very little evidence to support their diagnostic accuracy in clinical practice. They also concluded that lumbar facet joint nerve blocks performed for diagnostic purposes had moderate evidence for their use. This was based on systematic reviews and diagnostic accuracy studies performed by interventional pain physicians prior to 2008. Since then, the literature has expanded considerably. As such, despite the fact that a true placebo control technique may be the gold standard, due to practical difficulties, such as limited clinical utility and cost implications, as well as the ethical and logistic issues associated with using a true placebo[124-126], controlled comparative local anesthetic blocks with local anesthetics, both short-acting and long-acting, have become a recognized way for

Table 4 Methodological quality assessment of randomized trials utilizing Interventional Pain Management techniques - Quality Appraisal of Reliability and Risk of Bias Assessment criteria

	Manchikanti *et al*[102]	Carette *et al*[103]	Fuchs *et al*[104]	Nath *et al*[105]	van Wijk *et al*[97]	van Kleef *et al*[99]	Tekin *et al*[96]	Civelek *et al*[108]	Dobrogowski *et al*[98]	Cohen *et al*[109]	Ribeiro *et al*[107]	Moon *et al*[100]	Lakemeier *et al*[101]	Yun *et al*[106]
Ⅰ Trial design and guidance reporting														
(1) Consort or spirit	3	3	3	3	2	2	2	2	2	3	2	2	2	2
Ⅱ Design factors														
(2) Type and design of trial	2	3	2	3	3	3	3	2	2	2	2	2	2	2
(3) Setting/physician	2	1	1	3	3	3	2	2	2	2	2	2	1	1
(4) Imaging	3	3	2	3	3	3	3	3	2	3	3	3	3	3
(5) Sample size	3	2	2	1	1	1	1	1	1	3	2	2	2	2
(6) Statistical methodology	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ⅲ Patient factors														
(7) Inclusiveness of Population														
For facet joint interventions:	2	1	0	2	1	1	1	0	1	1	0	2	1	0
(8) Duration of pain	2	2	1	2	2	3	2	0	2	0	0	2	2	0
(9) Previous treatments	2	0	0	0	0	0	1	2	0	0	0	2	2	1
(10) Duration of follow-up with appropriate interventions	3	2	1	2	2	2	2	2	1	0	1	1	2	1
Ⅳ Outcomes														
(11) Outcomes assessment criteria for significant improvement	4	4	2	4	4	2	2	2	2	0	2	2	2	1
(12) Analysis of all randomized participants in the groups	2	2	2	2	2	2	2	2	2	2	2	0	2	2
(13) Description of drop out rate	2	1	2	2	2	2	2	2	2	2	2	2	2	2
(14) Similarity of groups at baseline for important prognostic indicators	2	2	2	2	2	2	2	2	2	2	2	2	2	2
(15) Role of co-interventions	1	0	0	1	1	1	1	1	1	1	1	1	1	1
Ⅴ Randomization														
(16) Method of Randomization	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Ⅵ Allocation concealment														
(17) Concealed treatment allocation	2	2	1	2	2	2	2	2	2	0	2	2	2	2
Ⅶ Blinding														
(18) Patient blinding	1	1	0	1	1	1	1	0	1	0	1	1	1	0
(19) Care provider blinding	1	1	0	1	1	1	1	0	1	0	0	1	0	0
(20) Outcome assessor blinding	0	1	0	0	1	0	0	0	0	0	0	1	0	0
Ⅷ Conflicts of interest														
(21) Funding and sponsorship	2	3	1	2	0	3	2	0	0	2	2	2	2	1
(22) Conflicts of interest	3	3	1	3	0	3	2	0	0	2	3	3	3	0
Total	45	40	26	42	36	40	37	28	29	28	32	32	38	37

Source: Manchikanti *et al*[79].

diagnosing chronic lumbar facet joint pain, without disc herniation or radicular pain, after failing conservative management. Once the diagnosis is established, patients may be offered treatment with lumbar facet joint nerve blocks or radiofrequency neurotomy, and perhaps intraarticular facet injections.

Significant progress also has been made with therapeutic interventions, according to RCTs and systematic reviews published over the past 5 years. Consequently, the quality and level of evidence for therapeutic interventions has been improving, with level Ⅱ evidence for long-term relief (longer than 6 mo) for radiofrequency neurotomy and therapeutic lumbar facet joint nerve blocks, even though the evidence for lumbosacral intraarticular injections continues to lack for long-term improvement and is level Ⅲ for short-term improvement.

There has been substantial controversy in reference to technique. Bogduk *et al*[71] have recommended parallel placement of the needle to achieve appropriate results

Table 5 Characteristics of studies assessing the accuracy of diagnostic facet joint injections and nerve blocks in the lumbar spine

