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EDITORIAL

Distinguishing erosive osteoarthritis and calcium pyrophosphate deposition disease

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Abstract

Erosive osteoarthritis is a term utilized to describe a specific inflammatory condition of the interphalangeal and first carpal metacarpal joints of the hands. The term has become a part of medical philosophical semantics and paradigms, but the issue is actually more complicated. Even the term osteoarthritis (non-erosive) has been controversial, with some suggesting osteoarthrosis to be more appropriate in view of the perspective that it is a non-inflammatory process undeserving of the "itis" suffix. The term "erosion" has also been a source of confusion in osteoarthritis, as it has been used to describe cartilage, not bone lesions. Inflammation in individuals with osteoarthritis actually appears to be related to complicating phenomena, such as calcium pyrophosphate and hydroxyapatite crystal deposition producing arthritis. Erosive osteoarthritis is the contentious term. It is used to describe a specific form of joint damage to specific joints. The damage has been termed erosions and the distribution of the damage is to the interphalangeal joints of the hand and first carpal metacarpal joint. Inflammation is recognized by joint redness and warmth, while X-rays reveal alteration of the articular surfaces, producing a smudged appearance. This ill-defined, joint damage has a crumbling appearance and is quite distinct from the sharply defined erosions of rheumatoid arthritis and spondyloarthropathy. The appearance is identical to those found with calcium pyrophosphate deposition disease, both in character and their unique responsiveness to hydroxychloroquine treatment. Low doses of the latter often resolve symptoms within weeks, in contrast to higher doses and the months required for response in other forms of inflammatory arthritis. Reconsidering erosive osteoarthritis as a form of calcium pyrophosphate deposition disease guides physicians to more effective therapeutic intervention.

Key words: Erosive osteoarthritis; Calcium pyrophosphate deposition disease; Rheumatoid arthritis; Spondyloarthropathy; Osteoarthritis; Hydroxychloroquine

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SEMANTICS

Semantics, philosophy and paradigms are at the core of how we name a disorder[1-11]. Thus, the term erosive osteoarthritis has been imbedded in the medical lexicon. The issue is complex. Even the term for the non-erosive phenomenon we recognize as osteoarthritis[7,8,10,12-26] is somewhat of a misnomer. Semantically, the suffix "itis" in osteoarthritis would suggest inflammation of a diarthrodial (synovial membrane-lined) joint. As osteoarthritis is associated with negligible inflammation[27,28], the suggestion has been made that osteoarthrosis is a more proper term[29]. Further, the term "erosions" has occasionally utilized in an imprecise manner to describe cartilage damage in osteoarthritis[27,28,30]. Actual erosions/disruption of subchondral bone does not occur.

INFLAMMATION

Inflammation of joints affected by osteoarthritis appears actually to be related to complications[31-35] and not to the primary disease. The most common complications are related to calcium pyrophosphate and hydroxyapatite crystals.

Erosive joint disease

The term "erosive osteoarthritis" has been utilized to describe a process which involves joints (interphalangeal and first carpal metacarpal) commonly affected by osteoarthritis, but is characterized by subchondral joint damage[36-38]. Joint tenderness, swelling, angulation, redness and warmth are often present, the latter two documenting an inflammatory process. Radiologic evaluation reveals abnormal articular surfaces, referred to as erosions. These erosions differ from what is found in the major forms of erosive arthritis, rheumatoid arthritis and spondyloarthropathy[3,39-42]. The term spondyloarthropathy defines a family of erosive arthritis including ankylosing spondylitis, psoriatic arthritis, reactive arthritis (replacing name of the war criminal, Reiter's syndrome), the arthritis of inflammatory bowel disease (ulcerative colitis and Crohn's disease) and an undifferentiated form). In contrast to the sharply delineated erosions of the latter, the term "crumbling" has been used to describe the joint damage characteristic of erosive osteoarthritis. The edges appear ill-defined or smudged[3,39,42]. There may be adjacent calcific flecks. This pattern actually describes the damage found in calcium pyrophosphate deposition disease[3,27,39,42].

Calcium pyrophosphate deposition disease

Not only is the character of osseous damage in erosive arthritis identical to that seen in other joints affected by calcium pyrophosphate deposition disease[3,39,43,44], the character of its response to therapeutic intervention is identical[43,44]. Hydroxychloroquine (Plaquenil) treatment, which has not effect on osteoarthritis, is extraordinarily effective in treatment of erosive osteoarthritis. Lower doses are required and the response rate is significantly more rapid in individuals with erosive osteoarthritis (now interpreted as a manifestation of calcium pyrophosphate deposition disease) than rheumatoid arthritis or spondyloarthropathy. Doses as low as 100 mg and control of inflammation within one to four weeks are not uncommon, in contrast to the three to six months required for recognizable response in patients with rheumatoid arthritis or spondyloarthropathy[44-46]. I suggest that the term "erosive osteoarthritis" has outlived its usefulness. Recognizing the characteristic damage as a manifestation of calcium pyrophosphate deposition disease directs attention to specific evidence-based interventions[39,44,47-59].

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REVIEW

Developmental dysplasia of the hip in the newborn: A systematic review

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Abstract

Developmental dysplasia of the hip (DDH) denotes a wide spectrum of conditions ranging from subtle acetabular dysplasia to irreducible hip dislocations. Clinical diagnostic tests complement ultrasound imaging in allowing diagnosis, classification and monitoring of this condition. Classification systems relate to the alpha and beta angles in addition to the dynamic coverage index (DCI). Screening programmes for DDH show considerable geographic variation; certain risk factors have been identified which necessitate ultrasound assessment of the newborn. The treatment of DDH has undergone significant evolution, but the current gold standard is still the Pavlik harness. Duration of Pavlik harness treatment has been reported to range from 3 to 9.3 mo. The beta angle, DCI and the superior/lateral femoral head displacement can be assessed *via* ultrasound to estimate the likelihood of success. Success rates of between 7% and 99% have been reported when using the harness to treat DDH. Avascular necrosis remains the most devastating complication of harness usage with a reported rate of between 0% and 28%. Alternative non-surgical treatment methods used for DDH include devices proposed by LeDamany, Frejka, Lorenz and Ortolani. The Rosen splint and Wagner stocking have also been used for DDH treatment. Surgical treatment for DDH comprises open reduction alongside a combination of femoral or pelvic osteotomies. Femoral osteotomies are carried out in cases of excessive anteversion or valgus deformity of the femoral neck. The two principal pelvic osteotomies most commonly performed are the Salter osteotomy and Pemberton acetabuloplasty. Serious surgical complications include epiphyseal damage, sciatic nerve damage and femoral neck fracture.