Study/methods Methodological quality scoring	Participants	Intervention(s)	Outcome measures	Comments	Results	
					Prevalence with 95%CI and criterion standard	False-positive rate with 95%CI
Pang *et al*[25], 1998 Prospective, single block 8/12	100 consecutive adult patients with chronic low back pain with undetermined etiology were evaluated with spinal mapping	Single block was performed by injecting 2% lidocaine into facet joints	Verbal analog scale Pain mapping 90% pain relief	This is the first study evaluating application of diagnostic blocks in the diagnosis of intractable low back pain of undetermined etiology with facet joint disease in potentially 48% of patients with a single block	Single block 90% pain relief Only facet joint pain = 24% Lumbar nerve root and facet disease = 24% Total = 48%	NA
Schwarzer *et al*[22], 1994 Prospective, controlled diagnostic blocks 9/12	176 consecutive patients with chronic low back pain after some type of injury	Zygapophysial joint nerve blocks or intraarticular injections were performed with either 2% lignocaine or 0.5% bupivacaine	At least 50% pain relief concordant with the duration of local anesthetic injected	First study of evaluation of controlled prevalence and false-positive rates	50% pain relief 15% (95%CI: 10%-20%)	38% (95%CI: 30%-46%)
Schwarzer *et al*[84], 1995 Randomized, impure placebo, controlled diagnostic blocks 9/12	63 patients with low back pain lasting for longer than 3 mo underwent computed tomography and blocks of the zygapophysial joints	Patients underwent a placebo injection followed by intraarticular zygapophysial joint injections with 1.5 mL of 0.5% bupivacaine	At least 50% reduction in pain maintained for minimum of 3 h	This study shows that computed tomography has no place in the diagnosis of lumbar zygapophysial joint pain, with an impure placebo design	50% pain relief 40% (95%CI: 27%-53%)	NA
Manchikanti *et al*[95], 2010 Retrospective, controlled diagnostic blocks 9/12	491 patients with chronic low back pain undergoing evaluation for facet joint pain with 80% pain relief and 181 patients with 50% pain relief	Controlled diagnostic blocks of lumbar facet joint nerves with 1% preservative-free lidocaine and 0.25% preservative-free bupivacaine 1 mL	At least 80% pain relief with the ability to perform previously painful movements	Higher prevalence than with 50% pain relief, but still higher than double block algorithmic approach	50% pain relief 61% (95%CI: 53%-81%) 80% pain relief 31% (95%CI: 26%-35%)	50% pain relief 17% (95%CI: 10%-24%) 80% pain relief 42% (95%CI: 35%-50%)
Manchikanti *et al*[85], 2000 Prospective, controlled diagnostic blocks 9/12	200 consecutive patients with chronic low back pain were evaluated	Controlled diagnostic blocks with 1% lidocaine and 0.25% bupivacaine were injected over facet joint nerves with 0.4 to 0.6 mL	75% pain relief with ability to perform previously painful movements	The study showed that the clinical picture failed to diagnose facet joint pain	75% pain relief 42% (95%CI: 35%-42%)	37% (95%CI: 32%-42%)
DePalma *et al*[24], 2011 Retrospective, controlled diagnostic blocks 9/12	A total of 156 patients with chronic low back pain were assessed for the source of chronic low back pain including discogenic pain, facet joint pain, and sacroiliac joint pain	Dual controlled diagnostic blocks with 1% lidocaine for the first block with 0.5% bupivacaine for the second	Concordant relief with 2 h for lidocaine and 8 h for bupivacaine with 75% pain relief as the criterion standard	This is the third study evaluating various structures implicated in the cause of low back pain with controlled diagnostic blocks[23,25]	75% pain relief 31% (24%-38%)	NA
Manchikanti *et al*[93], 2001 Prospective, controlled diagnostic blocks 9/12	Prevalence study in 100 patients with 50 patients below age of 65 and 50 patients aged 65 or over was assessed	Controlled diagnostic blocks	75% pain relief with ability to perform previously painful movements was utilized as the criterion standard	This study showed higher prevalence of facet joint pain in the elderly compared to the younger age group in contrast to the latest study by Manchikanti *et al*[117] which showed no differences	75% pain relief < 65 yr = 30% (95%CI: 17%-43%) > 65 yr = 52% (95%CI: 38%-66%)	< 65 yr = 26% (95%CI: 11%-40%) > 65 yr = 33% (95%CI: 14%-35%)
Manchikanti *et al*[94], 2001 Prospective, controlled diagnostic blocks 9/12	100 patients with low back pain were evaluated. Patients were divided into 2 groups, group Ⅰ was normal weight and group Ⅱ was obese	Facet joints were investigated with diagnostic blocks using lidocaine 1% initially followed by bupivacaine 0.25%, at least 2 wk apart	A definite response was defined as relief of at least 75% in the symptomatic area	This study showed no significant difference between obese and non-obese individuals either with prevalence or false-positive rate of diagnostic blocks in chronic facet joint pain	75% pain relief Prevalence: Non-obese individuals = 36% (95%CI: 22%-50%) Obese individuals = 40% (95%CI: 26%-54%)	Non-obese individuals = 44% (95%CI: 26%-61%) Obese individuals = 33% (95%CI: 16%-51%)

Manchikanti *et al*[23], 2001 Prospective, controlled diagnostic blocks 9/12	120 patients were evaluated with chief complaint of chronic low back pain to evaluate relative contributions of various structures in chronic low back pain. All 120 patients underwent facet joint nerve blocks	Controlled diagnostic blocks with 1% lidocaine followed by 0.25% bupivacaine	80% pain relief with ability to perform previously painful movements	This study evaluated all the patients with low back pain, even with suspected discogenic pain	80% pain relief 40% (95%CI: 31%-49%)	47% (95%CI: 35%-59%)
Manchikanti *et al*[86], 1999 Prospective, controlled diagnostic blocks 9/12	120 patients with chronic low back pain after failure of conservative management were evaluated	Controlled diagnostic blocks with 1% lidocaine followed by 0.25% bupivacaine	Concordant pain relief with 75% or greater criterion standard with ability to perform previously painful movements	This was the first study performed in the United States in the heterogenous population as previous studies were performed in only post-injury patients	75% pain relief 45% (95%CI: 36%-54%)	41% (95%CI: 29%-53%)
Manchikanti *et al*[79], 2014 Prospective, controlled diagnostic blocks 9/12	180 consecutive patients with chronic low back pain were evaluated after having failed conservative management	Controlled diagnostic blocks with 1% lidocaine and 0.25% bupivacaine with or without Sarapin and/or steroids	75% pain relief with ability to perform previously painful movements	This study showed no significant difference if the steroids were used or not	75% pain relief 36% (95%CI: 29%-43%)	25% (95%CI: 21%-39%)
Manchikanti *et al*[88], 2003 Prospective, controlled diagnostic blocks 9/12	At total of 300 patients with chronic low back pain were evaluated to assess the difference based on involvement of single or multiple spinal regions	Controlled diagnostic blocks with 1% lidocaine followed by 0.25% bupivacaine	80% pain relief with ability to perform previously painful movements	This study shows a higher prevalence when multiple regions are involved	80% pain relief Single region: 21% (95%CI: 14%-27%) Multiple regions: 41% (95%CI: 33%-49%)	Single region: 17% (95%CI: 10%-24%) Multiple regions: 27% (95%CI: 18%-36%)
Manchikanti *et al*[82], 2014 Prospective, controlled diagnostic blocks 9/12	120 consecutive patients with chronic low back pain and neck pain were evaluated to assess involvement of facet joints as causative factors	Controlled diagnostic blocks with 1% lidocaine followed by 0.25% bupivacaine	80% pain relief with ability to perform previously painful movements	The results are similar to involvement of multiple regions with a prevalence of 40% as illustrated in another study	80% pain relief 40% (95%CI: 31%-49%)	30% (95%CI: 20%-40%)
Manchikanti *et al*[90], 2004 Prospective, controlled diagnostic blocks 9/12	500 consecutive patients with chronic, non-specific spinal pain were evaluated of which 397 patients suffered with chronic low back pain	Controlled diagnostic blocks with 1% lidocaine followed by 0.25% bupivacaine	80% pain relief with ability to perform previously painful movements	Largest study performed involving all regions of the spine	80% pain relief 31% (95%CI: 27%-36%)	27% (95%CI: 22%-32%)
Manchukonda *et al*[91], 2007 Retrospective, controlled diagnostic blocks 9/12	500 consecutive patients with chronic spinal pain were evaluated of which 303 patients were evaluated for chronic low back pain	Controlled diagnostic blocks with 1% lidocaine followed by 0.25% bupivacaine	80% pain relief with ability to perform previously painful movements	Second largest study performed involving all regions of the spine	80% pain relief 27% (95%CI: 22%-33%)	45% (95%CI: 36%-53%)
Manchikanti *et al*[92], 2007 Prospective, controlled diagnostic blocks 9/12	A total of 117 consecutive patients with chronic non-specific low back pain were evaluated, after lumbar surgical interventions, with postsurgery syndrome and continued axial low back pain	Controlled, comparative, local anesthetic blocks with 1% lidocaine and 0.25% bupivacaine	80% relief as the criterion standard with ability to perform previously painful movements	Lower prevalence in postsurgery patients	80% pain relief 16% (95%CI: 9%-23%)	49% (95%CI: 39%-59%)

NA: Not applicable.

Table 6 Study characteristics of randomized controlled trials of lumbar radiofrequency neurotomy, facet joint nerve blocks, and intraarticular injections

Study/study characteristic/ methodological quality Scoring	No. of patients and selection criteria	Control	Interventions	Outcome measures	Time of measurement	Reported results	Strengths	Weaknesses	Conclusion/ comments
Radiofrequency neurotomy									
Civelek *et al*[108], 2012 Randomized, active-control trial Quality scores: Cochrane = 9/12 IPM-QRB = 28/48	100 patients with chronic low back pain with failed conservative therapy and strict selection criteria; however, without diagnostic blocks	Facet joint nerve block with local anesthetic and steroids in 50 patients	Conventional radiofrequency neurotomy at 80 ℃ for 120 s in combination with high dose local anesthetic and steroids, in 50 patients	Visual Numeric Pain Scale, North American Spine Society patient satisfaction questionnaire, Euro-Qol in 5 dimensions and ⩾ 50% relief	1, 6 and 12 mo	At one year, 90% of patients in the radiofrequency group and 69% of the patients in the facet joint nerve block group showed significant improvement compared to 92% and 75% at 6-mo follow-up	Randomized relatively large number of patients with 50 in each group	No diagnostic blocks were performed. High dose steroids and local anesthetics were utilized in both groups	Efficacy was shown even without diagnostic blocks, both for facet joint nerve blocks and radiofrequency neurotomy
Cohen *et al*[109], 2010 Randomized, double-blind, control trial Quality scores: Cochrane = 8/12 IPM-QRB = 28/48	151 chronic low back pain, 51 patients with no diagnostic block, 50 patients a single diagnostic block, 50 patients in double diagnostic block	Radiofrequency neurotomy in patients without diagnostic blocks	Conventional radiofrequency neurotomy at 80 ℃ for 90 s in all patients; however, in 2 groups with either a single block paradigm or a double block paradigm testing for positive results	Greater than 50% pain relief coupled with a positive global perceived effect persisting for 3 mo	3 mo	Denervation success rates in groups 0, 1 and 2 were 33%, 39% and 64%, respectively	Multicenter, randomized controlled trial with or without diagnostic blocks	Authors misinterpreted cost-effectiveness without consideration of many factors reported	Results showed efficacy when double diagnostic blocks were utilized
Nath *et al*[105], 2008 Randomized, double-blind, sham control trial Quality scores: Cochrane = 12/12 IPM-QRB = 42/48	40 patients with chronic low back pain for at least 2 yr with 80% relief of low back pain after controlled medial branch blocks. The patients were randomized into an active and a control group	Controlled sham lesion in 20 patients in the control group	The 20 patients in the active group received conventional lumbar facet joint radiofrequency neurolysis at 85 ℃ for 60 s. The 20 patients in the control group received sham treatment without radiofrequency neurolysis of the lumbar facet joints	Numeric Rating Scale, global functional improvement, reduced opioid intake, employment status	6 mo	Significant reduction not only in back and leg pain; functional improvement; opioid reduction; and employment status in the active group compared to the control group	Randomized, double-blind trial after the diagnosis of facet joint pain with triple diagnostic blocks	Short-term follow-up with small number of patients	Efficacy of radiofreqency neurotomy was shown compared to local anesthetic injection and sham lesioning
Tekin *et al*[96], 2007 Randomized, active and sham, double-blind controlled trial Quality scores: Cochrane = 12/12 IPM-QRB = 37/48	60 patients with chronic low back pain randomized into 3 groups with 20 patients in each group. Single diagnostic block of facet joint nerves with 0.3 mL of lidocaine 2% with	Sham control with local anesthetic injection	Either pulsed radiofrequency (42 ℃ for 4 min) or conventional radiofrequency neurotomy (80 ℃ for 90 s) in 20 patients in each group	Visual analog scale and Oswestry Disability Index	3, 6 and 12 mo	Visual analog scale and Oswestry Disability Index scores decreased in all groups from 3 procedural levels. Decrease in pain scores was maintained in the conventional radiofrequency group at 6 mo and one year.	Randomized, double-blind, controlled trial comparing control, pulsed radiofrequency, and conventional radiofreqency neurotomy. Authors also utilized a parallel needle placement	Small sample size with a single block and 50% relief as inclusion criteria. Authors have not described the significant improvement percentages	Efficacy with conventional radiofreqency neurotomy up to one year, whereas efficacy with local anesthetic block with sham control radiofrequency neurotomy and

	50% or greater relief					However, in pulsed radiofrequency group, the improvement was significant only at 6 mo, but not 1 yr	approach		pulsed radiofrequency neurotomy at 6 mo only
van Wijk *et al*[97], 2005 Randomized, double-blind, sham control trial Quality scores: Cochrane = 12/12 IPM-QRB = 36/48	81 patients with chronic low back pain were evaluated with radiofreqency neurotomy with 41 patients in the control group with at least 50% relief for 30 min with a single block with intraarticular injection of 0.5 mL lidocaine 2%	Sham lesion procedure after local anesthetic injection	40 patients received conventional radiofrequency lesioning at 80 ℃ for 60 s and 41 patients received sham lesioning	Pain relief, physical activities, analgesic intake, global perceived effect, short-form-36, quality of life measures	3 mo	Global perceived effect improved after radiofrequency facet joint denervation. The visual analog scale in both groups improved. The combined outcome measures showed no difference between radiofreqency facet joint denervation (27.5% *vs* 29.3% success rate)	Double-blind, sham control, randomized trial	Poor selection with a single diagnostic block of 50% pain reduction even though 17.5% of the patients tested positive. Further, authors described that the needle was positioned parallel; however, the radiographic figures illustrate the needle was being positioned perpendicularly rather than parallel to the nerve	Lack of efficacy with methodological deficiencies and a short-term follow-up
Dobrogowski *et al*[98], 2005 Randomized, active control trial Quality scores: Cochrane = 10/12 IPM-QRB = 29/48	45 consecutive patients with chronic low back pain judged to be positive with controlled diagnostic blocks	Injection of saline in patients after conventional radiofrequency (85 ℃ for 60 s) neurotomy to evaluate postoperative pain	Conventional radiofrequency neurotomy at 85 ℃ for 60 s, followed by injection of either methylprednisolone or pentoxifylline	Visual analog scale, minimum of 50% reduction of pain intensity, patient satisfaction score	1, 3, 6 and 12 mo	Greater than 50% of reduction of pain intensity was observed in 66% of the patients 12 mo later. There was no difference in the long-term outcomes	Randomized, active control trial	Very small study evaluating effectiveness of radiofrequency neurotomy and postoperative pain	Radiofrequency neurotomy effective with or without steroid injection after neurolysis
van Kleef *et al*[99], 1999 Randomized, double-blind, sham control trial Quality scores: Cochrane = 12/12 IPM-QRB = 40/48	31 patients with a history of at least one year of chronic low back pain randomly assigned to one of 2 treatment groups. Single diagnostic block with 50% relief	Sham control of radiofrequency after local anesthetic injection in 16 patients	The 15 patients in the conventional radiofrequency treatment group received an 80 ℃ radiofrequency lesion for 60 s	Visual analog scale, pain scores, global perceived effect, Oswestry Disability Index	3, 6 and 12 mo	After 3, 6 and 12 mo, the number of successes in the lesion and sham groups was 9 of 15 (60%) and 4 of 16 (25%), 7 of 15 (47%) and 3 of 16 (19%), and 7 of 15 (47%) and 2 of 16 (13%) respectively. There was a statistically significant difference	Double-blind, randomized, sham controlled trial	A single block with a small sample with inclusion criteria of 50% pain relief to enter the study. The study has been criticized that electrodes were placed at an angle to the target nerve, instead of parallel (51A)	Efficacy shown in a small sample with a single diagnostic block