Key words: Developmental dysplasia of the hip; Congenital; Pavlik harness; Ultrasound screening; Pelvic osteotomy

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INTRODUCTION

Developmental dysplasia of the hip (DDH) denotes a wide spectrum of pathologic conditions, ranging from subtle acetabular dysplasia to irreducible hip dislocation with proximal femoral displacement[1]. The reported incidence of DDH varies from 1.5 to 2.5 per 1000 live births[1-3]. Unlike "congenital dysplasia of the hip", DDH is not restricted to congenital malformation, but also includes developmental disturbance[4]. The radiological definition relies on the presence of an intact Shenton line (Figure 1)[5]. The Shenton line remains intact in "subluxation" but disrupted in "dysplasia"[6]. The term dysplasia tends to be used for a hip with a positive Ortolani sign, *i.e.*, a dislocated hip that can be relocated back into the acetabulum. The typical dysplastic hip has a ridge in the superior-posterior and inferior aspects of the acetabulum. The ridge, or neo-limbus, as described by Ortolani, is composed of very cellular hyaline cartilage. The femoral head glides in and out of the acetabulum, producing the palpable sensation known as Ortolani's sign. An additional diagnostic test used to detect dysplasia is the "Barlow manoeuvre", whereby hip flexion and adduction causes the femoral head to leave the acetabulum[7]. Good evidence exists to suggest that untreated dysplasia will culminate in degenerative joint disease. The term "dislocation" is reserved for any hip with a negative Ortolani's sign, *i.e.*, an unreducible hip, that is associated with "secondary adaptive changes of shortening, decreased abduction and asymmetry of the folds"[8].

CLASSIFICATION OF DDH

Graf classified DDH according to various ultrasound measurements (Table 1). The infant remains in a lateral decubitus position and coronal images are taken with subsequent measurement of alpha and beta angles[9]. The alpha angle refers to the angle between the acetabular roof and vertical cortex of the ilium. The beta angle is the angle formed between the vertical cortex of the ilium and the triangular labral fibrocartilage (echogenic triangle). Type 1 hips are deemed mature, type 3 are referred to as immature (Table 1). Dynamic coverage index (DCI) refers to ultrasound measured femoral head coverage with the hip in coronal flexion and adduction. Grill *et al*[10] and Alexiev *et al*[11] used DCI to help formulate a DDH classification system. DCI was greater than 50% in stable hips, DCI was 30%-50% in moderate subluxation, DCI was 10%-35% for severe subluxation; DCI was less than 10% for dislocation.

SCREENING FOR DDH

Screening for DDH may be based upon clinical and/or ultrasound methodology. With clinical screening only, the late dislocation rate is reported as between 0.5 and 0.8 per 1000 live births[9,12]. Some studies[13,14] have suggested that clinical examination for DDH should be delayed until after the newborn period, due to the high rate of spontaneous stabilisation in the first 4 wk of life. Vedantam *et al*[15] suggested that dislocatable hips at birth could be safely monitored with ultrasound for two weeks before determining the course of treatment, reducing the number of infants requiring treatment, without prejudicing the final outcome. Clegg *et al*[16] reported a late dislocation rate of 0% in the 11-year history of their universal ultrasound screening program, but an operative rate of 0.21/1000 live births. They attempted to make a financial case for universal ultrasound screening due to reduction in mean surgical cost by earlier diagnosis of dysplasia/dislocation with subsequent need for fewer, less invasive procedures. Universal ultrasound screening of newborns however, is not deemed cost-effective by most North American authors, although in Europe, non-selective screening is more widely used[17]. van der Sluijs *et al*[13] reported the terms of the Dutch screening programme, which recommended clinical and ultrasound screening of infants between the ages of three and five months with one or more of the following risk factors: breech delivery, family history, leg length discrepancy or limited abduction of the hip. The current United Kingdom programme recommends ultrasound screening of high risk infants at six weeks[18,19]. Sampath *et al*[14] reported a late dislocation rate of 0.22-0.68/1000 live births in selective ultrasound screening programs.

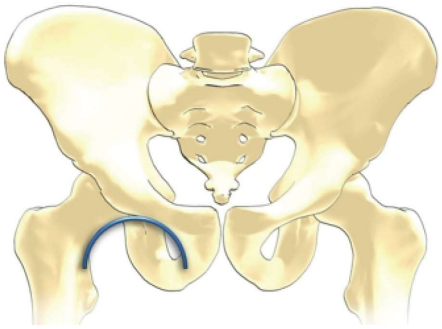

Figure 1 Diagram to demonstrate location of Shenton line. Shenton line is disrupted in developmental dysplasia of the hip[5].

NON-SURGICAL TREATMENT OF DDH: "A HISTORICAL EVOLUTION"

The treatment of children with DDH evolved markedly during the last century. Lorenz first proposed his method of forceful closed reduction and plastering in fixed maximal abduction. At the turn of the last century, most infants were not diagnosed to have dysplasia/dislocation until they started walking. The early 1900's saw the advent of the radiograph and blood transfusion, facilitating lower rates of morbidity from open reductions. Ortolani was the first to highlight the recognition of dislocation in infants below the age of 12 mo, using the clinical ma-

Table 1 The Graf classification[11]

Graf type	Angles
All type Ⅰ	Alpha angle > 60 degrees (normal)
Type Ⅰa	Beta angle < 55 degrees
Type Ⅰb	Beta angle > 55 degrees
All type Ⅱ	
Type Ⅱa	Alpha angle 50-59 degrees
Type Ⅱb	Alpha angle 50-59 degrees
Type Ⅱc	Alpha angle 43-49 degrees Beta angle < 77 degrees
Type D ("about to decenter")	Alpha angle 43-49 degrees Beta angle > 77 degrees
Type Ⅲ Type Ⅲa and Ⅲb distinguished on the grounds of structural alteration of the cartilaginous roof	Alpha angle < 43 degrees
Type Ⅳ (dislocated with labrum interposed between femoral head and acetabulum)	Alpha angle < 43 degrees

noeuvre that would come to bear his name. He supplemented this with his own version of an abduction brace.

In the 1950's, Arnold Pavlik published articles on hip dysplasia and "functional treatment" in response to high rates of avascular necrosis (AVN) and failed reductions using previous conservative treatments[2]. A system of a harness and stirrups was developed which is still in use today. The Pavlik harness is well established as the orthosis of choice for infants with DDH superseding multiple preceding devices[4,10,20-30]. The concept of manual, forceful reduction of the infant's hip with maintenance of limb flexion and abduction was updated to one of hip movement ("dynamic splintage") within a non-pathological range. This reduces the hip and corrects the acetabular dysplasia whilst also minimising the risk of femoral head AVN[7]. The principle centres upon the hip being a "basic joint of movement". Therefore, active and spontaneous motion results in "non-violent and unforced abduction and reduction". His landmark paper, *Zeitschrift fur Orthopaedie*, reported on 1912 hips, with an 85% rate of successful reduction and a 2.8% rate of AVN. This is in marked contrast to success rates of 30% using previously prevalent "passive mechanical" methods[9].

The Pavlik harness consists of two shoulder straps crossing on the back and fastened to a broad thoracic belt anteriorly (Figure 2)[31]. The legs are held in slings consisting of two straps and the hips are flexed to at least 90°. This flexion lines the proximal femoral metaphysis to point towards the triradiate cartilage, the conjoined physeal plate of the pelvic bones. The anterior strap keeps the hips in flexion, limiting extension. The posterior strap is adjusted to stop the lower limb breaking the midline, *i.e.*, to prevent adduction, rather than forcing abduction. Grill *et al*[10] noted that this is remarkably similar to the position of prenatal flexion of the thigh and the position of babies when traditionally carried on a mothers' back[2,32].