Moon *et al*[100], 2013 Prospective, randomized, comparative study Quality scores: Cochrane = 9/12 IPM-QRB = 38/48	82 patients were included with low back pain with 41 patients in each group either with a parallel placement of the needle or perpendicular placement of the needle	An active control trial with needle placement with perpendicular approach	41 patients in each group were treated with radiofrequency (80 ℃ for 90 s) after appropriate diagnosis of facet joint pain with dual diagnostic blocks with 50% relief as the criterion standard. The needle was positioned either utilizing a discal approach or perpendicular or utilizing tunnel vision approach with parallel placement of the needle	NRS, ODI	1 and 6 mo	Patients in both groups showed a statistically significant reduction in NRS and Oswestry disability index scores from baseline to that of the scores at 1 and 6 mo (all $P < 0.0001$, Bonferroni corrected)	Randomized, double-blind, controlled trial. The major strength is that authors have proven that parallel approach may not be the best as has been described. Diagnosis of facet joint pain by dual blocks	Active controlled trial without placebo group. Short-term follow-up	Positive results in an active controlled trial, in a relatively short-term follow-up of 6 mo, with positioning of the needle either with distal approach (perpendicular placement or tunnel vision) with parallel placement of the needle with some superiority with perpendicular approach. This trial abates any criticism of needle positioning one way or the other and the traditional needle positioning appears to be superior to parallel needle placement
Lakemeier *et al*[101], 2013 Randomized, double-blind, active controlled trial Quality scores: Cochrane = 9/12 IPM-QRB = 37/48	56 patients were randomized into 2 groups with 29 patients receiving intraarticular steroid injections and 27 patients receiving radiofrequency denervation after the diagnosis was made with intraarticular injection of local anesthetic with a single block	Intraarticular injection of local anesthetic and steroid	Radiofrequency neurotomy for 90 s at 80 ℃	Roland-Morris questionnaire, VAS, ODI, analgesic intake	6 mo	Pain relief and functional improvement were observed in both groups. There were no significant differences between the 2 groups for pain relief and functional status improvement	Lack of placebo group. Relatively short-term follow-up	Randomized, double-blind trial with single diagnostic block with intraarticular injection	Both groups showed improvement. Effectiveness at 6 mo in both groups with intraarticular injection or radiofrequency neurotomy
Lumbar facet joint nerve blocks									
Civelek *et al*[108], 2012 Randomized, active-control trial Quality scores: Cochrane = 9/12 IPM-QRB = 28/48	100 patients with chronic low back with failed conservative therapy and strict selection criteria; however, without diagnostic blocks	Blocks of facet joint nerves with local anesthetic and steroids	Conventional radiofrequency neurotomy at 80 ℃ for 120 s in combination with high dose local anesthetic and steroids	Visual Numeric Pain Scale, North American Spine Society patient satisfaction questionnaire, Euro-Qol in 5 dimensions and ⩾ 50% relief	1, 6 and 12 mo	At the end of one year, 90% of patients in the radiofrequency group and 69% of the patients in the facet joint nerve block group showed significant improvement *vs* 92% and 75% at 6-mo follow-up	Randomized active-control trial with relatively large number of patients with 50 in each group	No diagnostic blocks were performed. High dose steroids and local anesthetics were provided in both groups	Results showed efficacy even without diagnostic blocks, both for facet joint nerve blocks and radiofrequency neurotomy

Manchikanti *et al*[102], 2010 Randomized, double blind, active control trial Quality scores: Cochrane = 11/12 IPM-QRB = 45/48	120 patients with chronic low back pain of facet joint origin treated with therapeutic lumbar facet joint nerve blocks Double diagnostic blocks with 80% relief	Local anesthetic only	Total of 120 patients with 60 patients in each group with local anesthetic alone or local anesthetic and steroids. Both groups were also divided into 2 categories each with the addition of Sarapin	Numeric Rating Scale, Oswestry Disability Index, employment status, and opioid intake	3, 6, 12, 18 and 24 mo	Significant pain relief was shown in 85% in local anesthetic group and 90% in local anesthetic with steroids group at the end of the 2 yr study period in both groups, with an average of 5-6 total treatments	Randomized trial with relatively large proportion of patients with 2-yr follow-up, with inclusion of patients diagnosed with controlled diagnostic blocks	Lack of placebo group	Effectiveness demonstrated with facet joint nerve blocks with local anesthetic with or without steroids
Lumbar intraarticular injections									
Carette *et al*[103], 1991 Randomized, double blind, impure placebo or active-control trial Quality scores: Cochrane = 11/12 IPM-QRB = 40/48	Patients with chronic low back pain who reported immediate relief of their pain after injection of local anesthetic into the facet joints. Single diagnostic blocks with 50% relief were randomly assigned to receive injections under fluoroscopic guidance	Intraarticular injection of isotonic saline	Injection of either sodium chloride or methylprednisolone into the facet joints (49 for isotonic saline and 48 for sodium chloride). Only one injection was provided	Visual Analog Scale, McGill Pain Questionnaire, mean sickness impact profile	1, 3 and 6 mo	After 1 mo, 42% of the patients in the methylprednisolone group and 33% in the sodium chloride group reported marked or very marked improvement. At the 6 mo evaluation, 46% in the methylprednisolone group and 15% in the placebo group showed sustained relief. Revised statistics showed 22% improvement in active group and 10% in control group	Well-performed randomized, double-blind controlled trial	Only single block was applied and patients were treated with steroids without local anesthetic with only one treatment and expected 6 mo of relief	The authors concluded that results were negative in an active-control trial with injection of either sodium chloride solution or steroid into the facet joints after diagnosis with a single block
Fuchs *et al*[104], 2005 Randomized, double-blind, active-control trial Quality scores: Cochrane = 8/12 IPM-QRB = 26/48	60 patients with chronic low back pain were included with patients randomly assigned into 2 groups. No diagnostic blocks	Active-control study with no control group	Intraarticular injection of hyaluronic acid *vs* glucocorticoid injection	VAS, Rowland-Morris Questionnaire, ODI, low back outcomes score, short form-36	3 and 6 mo	Patients reported lasting pain relief, better function, and improved quality of life with both treatments	Randomized, active-control, double-blind study	Relatively small sample of patients with 6 mo follow-up without a placebo group, without diagnostic blocks	Undetermined (clinically inapplicable) results with high number of injections during a 6-mo period
Ribeiro *et al*[107], 2013 Randomized, double-blind, active control Quality scores: Cochrane = 10/12 IPM-QRB = 32/48	60 patients with a diagnosis of facet joint syndrome randomized into experimental and control groups	Triamcinolone acetonide intramuscular injection of 6 lumbar paravertebral points	Intraarticular injection of 6 lumbar facet joints with triamcinolone hexacetonide	Pain visual analogue scale, pain visual analogue scale during extension of the spine, Likert scale, improvement percentage scale, Roland-Morris, 36-Item Short Form Health Survey, and	1, 4, 12 and 24 wk	Both groups showed improvement with no statistical difference between the groups. Improvement "percentage" analysis at each time point showed significant differences between the groups at week 7 and week 12. Improvement percentage was > 50% at all times in the	Randomized, double-blind controlled trial	Diagnostic blocks were not employed, thus, many patients without facet joint pain may have been included in this trial	Overall intraarticular steroids showed positive effectiveness for 24 wk compared to intramuscular steroids provided in a double-blind manner

				accountability of medications taken		experimental group with intraarticular steroids; however, significant difference was noted at 24 wk			
Lakemeier *et al*[101], 2013 Randomized, double-blind, active controlled trial Quality scores: Cochrane = 9/12 IPM-QRB = 37/48	56 patients were randomized into 2 groups receiving intraarticular steroid injections or radiofrequency denervation after the diagnosis was made with intraarticular injection of local anesthetic with a single block	Intraarticular injection of local anesthetic and steroid in 29 patients	Radiofrequency neurotomy for 90 s at 80 ℃ in 27 patients	Roland-Morris questionnaire, VAS, ODI, analgesic intake	6 mo	Pain relief and functional improvement were observed in both groups. There were no significant differences between the 2 groups for pain relief and functional status improvement	Lack of placebo group. Relatively short-term follow-up	Randomized, double-blind trial with single diagnostic block with intraarticular injection	Both groups showed improvement. Effectiveness of both modalities at 6 mo in both groups
Yun *et al*[106], 2012 Randomized, active controlled trial Quality scores: Cochrane = 9/12 IPM-QRB = 26/48	57 patients with facet syndrome were assigned to 2 groups with 32 patients in the fluoroscopy group and 25 patients in the under ultrasonography group without diagnostic blocks	Intraarticular injection of lidocaine and triamcinolone under fluoroscopic guidance	Intraarticular injection of lidocaine and triamcinolone under ultrasonic guidance	VAS, physician's and patient's global assessment (PhyGA, PaGA), modified ODI	1 wk, 1 and 3 mo	Each group showed significant improvement from the facet joint injections. However at a week, a mo, and 3 mo after injections, no significant differences were observed between the groups	Randomized trial	Short-term follow-up with no diagnostic blocks, thus increasing the potential for inclusion of patients without facet joint pain. The aim of study mainly was to confirm if ultrasonic imaging was appropriate	The study showed positive results in both groups with intraarticular steroid injections with a short-term follow-up whether performed under ultrasonic guidance or fluoroscopy

IPM-QRB: Interventional Pain Management Techniques - Quality Appraisal of Reliability and Risk of Bias Assessment; VAS: Visual analog scale; ODI: Oswestry Disability Index.

with conventional radiofrequency neurotomy. However, an analysis of results shows no significant difference in outcomes with placement of the needle, either parallel or perpendicular. In fact, Moon *et al*[100], in a prospective randomized comparative trial of 82 patients, showed improvement to be equal in both groups. The selection criteria were dual diagnostic blocks with 50% relief. Dobrogowski *et al*[98] compared 45 consecutive patients in a randomized active-control trial studying the role of methylprednisolone or pentoxifylline after performing conventional radiofrequency neurotomy. The results were similar in both groups without any significant influence of methylprednisolone. The study essentially looked at postoperative pain relief with steroids after conventional radiofrequency neurotomy. Cohen *et al*[109] assessed the efficacy of radiofrequency neurotomy with a 3 mo follow-up with either no diagnostic blocks, single diagnostic block, or dual diagnostic blocks. The results were superior in patients selected after dual diagnostic blocks, with 64% responding; whereas in patients without a diagnostic block, the response rate was 33% and in the group with a single diagnostic block, the response rate was 39%. Civelek *et al*[108] performed conventional radiofrequency neurotomy in 50 patients without first performing any diagnostic blocks with significant improvement in 90% of patients at the end of one year. Nath *et al*[105], in a randomized double-blind sham control trial with a 6 mo follow-up, showed effectiveness of conventional radiofrequency neurotomy compared to sham lesioning and local anesthetic injection. The 2 RCTs assessing facet joint nerve blocks showed positive results in 69% of the patients by Civelek *et al*[108] and 90% of the patients by Manchikanti *et al*[102] with local anesthetic alone or with local anesthetic and steroids (85% in the local anesthetic group and 90% in the local anesthetic with steroids group) at the end of a 2-year period. However, lumbosacral intraarticular injections did not produce

convincing positive results, with some benefit on a short-term basis in 3 cases[101,106,107] and 2 trials[103,104] showing no response.

Even now, there remains significant controversy regarding the diagnostic accuracy and therapeutic efficacy of facet procedures, particularly in reference to interventional techniques, including escalating utilization patterns and costs[6,10,13,14,68,127]. In fact, in the United States, the Office of Inspector General of the Department of Health and Human Services conducted an assessment of the appropriateness of facet joint injections, concluding that many of the procedures were inappropriate, without medical necessity and indications[117]. Further, in the current regulatory atmosphere, many local coverage determinations may paradoxically increase the utilization of facet joint interventions[68]. The present data show that facet joint interventions have increased 293% per 100000 fee-for-service (FFS) Medicare population from 2000 to 2013, with an increase of 213% for lumbar facet joint interventions and a 522% for lumbosacral facet neurolysis. Likewise, there has been an increase in cervical and thoracic facet joint nerve blocks of 350%, and an increase in facet neurolysis of 845% from 2000 to 2013 in the FFS population[6,13,14,68]. However, the lumbar procedure increases appear to be smaller than cervical and thoracic facet joint interventions, even though the absolute procedure numbers are much higher for lumbar facet joint interventions. These data reflect only FFS Medicare patients in the United States, thus increases could be even higher.