The main objective of harness application remains atraumatic, expedient relocation and maintenance of the

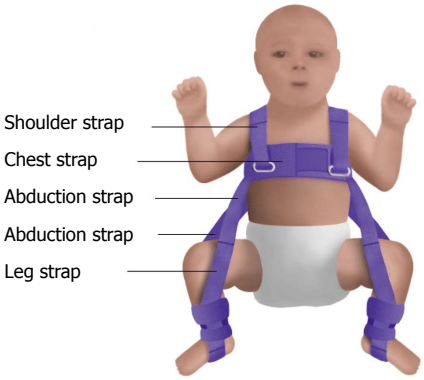

Figure 2 The Pavlik harness[31].

hip to resume normal development. Controlled reduction of the hip depends primarily on flexion and passive abduction. The concept of a "safe zone" for this movement was defined by Ramsey *et al*[27] as the "arc between the angle of abduction that can be comfortably attained and the angle that allows redislocation". Suzuki *et al*[33] reported that in some cases of dislocation, AVN rates could be reduced by the use of under thigh pillows during harness application. However, in cases of severe dislocation, some groups have stated that prevention of extreme abduction with under thigh pillows, was useless in reducing AVN[32]. In such cases, factors such as an inverted labrum, intraarticular interposition of pulvinar, elevated transverse ligament and hypertrophied round ligament are thought to be involved in the pathogenesis of AVN[3].

Weinstein *et al*[2] first highlighted the importance of quadriceps and gluteal muscle activity for optimal harness function. Iwaya *et al*[34] attributed the activity of the hamstrings in reducing dislocation. Relief of the adductor contracture was recognised by Pavlik as being indispensable for reduction. Early studies suggested that this was achieved *via* spontaneous lower limb movements. Modern thinking suggests the weight of the lower extremities plays a more significant role.

Use of the Pavlik harness is contraindicated when there is a major muscle imbalance, as in myelomeningocele (L2 to L4 functional level); major stiffness, as in arthrogryposis; or ligamentous laxity; as in Ehlers-Danlos syndrome[2].

PAVLIK HARNESS TREATMENT REGIMES

Various studies have recommended different durations of harness treatment. Erlacher[30] instructed his patients to wear the harness for approximately 6 mo, whilst Hirsch *et al*[35] believed in an average duration of 3 mo. Others have proposed regimes centred upon age at initiation of harness. Mubarak *et al*[36] suggested the harness should be worn for at least 3 mo by children younger than 3 mo of age, whereas in children older than 4 mo, it

should be worn for approximately double their age. They proposed weekly follow up with ultrasonography and appropriate harness adjustment. They believed such a regime would normally achieve hip stability within three weeks in cases of newborn true dislocation. Ramsey *et al*[27] recommended a mean treatment duration of 3.6 mo when treatment commenced before 1 mo, 7.0 mo between 1 and 3 mo, and 9.3 mo between 3 and 9 mo.

van der Sluijs *et al*[13] noted that one disadvantage of prolonged harness treatment destined to failure was a delay in the management of DDH using alternative strategies which could potentially be successful. Closed reduction at increasing ages is problematic, resulting in an increased incidence of open reductions and possibly higher rates of AVN. They concluded that the use of the Pavlik harness could be prolonged in patients with Graf type Ⅲ hips only if physical examination and ultrasonography showed improvement. A number of studies, including one in a cohort of Graf type Ⅲ/Ⅳ hips by Uçar *et al*[37] report that the likelihood of Pavlik harness treatment leading to a stable reduction markedly decreases after 3-4 wk duration. If the hip is not improved or reduced after 3 wk, some studies have suggested that the use of the harness be discontinued and the treatment plan changed[3,12,27,37-39].

MONITORING PAVLIK HARNESS TREATMENT WITH IMAGING

Grissom *et al*[40] and Polanuer *et al*[41] reported the results of ultrasound evaluation of the harness treatment in two cohorts of fifty patients. Their subjects remained in the harness with periodic adjustments to ensure proper fit and position with interval radiographs to monitor hip position. Ultrasound was deemed particularly useful in allowing good antero-posterior assessment of femoral-acetabular association in two dimensions. Several papers have reported the increased sensitivity of ultrasound scanning when compared with clinical examination[40,42]. One such study reported 100% sensitivity and 94% specificity for all dislocation/significant instability and noted the benefit of ultrasound monitoring for visualisation of soft tissue structures alongside the ability to assess hip position during harness adjustment. Viere *et al*[43] described "surreptitious reduction" as the process whereby hips treated by the harness remain dislocated and locked behind the posterior rim of the acetabulum. Ultrasound allows visualisation of such cases which can result in posterolateral acetabular deficiency with prolonged harness use.

Suzuki[44] reported the use of ultrasound in providing us with an indication of the likelihood of harness success by identifying three degrees of residual head displacement. Type A dislocations demonstrate contact between the femoral head and the acetabular wall, with no significant obstruction to the head returning to the bottom of the fossa. In type B dislocations the femoral head contacts the posterior margins of the socket. In type C dislocations the femoral head is displaced outside the socket, with its centre posterior to the acetabular rim. They suggested that the Pavlik harness was indicated in type A hips, appropriate for type B hips along with daily ultrasound monitoring and contraindicated in type C hips.

Whilst many authors showed that static ultrasound imaging could be a reliable way of detecting abnormality, Engesaeter *et al*[45] and Dias *et al*[46] reported poor reliability of static ultrasound and advocated solely dynamic assessment. A landmark study by Graf indicated that static and dynamic images should be used in conjunction[47]. Some studies have suggested the use of ultrasound in the prediction of poor acetabular development after walking age[11,48]. At a mean follow-up of 5 years, Alexiev *et al*[11] found that dynamic sonographic measures of stability such as a reduced DCI < 22% and a beta angle of < 43° showed 100% sensitivity for medium-term instability. They suggested that increased echogenicity of the cartilaginous roof on initial ultrasound was the most specific single predictor of residual dysplasia (sensitivity 100% and specificity 88%). The structurally normal cartilaginous roof is non-echogenic except for the labrum and ultrasound showed that in all successfully reduced hips in this series[11], the echogenic cartilage reverted to non-echogenic tissue. White *et al*[49] agreed that a DCI < 22% was predictive of failure. An inverted labrum and superior femoral head displacement correlated with poor outcome. Authors reported that a femoral head positioned below the labrum was strongly correlated with Pavlik harness success. They found that hips which displayed Pavlik failure had a significantly greater beta angle and significantly less lateral femoral head coverage at the time of presentation. Such cases are more likely to have an inverted labrum and to present later. They identified two new ultrasonographic markers, superior femoral head displacement relative to the labrum and total femoral head displacement. They found the latter to be the more reliable marker of failure.

The use of ultrasonography is not problem-free. Gwynne Jones[48] showed the considerable inter- and intra-observer variability of ultrasound measurement in neonatal hips. Ultrasound can detect abnormalities in the first few weeks of life which resolve spontaneously and scans at 4, 6 or 9 wk are more specific than earlier scans but this limits usefulness in screening.

In spite of these issues, many authors agree that the use of ultrasonography is the most significant development in the management of DDH since the development of the Pavlik harness itself[50-53].