There has been substantial discussion about various treatment strategies, control design of trials, placebo and nocebo effects, outcomes assessment between 2 active treatments rather than baseline to follow-up period, and ever-changing methodological quality assessment[10,15,50,51,55,128,129]. For interventional techniques, complex mechanisms and variations in placebo and nocebo responses have been well described[123-126,128-133]. Thus far, appropriately designed placebo studies, *i.e.*, injecting inactive solutions into inactive structures, have shown substantially accurate results without significant placebo effect[134,135]. Further, it is crucial to note that most investigators are missing the role of the nocebo effect[123-126]. Thus, clinical trials must be designed appropriately with clinical relevance to avoid erroneous conclusions. Further, many studies have used subacute or acute patients without standard conservative management.

The results of this systematic review are similar to the results of numerous other systematic reviews[10,28,51,54,55,69-73]; however, they do not agree with the systematic reviews of others[15,50]. Systematic reviews that showed a lack of effectiveness were often based on flawed methodology, also utilized in RCTs[136-144]. Our results are similar to those of Falco *et al*[28,54] even though we used stricter criteria for the methodological quality assessment. In addition, in a systematic review of the comparative effectiveness of different solutions, including local anesthetics and steroids, Manchikanti *et al*[136] showed equal efficacy of local anesthetic compared to steroids in long-term follow-up of lumbar facet joint nerve blocks; lumbar intraarticular facet injections were not found to be effective.

This evaluation included only RCTs for efficacy assessment, thus it can be argued that we missed many high quality observational studies[71,144]. However, with adequate randomized trials available for radiofrequency neurotomy and intraarticular injections, inclusion of observational studies would not alter the findings.

The current study illustrates the diagnostic value and validity of nerve blocks and the therapeutic effectiveness of facet joint interventions, specifically radiofrequency neurotomy and facet joint nerve blocks for managing lumbar spine pain. Sixteen diagnostic accuracy studies and 14 RCTs of therapeutic interventions demonstrated level Ⅰ evidence for using lumbar facet joint nerve blocks as a diagnostic tool for chronic low back pain, level Ⅱ evidence for the therapeutic benefit of radiofrequency neurotomy and facet joint nerve blocks for long-term improvement (longer than 6 mo), and level Ⅲ evidence with lumbosacral intraarticular injections for short-term improvement. Despite the debate regarding appropriate use of therapeutic modalities in managing lumbar facet joint pain, the accuracy of diagnostic facet joint nerve blocks and the efficacy of therapeutic facet joint interventions are supported by high-quality evidence for appropriately selected patients after failure of conservative treatment.

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COMMENTS

Background

In this systematic review, the diagnostic validity and therapeutic value of lumbar facet joint interventions in managing chronic low back pain were performed. Facet joint interventions are one of the multitude of modalities in managing chronic low back pain without disc herniation. There is a paucity of literature of not only systematic reviews, but also randomized controlled trials (RCTs) describing the efficacy of various modalities utilized and also diagnostic validity with controlled diagnostic blockade.

Research frontiers

There is a paucity of literature in assessing the diagnostic capability of various non-interventional and interventional modalities including radiologic investigations. Due to a lack of validity of various types of investigations, controlled diagnostic blocks have been considered as a reliable method in arriving at the diagnosis of facet joint pain. Similarly, there is also a paucity of literature in reference to therapeutic efficacy of various types of facet joint interventions utilized in managing chronic low back pain including intraarticular injections, facet joint nerve blocks, and radiofrequency neurotomy. By the same

token, there is also a paucity of systematic reviews assessing the value and validity of diagnostic and therapeutic facet joint interventions in the lumbar spine.

Innovations and breakthroughs

The previous systematic reviews have limited their assessment to either diagnostic or therapeutic validity and value. Further, assessment has been carried utilizing variable methodologic quality assessments. In this systematic review, the authors have utilized the most recent methodologic quality assessment instruments to assess not only bias, but also the methodologic quality of the studies included. Further, this systematic review includes all the up-to-date RCTs which were not included in previous systematic reviews.

Applications

The results of this systematic review are clinically oriented and applicable in daily practices. However, facet joint interventions must be performed only after the failure of all conservative modalities of treatments.

Terminology

Facet joint pain is described variously across the globe as facet joint pain, facet joint syndrome, and zygapophysial joint pain. Similarly, the structures are also described as either facet joints or zygapophysial joints. The innervation is described as medial branches from lumbar 1 (L1) through L4, whereas L5 innervation is described as the dorsal ramus.

Peer-review

This article is concerning management of lumbar zygapophysial (facet) joint pain. This thesis is an excellent review.

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CASE REPORT

Methicillin-resistant *Staphylococcus aureus* infected gluteal compartment syndrome with rhabdomyolysis in a bodybuilder

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Author contributions: Woon CYL designed the report and wrote the paper; Patel KR collected data and revised the paper; Goldberg BA revised and reviewed the paper for critical content.

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Abstract

Gluteal compartment syndrome (GCS) is a rare condition. We present a case of gluteal muscle strain with hematoma formation, methicillin-resistant *Staphylococcus aureus* (MRSA) superinfection, leading to acute GCS, rhabdomyolysis and acute kidney injury. This combination of diagnoses has not been reported in the literature. A 36-year-old Caucasian male presented with buttock pain, swelling and fever after lifting weights. Gluteal compartment pressure was markedly elevated compared with the contralateral side. Investigations revealed elevated white blood cell, erythrocyte sedimentation rate, C-reactive protein, creatine kinase, creatinine and lactic acid. Urinalysis was consistent with myoglobinuria. Magnetic resonance imaging showed increased T2 signal in the gluteus maximus and a central hematoma. Cultures taken from the emergency debridement and fasciotomy revealed MRSA. He had repeat, debridement 2 d later, and delayed primary closure 3 d after. GCS is rare and must be suspected when patients present with pain and swelling after an inciting event. They are easily diagnosed with compartment pressure monitoring. The treatment of gluteal abscess and compartment syndrome is the same and involves rapid surgical debridement.

Key words: Compartment syndrome; Rhabdomyolysis; Methicillin-resistant *Staphylococcus aureus*; Gluteal compartment; Acute kidney injury

Core tip: Gluteal compartment syndrome (GCS) is rare. Methicillin-resistant *Staphylococcus aureus* infected GCS with rhabdomyolysis and acute kidney injury has

not been reported. Compartment pressure monitoring and magnetic resonance imaging are useful for the diagnosis of this condition. Successful management comprises surgical fasciotomy, debridement together with antibiotics.

Woon CYL, Patel KR, Goldberg BA. Methicillin-resistant *Staphylococcus aureus* infected gluteal compartment syndrome with rhabdomyolysis in a bodybuilder. *World J Orthop* 2016; 7(5): 338-342 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i5/338.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i5.338

INTRODUCTION

Gluteal compartment syndrome (GCS) is a rare condition. It may present after prolonged immobilization[1] or after surgical procedures[2-4]. In this report, we present a case of gluteal muscle strain with hematoma formation, secondary bacterial superinfection by methicillin-resistant *Staphylococcus aureus* (MRSA), leading to elevated compartment pressures, resulting in acute GCS. This led to rhabdomyolysis and acute kidney injury. This combination of diagnoses has not previously been reported in the literature.