PAVLIK HARNESS TREATMENT OUTCOMES

Overall, success rates of 7%-99% have been reported in cases of DDH using the Pavlik harness[8,38,39,54-58]. Cer-

tain studies have given lower peak success rates of 50%-80%[8,13,15,43,59]. Weinstein *et al*[2] highlighted the role of the harness in infants with limited hip abduction and documented acetabular dysplasia with or without subluxation. Following appropriate harness application, the contracted hip adductors stretch, allowing a full range of abduction within two weeks. Relief of adductor contracture is a key component of success, necessitating adductor tenotomy in some instances as originally proposed by Pavlik.

Failure of the device has been linked to improper use and poor compliance as noted by Lerman *et al*[38] and Mubarak *et al*[36]. The reported incidence of AVN ranges from 0%-28%[60-64]. Use of the Pavlik harness is associated with excessive flexion causing injury to the femoral nerve, excessive abduction causing AVN, and conversely insufficient flexion or abduction for maintenance of a stable reduction[65]. The maximum period for use of the harness is unknown. Some studies have suggested that long-term unsuccessful treatment is associated with a high rate of AVN, deformity of the femoral head and deficiency of the posterior acetabulum. van der Sluijs *et al*[13] disagreed with this and suggested that continued use of the harness could increase the number of successful reductions as long as abduction of the hip was continually improving, without risk of AVN or residual dysplasia[66]. By 12 wk, they reported that half of the type Ⅲ hips which eventually responded to bracing were not yet reduced. Consequently, a substantial proportion of these hips would have been potentially treated by surgery if Pavlik harnessing was limited to the conventional 4 wk. They reported that development of the hip was related to Graf type, rather than duration of bracing. The authors reported that prolonged bracing did not increase AVN, with their rates of AVN in Graf type Ⅲ and Ⅳ hips (16%), being equivalent to that of a previous study[33] where bracing was shorter. Suzuki[44] described the "type 1 error", occurring with incorrect prolonged use of the Pavlik harness in hips that remained unreduced in a posteriorly dislocated position. In such hips, the femoral head became adherent to the posterior capsule. This was reported to require open reduction from an anterior approach. The "type 2 error" occurs in hips that are too loose for successful treatment with the harness and require a more stable orthosis. Excessive duration of Pavlik harness use can therefore lead to erosion of the posterior acetabulum. Swaroop *et al*[18] highlighted the benefits of ultrasound in recognising failed improvement in abduction at three weeks.

The treatment of dislocated but reducible hips has proved problematic, with previous studies reporting success rates of 60%-70%[67,68]. The failed cases ultimately require operative treatment with closed or open reduction and hip spica casting. Swaroop *et al*[18] reported an increase in successful reductions of Ortolani positive hips, with two specific changes in treatment protocol; routine use of serial office based ultrasound examinations and transition to fixed hip abduction orthosis in hips remaining stable after three weeks in a Pavlik harness. The use of abduction braces in failed Pavlik harness treatment is contentious. Hedequist *et al*[69] suggested that it may be successful because cases of inferior dislocation were often resistant to Pavlik treatment and could be aggravated by flexion. Whilst numerous studies have highlighted the increased risk of AVN with more rigid devices, Hedequist *et al*[69] and Eberle[70] reported on a series of Ortolani positive hips treated with rigid devices after Pavlik failure, who were followed up until the development of a normal appearing ossific nucleus. They reported no incidence of AVN in their patients. Clearly, the numbers in these series were small and further study could establish more accurate incidence of AVN with abduction orthosis.

CONSEQUENCES OF PAVLIK HARNESS FAILURE

Harness failure has historically been associated with impaired femoral head/acetabular development and AVN. Rates of AVN following Pavlik treatment vary widely in historical studies from 0% to 28%[23,24,27,71], due to differences in definition of AVN and length of follow-up, indication for treatment and severity of dislocation.

The diagnosis of AVN has traditionally been made according to the Salter criteria[63]: (1) Failure of appearance of the ossific nucleus of the femoral head during 1 year or more after reduction; (2) Failure of growth in an existing ossific nucleus during 1 year or more after reduction; (3) Broadening of the femoral neck during 1 year after reduction; (4) Increased radiographic density of the femoral head followed by the radiographic appearance of fragmentation; and (5) Residual deformity of the femoral head and neck when reossification is complete.

Early studies did not analyse the reasons for any failure. Felipe and Carlioz mentioned 7 failures in 112 hips without discussing contributing factors or subsequent management, whilst the European Paediatric Society reported a failure rate of 14%, and also did not analyse reasons for failures[43]. An early study by Wilkinson suggested that an irreducible dislocation (Ortolani negative) hip was a contraindication to the use of the harness. Others[2,8,38,59,63,72] have disagreed. Viere *et al*[43] reported an early series in which despite recognition of an increased risk of harness failure, 11 of 27 such patients were treated successfully with the harness. They recommended a harness trial in patients with an Ortolani negative dislocation below the age of 7 mo, with discontinuation of treatment if concentric reduction was not achieved within 4 wk.

A number of early studies have highlighted delay in treatment beyond the age of 3 wk[67] and 7 wk[43], poor stability of the reduced hip, the initial acetabular index and an Ortolani negative clinical examination as risk fac-

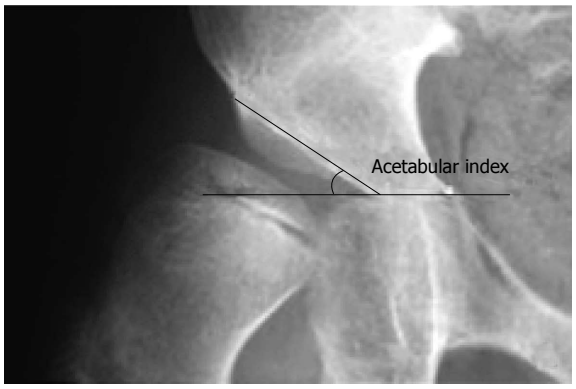

Figure 3 Calculation of acetabular index[95].

tors for Pavlik harness failure[63]. Inoue *et al*[73] highlighted poor treatment technique, including improper application of the harness leading to rigid fixation of the hip in a "frog-leg" position. Traditionally, there have been differing opinions concerning the relationship between instability and acetabular dysplasia, with some authors finding that instability could lead to dysplasia[63,74] and vice-versa[33,59].

Male gender is a recently cited factor[75] with some disagreement between studies[38]. Viere *et al*[43] and Lerman *et al*[38] found a statistically increased likelihood of failure with bilateral involvement, whereas Harding *et al*[67] and more recently, Borowski *et al*[76] found no increased association with bilaterality. A retrospective study by Kitoh *et al*[7] found that patients with bilateral DDH were approximately six times as likely to fail Pavlik harness treatment as those with unilateral DDH, whereas Borowski *et al*[76] found no significant association. Despite progression in radiological imaging, a number of studies have reported the severity of initial clinical examination to be the most powerful univariate predictor of failure of Pavlik harness treatment[38,43].