CASE REPORT

A 36-year-old healthcare professional presented with increasing right buttock pain, swelling and stiffness for two days. Six days prior, he performed stiff-leg deadlifts with 295lbs, and 2 d prior, he performed seated cable rows with 240lbs. This was an increase from his normal routine. After the cable rows, he developed increasing right buttock pain and swelling and a limp. He had no fever, chills or paresthesias and denied a history of penetrating trauma, use of intramuscular anabolic agents or personal or family history of bleeding diathesis. His past medical history was significant for acute disseminated encephalomyelitis at 24-25 years of age, treated with steroids and intravenous immunoglobulins for 6 mo. Because of this, he had persistent diminished sensation from the T6 dermatome distally. There were no previous episodes of sepsis following dentistry or innocuous trauma.

At the emergency department, he had 40.4 ℃ fever, pulse rate was 124 bpm, respiratory rate was 22 bpm, blood pressure was 131/60 mmHg. Examination revealed warm, erythematous, tender, hard swelling of the right buttock. The left buttock was normal. Right hip motion was limited by pain, with flexion to 45°, abduction to 30°, and internal and external rotation in flexion to 30°. Lower extremity sensibility was symmetrical and unchanged from before. Ankle dorsi- and plantar flexion strength was 5/5 bilaterally. Distal pulses were symmetric. Of note, he demonstrated gross hematuria at the bedside.

Laboratory tests revealed white blood cell count 20300/μL (normal, 3.9-12.0), 88.9% neutrophils, erythrocyte sedimentation rate 31 mm/h (normal: 0-10) and C-reactive protein 17.7 mg/dL (normal: 0.0-0.8). Creatine kinase (CK) was 740/μL (normal: 21-232, Figure 1A), and potassium was 5.0 mmol/L (normal: 3.5-5.3), ionized calcium was 3.1 mg/dL (normal: 4.2-5.4), phosphate was 2.3 mg/dL (normal: 3.0-4.5) and blood urea nitrogen/creatinine ratio was 11.6 (normal: 12-20), suggestive of rhabdomyolysis. Lactic acid was 2.3 mEq/L (normal: 0.5-2.2), creatinine was 1.72 mg/dL (normal: 0.5-1.5, Figure 1B). Urinalysis revealed moderate blood on macroscopic exam, but only 3 red blood cells/high-power field on microscopic exam, consistent with myoglobinuria.

Radiographs were unremarkable. Magnetic resonance imaging showed gluteus maximus swelling and increased T2 signal, consistent with a high-grade muscle strain, and a central 13 cm × 5 cm area of non-enhancement, suggestive of a hematoma (Figure 2). There was no hip joint effusion. A single dose of vancomycin and ceftriaxone was administered in the emergency room. Gluteal compartment pressures measured with the Stryker intra-compartmental pressure monitor (Stryker Surgical, Kalamazoo, MI) revealed compartment pressures of 58 mmHg and 4 mmHg for the right and left sides, respectively.

In the operating room, the gluteus maximus compartment was released using a Kocher-Langenbeck incision. Gross purulence was noted (Figure 3). Fascia over the tensor fascia lata (TFL) and gluteus medius was released and these 2 compartments were found to be uninvolved. The wound was irrigated and packed with wet-to-dry dressings. He was transferred to the intensive care unit for hydration and monitoring of renal function and serial CK (Figure 2). Intraoperative cultures revealed MRSA. Blood cultures were negative. Nasal cultures were negative for MRSA. He was started on vancomycin, cefepime and metronidazole after intraoperative cultures and adjusted to clindamycin based on final sensitivities.

He underwent repeat exploration, irrigation and debridement 2 d later. Necrotic, non-contractile gluteal muscle and cloudy interstitial fluid was noted. A necklace of antibiotic beads (Cobalt PMMA cement, Biomet, Warsaw, IN and 4 g of vancomycin powder) was placed and the wound was dressed with Ioban (3M, St Paul, MN). He underwent a third exploration 3 d later. The wound was clean and delayed primary closure was performed.

He was discharged the following day and seen in the office 10 d later. The incision had healed with no recurrence. He was discharged from further follow-up.

DISCUSSION

This patient had a unique combination of: (1) unilateral GCS; (2) MRSA infection of a hematoma; and (3) rhabdomyolysis and acute kidney injury following weightlifting.

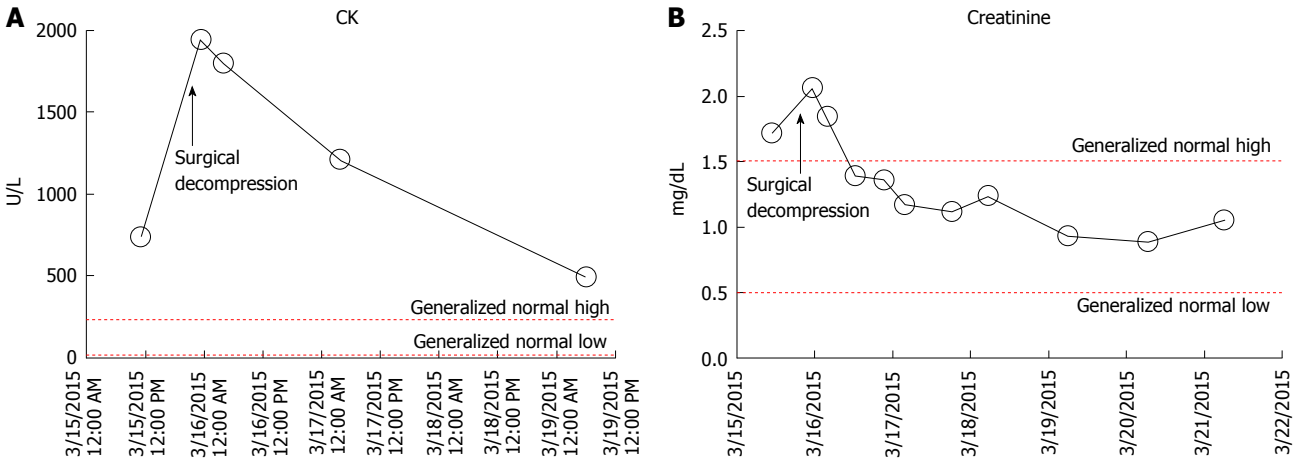

Figure 1 Graph of serum creatine kinase with time, showing (A) rapid normalization following surgical decompression, and (B) normalization following surgical decompression and aggressive hydration. CK: Creatine kinase.