ALTERNATIVE NON-SURGICAL TREATMENT METHODS FOR DDH

Historically, there have been a number of alternative reduction devices used in DDH, such as stirrup devices proposed by LeDamany, Frejka, Lorenz and Ortolani[72]. However, the majority of the literature has shown the Pavlik harness to be superior in terms of successful reduction and AVN rates. The Frejka pillow for example has been associated with poor outcomes and high rates of AVN because it has the tendency to forcibly abduct the hips. Czubak *et al*[77] showed 89% successful reduction using the Frejka pillow, compared to 95% with the Pavlik harness and found the Pavlik harness to be more effective in hips diagnosed before 24 wk. They noted AVN in 12% and 7% of hips treated with the Frejka pillow and Pavlik harness respectively. The Rosen splint[72] is still used in many Scandinavian centres. Whilst reported to have high rates of success and few complications, it is only of use in newborns. Its use otherwise is associated with AVN and increased risks of skin irritation and pressure sores[18].

Recently various devices essentially based on the Pavlik harness have shown promising results. The "Wagner stocking" was reported by Pach *et al*[78] to have high rates of successful reduction and AVN rates in the region of 2.6%, comparable to some studies of the Pavlik harness. Clearly the evidence behind this is small compared to that concerning the Pavlik harness and longitudinal studies of outcomes are needed for significant comparison.

SURGICAL TREATMENT OF DDH

Failure to achieve hip reduction *via* closed techniques may dictate surgical open reduction techniques combined with femoral or pelvic osteotomy. Femoral osteotomies are performed to correct excessive anteversion or valgus deformity of the femoral neck. The pelvic osteotomies principally used for DDH include: (1) Salter innominate osteotomy[79-91] or (2) Pemberton pericapsular osteotomy[83,92-94]. Selection of a or b has been linked to the acetabular index (Figure 3)[31,95]. The Acetabular Index is the angle between the Hilgenreiner line and a line drawn from the triradiate epiphysis to the lateral edge of the acetabulum. This angle should decline with age and typically is less than 20 degrees by the time the child is 2-year-old. The Pemberton osteotomy tends to be favoured in cases where the acetabular index is greater than 40 degrees[96]. The Salter osteotomy is an open wedge osteotomy which retroverts and extends the acetabulum around a fixed axis such that the acetabular roof covers the femoral head both superiorly and anteriorly[97,98]. This osteotomy is designed to deliver more anterior femoral head coverage with less posterior coverage provided par consequence. Success depends upon a mobile pubic symphysis[99]. Böhm *et al*[100] reviewed the cases of 61 patients who had 73 Salter osteotomies and reported 15 failures; defined by the need for revision surgery or obtaining a Harris Hip Score of less than 70 points. The Pemberton Osteotomy is an incomplete transiliac osteotomy which starts approximately 10 mm superior to the anterior inferior iliac spine and advances posteriorly, ending at the ilioischial limb of the triradiate cartilage[101]. Wu *et al*[102] evaluated the results of 106 children (116 hips) with DDH treated with a Pemberton acetabuloplasty, reporting good to excellent results in 87% (with follow up ranging from 2 to 10 years). Complications of surgery for DDH include: AVN of the femoral head, sciatic nerve damage, K-wire breakage or migration, damage to the epiphyseal centre, femoral fracture and leg-length discrepancy[83].

CONCLUSION

DDH refers to a broad spectrum of conditions from mild acetabular dysplasia to irreducible hip dislocation. Screening programmes for DDH still vary worldwide

and more large-scale, longitudinal studies are needed to allow standardisation of policy across regions. Ultrasound imaging allows DDH classification based upon alpha/beta angles and the DCI. The appropriate management of DDH can have lasting consequences for lifetime morbidity. Non-surgical treatment methods for DDH have undergone historical evolution with the Pavlik harness remaining the treatment of choice worldwide. The Pavlik harness has undoubtedly led to progression in the successful treatment of DDH with a reduction in the incidence of short-term complications and developmental disturbance. Pavlik harness treatment does require meticulous clinical follow up often in conjunction with routine ultrasound imaging. Harness failure can however lead to femoral and acetabular developmental disturbance along with devastating AVN. Alternative non-surgical treatment methods have been reported for DDH such as the Wagner stocking and Frejka Pillow. Surgical management is a last resort for patients where harness treatment has failed. A combination of open reduction with femoral/pelvic osteotomy may be required.

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REVIEW

Pathophysiology, diagnosis, and treatment of discogenic low back pain

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Abstract

Discogenic low back pain is a serious medical and social problem, and accounts for 26%-42% of the patients with chronic low back pain. Recent studies found that the pathologic features of discs obtained from the patients with discogenic low back pain were the formation of the zones of vascularized granulation tissue, with extensive innervation in fissures extending from the outer part of the annulus into the nucleus pulposus. Studies suggested that the degeneration of the painful disc might originate from the injury and subsequent repair of annulus fibrosus. Growth factors such as basic fibroblast growth factor, transforming growth factor β1, and connective tissue growth factor, macrophages and mast cells might play a key role in the repair of the injured annulus fibrosus and subsequent disc degeneration. Although there exist controversies about the role of discography as a diagnostic test, provocation discography still is the only available means by which to identify a painful disc. A recent study has classified discogenic low back pain into two types that were annular disruption-induced low back pain and internal endplate disruption-induced low back pain, which have been fully supported by clinical and theoretical bases. Current treatment options for discogenic back pain range from medicinal anti-inflammation strategy to invasive procedures including spine fusion and recently spinal arthroplasty. However, these treatments are limited to relieving symptoms, with no attempt to restore the disc's structure. Recently, there has been a growing interest in developing strategies that aim to repair or regenerate the degenerated disc biologically.

Key words: Intervertebral disc; Degeneration; Diagnosis; Treatment; Discogenic low back pain; Classification; Internal disc disruption; Internal annular disruption; Internal endplate disruption

Core tip: Discogenic low back pain is the most common type of chronic low back pain. Why lumbar disc degeneration leads to pain is one of the most important topics in medical field. Studies have revealed that pathologic features of painful discs were the formation of the zones of vascularized granulation tissue, with extensive innervation in annular fissures. Provocation discography now still is the only available means by which to identify a painful disc. There are a multitude of treatments used in clinical practice to treat chronic low back pain, with little consensus amongst clinicians as to which is the best approach.

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INTRODUCTION

Chronic low back pain is a serious medical and social problem, and one of the common causes responsible for disability. It is estimated that, in all populations, an individual has an 80% probability of having low back

pain at some period during their life time, and about 18% of the population experiences low back pain at any given moment[1,2]. According to US National Center for Health Statistics reports, 14% of new patients that went to a hospital for treatment were patients with low back pain, which represents 13 million people. About 3% of all patients discharged from hospitals have symptomatic low back pain. The expense of treating low back pain is higher than $100 billion each year[3].

The prerequisite for successfully treating low back pain is to make an accurate pathological diagnosis. Despite the inherent challenge in elucidating the specific etiology of chronic low back pain, diagnostic procedures can reveal its source in 90% of patients. DePalma *et al*[4] found that the prevalence of zygapophysial joints, sacroiliac joints, and lumbar discs was 31%, 18%, and 42%, respectively. They confirmed the disc as the most common etiology of chronic low back pain in adults. Crock[5] first proposed the concept of internal disc disruption (IDD), which indicated the discogenic pain syndrome caused by disc degeneration and non-nerve root referred pain. IDD causing discogenic low back pain accounts for 26%-42% of chronic low back pain patients[4,6,7]. IDD had been assigned as a separate clinical entity to differentiate it from other types of disc degenerative low back pain, such as lumbar disc herniation, degenerative disc disease (DDD) and lumbar segment instability[8]. Lumbar X-ray images of IDD patients show no characteristic changes in degenerative disc diseases such as intervertebral space narrowing, osteophyte formation, endplate sclerosis, and gas formation within disc space[8].

This paper reviews the pathophysiology, diagnosis, and treatment of discogenic low back pain according to the existing literature.

PATHOPHYSIOLOGY

The intervertebral disc is the main joint between two consecutive vertebrae in the vertebral column. Each disc consists of three different structures: an inner gelatinous nucleus pulposus, an outer annulus fibrosus that surrounds the nucleus pulposus, and two cartilage endplates that cover the upper and lower surfaces of vertebral bodies. The cells that form the annulus fibrosus, particularly in the outer region, are fibroblast-like and arranged parallel to the collagen fibers, whereas those in the inner annulus fibrosus are chondrocyte-like. The nucleus pulposus contains collagen fibers that are randomly distributed and elastin fibers that are radially organized embedded in a highly hydrated aggrecan-containing gel. Chondrocyte-like cells synthesize type Ⅱ collagen, proteoglycans, and non-collagenous proteins that form the matrix of the nucleus pulposus and the cartilage endplate. Fibroblast-like cells synthesize type I and type Ⅱ collagen for the annulus fibrosus[9]. Proteoglycans consist of a core protein from which radiate chains of glycosaminoglycans containing keratin sulphate and chondroitin sulphate. Multiple proteoglycans are joined to a hyaluronic acid chain to form aggrecan. Aggrecans are held together by type Ⅱ collagen, which is cross-linked by type Ⅸ collagen. Aggrecan is the most common proteoglycan in the disc, and comprises approximately 70% of the nucleus pulposus and 25% of the annulus fibrosus. Aggrecan provides a high level charge density, which creates a high osmotic pressure for retaining water within the nucleus pulposus[10]. A young healthy disc behaves like a water bed, with the high water content of the nucleus and inner annulus enabling the tissue to act like a fluid. Only the outermost annulus acts as a tensile "skin" to restrain the nucleus.

Disc cells synthesize their matrix and break down existing matrix by producing and activating degradative enzymes, including matrix metalloproteinases (MMPs) and "a disintegrin and metalloproteinase" (ADAMS). Degradation of the matrix allows it to be refreshed by newly-synthesized components. Several growth factors, such as bone morphogenetic protein-2 (BMP-2), BMP-7 (also known as osteogenic protein-1; OP-1), growth differentiation factor-5 (GDF-5), transforming growth factor-β (TGF-β), insulin-like growth factor-1 (IGF-1), and others have been found to stimulate matrix production, while interleukin-1 (IL-1) and tumor necrosis factor-α (TNF-α) inhibit the synthesis of matrix by enhancing its catabolism[9,10].

Disc degeneration will occur if the matrix is not normal. At a molecular level, degeneration will be expressed by the production of abnormal components of the matrix or by an increase in the mediators of matrix degradation, such as IL-1 and TNF-α, and of MMPs and a reduction in the levels of tissue inhibitors of metalloproteinases (TIMPs). Several factors have been considered to cause disc degeneration. Genetic predisposition, mechanical load, and nutritional factors are widely regarded as important contributors to the degenerative process[11]. However; detailed characterization of this complex interplay remains elusive. With the disc degeneration, there is a net loss of proteoglycans and water from the nucleus, leading to poor hydrodynamic transfer of axial stresses to the outer anulus fibrosus. The disc degeneration may result from an imbalance between the anabolic and catabolic processes or the loss of steady state metabolism that is maintained in the normal disc. Alterations in both anabolic and catabolic processes are thought to play key roles in the onset and progression of disc degeneration.

Disc degeneration usually appears in magnetic resonance imaging (MRI) T2-weighted images as a decline in signal intensity, *i.e.*, the so-called "black" disc. MRI may identify a degenerative disc and an annular tear, but it will not help differentiate between a disc which is pathologically painful and one which is physiologically aging[12]. Disc degeneration is a very complicated biological process. Previous views on disc degeneration and the mechanism underlying it were mainly based on histological and biochemical studies using human disc herniation specimens from surgery and animal models of aging and degenerative discs[13,14]. However, the main histological

changes and the exact molecular mechanisms underlying the painful pathological disc remain unknown.

With the development and popularization of lumbar fusion, a greater number of painful pathological disc specimens can be obtained, which are beneficial for studies regarding the pathogenesis of painful disc degeneration. Based on our previous histological studies[15-17], we found that the composition and structure of painful disc differed from those of non-painful degenerative disc. Specifically, normal fibroblasts in the annulus fibrosus were replaced by cartilage-like cells. The annulus fibrosus lamellar structure was disordered and fractured. The normal highly hydrated gelatin-like nucleus pulposus, whose matrices showed obvious fibrosis, and cartilage-like cells, were completely replaced with fibroblasts, was substituted by fibrous tissues. The histological changes in the nucleus pulposus were divided into 3 major types: obvious fibrosis, vascular invasion, and inflammatory granulation tissue formation. In addition, we found that the characteristic change in painful pathological discs was the formation of inflammatory vascular granulation tissues with extensive innervation along the tears in the posterior annulus fibrosus, along with mass expression of some growth factors such as basic fibroblast growth factor (bFGF), TGF-β1, and connective tissue growth factor (CTGF). Vascular granulation tissue was not formed in asymptomatic degenerative discs, and only a few growth factors were expressed. Asymptomatic degenerative discs with tears are not painful, because these discs have not been innervated[15].

Blood vessels only exist in the longitudinal ligaments and the outermost layers of the annulus fibrosus in a normal disc. The ingrowth of vascularized granulation tissue along the tear deep into the inner annulus and nucleus pulposus in the painful disc probably begins soon after the injury when repair of the tear starts from the margin of the annulus fibrosus[15]. Owing to the absence of blood vessels in the inner annulus fibrosus and nucleus pulposus, it is unlikely that vascularized granulation tissue which is induced by the tear should originate from there. Different animal models of outer annular injury have proved that the healing of the annulus might initiate a progressive degeneration of the disc[18-24]. In addition, the whole process of healing of annulus fibrosus injury, including inflammatory reaction, formation of granulation tissue, and tissue reconstruction had been observed, implying that the disc has actually been torn and there has been a process of healing in progress[16].