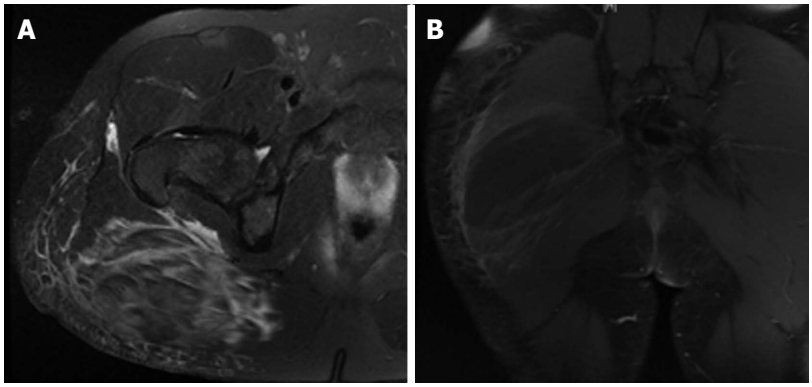

Figure 2 Magnetic resonance image. A: Axial PD FS MR image showing increased T2 signal in the gluteus maximus, with fluid extension to the trochanteric bursa and semitendinosus bursa, fluid in the deep fascia, and subcutaneous edema. There was no hip joint effusion; B: Coronal contrast-enhanced RT FS MR image showing a central 13 cm × 5 cm area of non-enhancement in the gluteus maximus, suggestive of a hematoma. MR: Magnetic resonance.

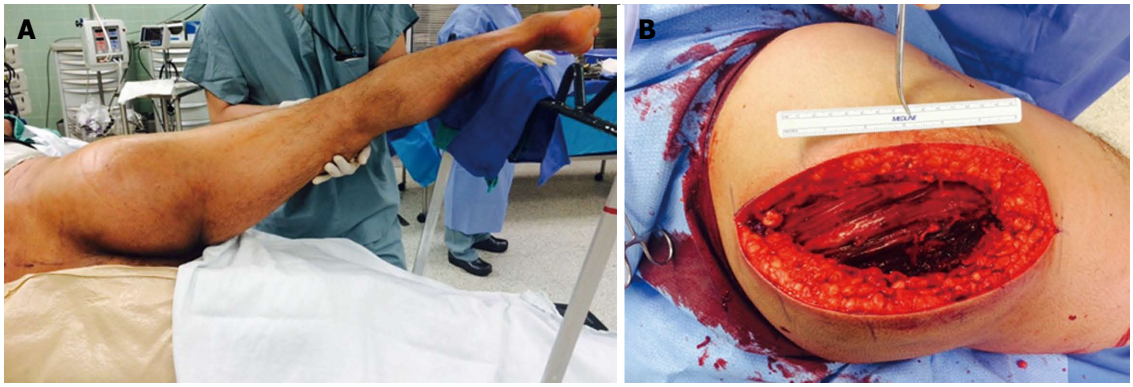

Figure 3 Intraoperative photograph (A) showing buttock swelling prior to surgical release, and (B) following surgical decompression.

Possible explanations include: (1) Acute muscle strain with expanding hematoma and bacterial superinfection, leading to elevated intracompartmental pressures; (2) Acute exertional compartment syndrome from acute muscle hypertrophy, causing GCS and late bacterial superinfection; (3) MRSA pyomyositis leading to GCS, and muscle ischemia; (4) Valsalva-related arteriole rupture, leading to an expanding hematoma, elevated intracompartmental pressures and muscle ischemia, and subsequent bacterial superinfection; and (5) Surreptitious intramuscular injection of anabolic agents (which he vehemently denies), community-acquired MRSA superinfection, late compartment syndrome and muscle necrosis. All these hypotheses share a final common pathway of elevated compartment pressures, muscle necrosis and rhabdomyolytic kidney injury.

The temporal relationship of events leads us to believe that the first scenario is the most likely. Acute exertional compartment syndrome is unlikely as he would have presented within hours of exertion with overwhelming signs of compartment syndrome.

This combination of findings has not been reported in the literature. GCS occurs most commonly following immobilization[1,5] because of diminished consciousness related to alcohol or illicit drugs[6], or prolonged surgery, *e.g.*, knee arthroplasty[2], hip arthroplasty[3], abdominal aortic aneurysm repair[7], and bariatric surgery[8]. Less common causes include falls and blunt trauma[9], intramuscular injections[10], and aerobic exercise[11].

Infected GCS can occur in tropical pyomyositis[12]. *Staphylococcus aureus* is responsible for > 75% of cases and the quadriceps, iliopsoas and gluteal muscles are most commonly affected. In these cases, it is believed that exercise elevates intracompartmental pressure with subsequent bacterial seeding[12]. Infected GCS can also occur with Group A Streptococcus pyogenes (GAS) infection. This usually occurs in immunocompetent individuals and mortality is lower than expected (15%) with other GAS infections because of earlier detection and debridement[13].

Iatrogenic bacterial seeding causing GCS can occur after intramuscular injection[10] or acupuncture. The risk is increased in anticoagulated patients, patients with bleeding diathesis, immunocompromised patients, and those with diabetes mellitus.

Acute exertional rhabdomyolysis, acute renal failure, and myoglobinuria after GCS, usually involves multiple other limb compartments[11]. Here, exercise-induced dehydration leads to rhabdomyolysis, while subsequent aggressive fluid resuscitation leads to limb swelling[11].

The diagnosis of GCS was made with needle manometry. David *et al*[14] described the entry points for manometry in the gluteus maximus, gluteus medius-minimus, and the TFL compartments[5]. Most authors advocate using either absolute compartment pressures > 30 mmHg or delta *P* < 30 mmHg as thresholds for surgical decompression.

The Kocher-Langenbeck incision provides excellent access to all 3 compartments and preserves femoral head vascularity[14]. Should greater exposure be required, Henry's "question mark" incision and medial reflection of the gluteus maximus as a "gluteal lid" is a feasible alternative[15]. Buttock soft tissue is pliable, well vascularized and mobile. Delayed primary closure is usually possible. Closure by secondary intention or skin grafting is almost never necessary. Rapid resolution of CK (Figure 1) after fasciotomy is an indicator of successful decompression[11].

COMMENTS

Case characteristics

This patient presented with right buttock pain and swelling after working out.

Clinical diagnosis

Examination revealed tender, hard swelling of the right buttock.

Differential diagnosis

Differential diagnoses includes compartment syndrome, myositis, cellulitis, necrotizing fasciitis, abscess, septic arthritis, deep vein thrombosis.

Laboratory diagnosis

Elevated serum white blood cell count with left shift, elevated erythrocyte sedimentation rate and C-reactive protein, elevated creatine kinase, potassium, creatinine and lactic acid.

Imaging diagnosis

Magnetic resonance imaging showed gluteus maximus swelling and hematoma.

Pathological diagnosis

Compartment pressures monitoring revealed elevated gluteal compartment pressures.

Treatment

Urgent surgical debridement, fasciotomy and intravenous antibiotics.

Related reports

Gluteal compartment syndrome (GCS) is rare but presents with similar physical findings as compartment syndromes of the leg, thigh and upper extremity. If constitutional signs and signs of local sepsis are present, suspect infected compartment syndrome.

Experiences and lessons

With methicillin-resistant *Staphylococcus aureus* (MRSA) superinfection of GCS urgent debridement is necessary to prevent systemic septicemia and tissue necrosis.

Peer-review

The manuscript on the management of the gluteal compartment syndrome due to MRSA infection and abscess is interesting, well-written and does have educational value to both practicing and trainee surgeons.

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