According to recent researches on injury and repair, growth factors have been considered to be essential to regulate and control the whole process of repair of an injury. Some growth factors, such as bFGF, TGF-β, and CTGF, may be important as promoters in tissue repair. Growth factors that control cellular proliferation and differentiation *in vitro* have been identified. These factors mediate cellular interactions *in vivo*, which not only contribute to development and growth, regeneration, and wound healing, but also may incite abnormal changes[16]. Growth factors through their each receptor signal transduction pathway, promote cellular proliferation and collagen synthesis of matrix cells such as fibroblast and vascular endothelial cells, which exert a strong effect on adjustment and control of wound and repair[16]. Previous studies have indicated that bFGF as an important mitogen accelerator may directly act on the mitotic cycle of tissue repair cells (for example fibroblast), resulting in shortening of G1 phase, prolongation of G2 and M phases, thus mitotic cycle is shortened, and cell division and proliferation accelerates. TGF-β, as a multi-functional growth factor, not only can attract inflammatory cells and tissue repair cells to aggregate in the wound region, but also directly act on fibroblasts to stimulate synthesis of type I procollagen, formation of granulation tissue, and tissue reconstruction in the later stage of repair[25-27]. Nagano *et al*[28] in an animal model of disc degeneration found that bFGF was a proliferation stimulating factor promoting proliferation of chondrocytes to replace normal annular cells in degenerated discs in an autocrine or paracrine manner. Tolonen *et al*[29] studied expression of bFGF and TGF-β in painful degenerative discs, and found that growth factors strongly express in both the annulus fibrosus and the nucleus pulposus. Their study suggests that these growth factors promote cellular remodeling, and create a cascade in the process of disc degenerateion.

Disc tissues are different from other tissues because they comprise the largest avascular tissue. In other tissues, injury healing proceeds from the inside to the outside. On the contrary, healing in disc tissues proceeds from the outside to inside[16]. When the annulus fibrosus is lacerated or injured, vascular tissues can only gradually develop from the outer to the inner annulus fibrosus. Endothelial cells migrating into discs form the principal parts of a new capillary vessel. With the help of various growth factors, endothelial cells migrating into the avascular disc tissues differentiate, proliferate, and gradually form complicated capillary networks. Our studies[15-17] suggested that as annulus fibrosus injuries stimulated local vascular inflammatory reactions, cells including macrophages and mast cells in inflammatory regions produce a large number of growth factors such as bFGF, TGF-β1, and CTGF. The cells in normal disc are separated from the circulatory system. These increased growth factors acted on the intervertebral disc cells, and promoted disc cell dedifferentiation and proliferation, as well as large-scale extracellular matrix synthesis via signal transduction. This may be the main cause of painful disc fibrosis and degeneration. The strong expression of proliferating cell nuclear antigen (PCNA) in painful discs seemed to be an evidence of this hypothesis. PCNA, a nucleoprotein of nonhistone, is an essential auxiliary protein of DNA polymerase-δ[16]. It can markedly increase activity of DNA polymerase-δ, and its expression level is believed to be an important measure of cell proliferation activity[30].

The normal disc is believed to be an organ that is poorly innervated supplied only by sensory and sym-

pathetic perivascular nerve fibers. In the early 1980s, Bogduk[31] clarified the innervation of the outer layers of the annulus. The posterior part of the human disc was supplied not only from the sinuvertebral nerve but also received direct branches in its posterolateral aspect from the ramus communicans or the ventral ramus. Branches from the grey ramus communicans also supplied the lateral aspect of the disc. Anterior discal nerves were observed to arise solely from the sympathetic plexus surrounding the anterior longitudinal ligament. The sensory fibers that innervated the disc are mainly nociceptive and, to a lesser extent, proprioceptive. The sympathetic fibers are considered vasomotor efferents, and also sympathetic afferents conveying pain impulses[32]. The close association of the postganglionic efferent and sympathetic afferent fibers reflected a similar pattern to that seen in certain enteric organs, leading them to suggest that low back pain is a kind of visceral pain[33-35]. In human degenerated disc, as well as in animal models of disc degeneration, the number of nerve fibers in the disc increases[15,36,37]. Furthermore, the nociceptive nerve fibers grow into what are usually aneural inner parts of the annulus and even into the nucleus. In addition to the sensory nerve fibers, there is growing evidence that sympathetic afferents are also increased in degenerated disc and that they play a significant role in low back pain[38-40]. In human normal disc, protein gene product 9.5-positive nerve fibers, either associated with blood vessels or distant from them, innervate the outer layers of the annulus. These nerve fibers are also positive for acetylcholinesterasem NFP, SP, CGRP, VIP, neuropeptide Y, C-flanking peptide and synaptophysin. The nerves entering the rat disc have an identical expression pattern[32]. Mechanical stimuli which are normally innocuous to disc nociceptors can, in certain circumstances, generate an amplified response which has been termed 'peripheral sensitization'. This may explain why some degenerative discs are painful and others not. There is growing evidence that these pain receptors in painful disc are peripherally sensitized by the activity of sympathetic efferents which may initiate a pain impulse in response to ischaemia, pressure changes or inflammatory irritation[32].

It is accepted that the lumbar disc, which are the main source of discogenic back pain in humans, are innervated segmentally. However, the ventral portions of the rat lower lumbar discs are innervated by upper (L1-L2) dorsal root ganglion neurons and the nerve fibers innervating the posterolateral portion of the disc come from the upper and lower dorsal root ganglion (L3-L6)[38,39]. Nerve fibers reach the lumbar disc through the sinuvertebral nerves or from branches of the paravertebral sympathetic trunks[40]. Clinical studies have indicated those local anaesthetic blocks of L2 nerve root can relief discogenic low back pain[41].

DIAGNOSIS

The diagnostic criteria for IDD established by the International Association for the Study of Pain (IASP) are emergence of a concordant pain response during discography, internal annular disruption shown by CT after discography (CTD) and at least one adjacent disc without concordant pain[42]. The term IDD was first coined by Crock[5] on the basis of a large group of patients whose disabling back and leg pain became worse after operation for suspected disc prolapse. He reported this condition, characterizing it by disruption of the internal architecture of the disc, discogenic back pain in the absence of peripheral disc shape abnormality, and the absence of nerve root compression. At present, IDD has been described as a distinct clinical entity to be distinguished from other painful processes such as degenerative disc disease and segmental instability[8]. In our a previous study, according to discography, we classified discogenic low back pain into two types that were annular disruption-induced low back pain (IAD) and internal endplate disruption-induced low back pain (IED), which have been fully supported by clinical and theoretical bases[43]. The term IAD should be more reasonable than the term IDD clinically and pathologically. Clinically, these two types of low back pain should be confirmed by lumbar discography. The diagnostic processes, radial tear and pain responses are identical. During the process of contrast medium injection, the contrast medium was either flowing to the outside of disc through a radial annular tear, or flowing to the vertebral body through the radial endplate tear. The concordant pain responses would be induced in either way.

According to the "Modified Dallas Discogram Description" method[44,45], the degrees of annular disruption could be classified into four grades. The definitions are Grade 0: the contrast medium is confined within the normal nucleus pulposus; Grade 1: the contrast medium flows into the inner third of the annulus through annular fissure; Grade 2: the contrast medium flows into the middle third of the annulus; Grade 3: the contrast medium flows into the outer third of the annulus, and extends circumferentially less than 30° arc at the disk center; Grade 4: the contrast medium flows into the outer third of the annulus, and extends circumferentially more than 30° arc at the disk center; and Grade 5: the contrast medium leakage into the outer space. Grades 0, 1 and 2 are normal, while Grades 3 and above are indicative of annular disruption. We combined the discogram and CT scan after discography to evaluate the degree of endplate disruption in IED patients. The disruptive degrees were classified into four grades (Figure 1): Grade 0 (no disruption), Grade 1 (contrast medium flows into the cartilage endplate through tear), Grade 2 (contrast medium flows into the bony endplate), Grade 3 (contrast medium flows into the cancellous bone of vertebra under endplate, showing local dispersion) and Grade 4 (contrast medium disperses extensively in the cancellous bone)[43]. In this group of patients with IED, all intervertebral discs that showed concordant pain responses had endplate disruptions more severe than Grade 3, which was consistent with the distributions of blood vessels and nerves in the

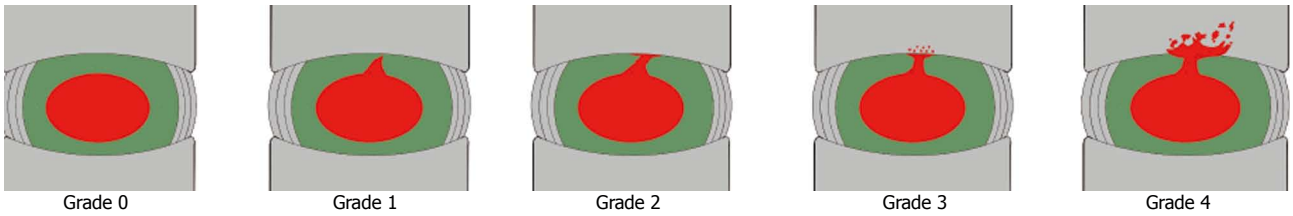

Figure 1 Endplate disruption grading method schematic diagram.

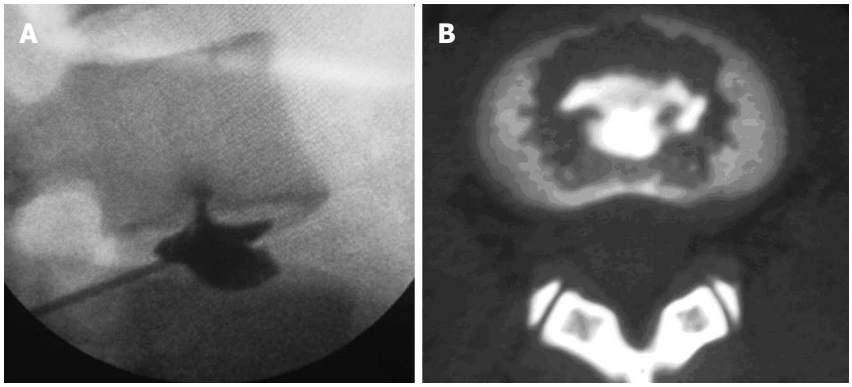

Figure 2 Discography and computed tomography. A: Discography showing a radial disruption on the lower endplate of L4 vertebra and that the contrast medium flows into the cancellous bone of the lower endplate of L4 vertebra through the fissure; B: Computed tomography scan showing the contrast medium dispersed in the lower endplate of L4 vertebra, with Grade 4 endplate disruption.

endplate (Figure 2)[43].

Theoretically, any innervated vertebra and its peripheral structures might be the source of low back pain. An intervertebral disc has such a structure that, except for the peripheral parts around annulus fibrosus, the endplate also has nerve supplies. Normally, one vertebral endplate has two nerve supplies: one enters the endplate along with perivertebral blood vessels, while the other that belongs to the sinuvertebral nerve branch that enters the endplate through the intervertebral foramen. The nerve density within the endplate is similar to that of the annulus, indicating that the endplate is also an important source of discogenic low back pain[46]. Recently, we published a clinical study article[47], 21 patients with chronic back pain originating from the endplate injuries were selected to explore the methods of diagnosis and surgical treatment. Pain level of disc was determined through discography in each patient. All 21 patients with a diagnosis of back pain originating from endplate injuries according to discography were treated with anterior or posterior fusion surgery. After operation, through a mean follow-up of three years and five months, we found that in all the 21 patients, 20 (20/21) reported a disappearance or marked alleviation of low back pain and experienced a definite improvement in physical function. The study suggests that discography and fusion surgery may be very effective methods for the diagnosis and treatment, respectively, of chronic back pain originating from the endplate injuries. In fact, endplate damage-induced low back pain occurs quite often clinically. In clinical research, we found that endplate damage-induced low back pain accounted for 16.7% of chronic discogenic low back pain. Epidemiological investigation showed that the incidence of endplate damage among populations without low back pain was 30%[48].

Theoretically, the pathogenesis of endplate disruption-induced discogenic low back pain is presumed to be consistent with that of annular disruption. A large number of animal experiments have indicated that damage to the outer layer of the annulus could induce a progressive degeneration of the entire disc[19-23]. Similarly, animal models have indicated that needle punctures from the vertebral side all the way through the endplate into the disc could induce a progressive degeneration of the entire disc[49]. It was found that the apoptosis of nucleus pulposus cells increased and the proteoglycan content decreased after endplate injury in the endplate damage animal model[50]. The ingrowth of nerves and blood vessels is a characteristic of tear discs, and is also directly correlated with discogenic low back pain. Freemont *et al*[51] found that blood capillaries grew in companion with nerve endings into the painful discs through endplates.

Basic and clinical studies have overwhelmingly illustrated the nerve supply of the disc and pathomorphologic correlates[6-9,15,18,36,37,52-58]. Based on controlled evaluations, the lumbar intervertebral discs have been shown to be sources of chronic low back pain without disc herniation in 26% to 42%[4,6,7]. Because of the variety of anatomic and pathophysiologic causes of chronic low back pain, it is a difficult diagnosis for clinicians to make. Clinicians primarily use advanced imaging techniques, such as MRI to diagnosis low back pain. Studies show that MRI findings such as disc degeneration do not correlate with the presence or severity of low back symptoms. Lumbar

provocation discography is a procedure that is used to characterize the pathoanatomy and architecture of the disc and to determine if the disc is a source of chronic low back pain. Recently, the American Pain Society developed and published multiple guidelines[59,60] in managing low back pain which did not recommend discography as a diagnostic test because of poor evidence for its sensitivity, specificity, and predictive value. However, subsequently, these guidelines were severely criticized[52]. There were deficiencies and inappropriate evaluation in almost all areas; inappropriate studies were included and appropriate studies were excluded. The basic deficiency of these guidelines by Chou and Huffman[59] was their failure to recognize the discography must not be performed in asymptomatic volunteers or patients with mild low back pain. They also utilized outdated guidelines from AHCPR and European COST guidelines[52]. In the interim, questioning the validity of discography warrants questioning the role of the disc as a discrete pain generator, or more specifically, challenges the concept of symptomatic internal disc disruption. If one considers discography to be a useless test, then one may have to abandon the concept of the disc as a discrete pain generator and abandon the pursuit of intradiscal therapies, whether surgical or non-surgical[52]. Recent systematic reviews have concluded that there is strong evidence that lumbar discography can identify the subset of patients with chronic discogenic pain[61,62].

TREATMENT

Treatment for discogenic low back pain has traditionally been limited to either conservative management or surgical fusion. However, to accurately assess the effect of any therapy for treating discogenic low back pain, the natural history of such pain should be known beforehand. Recently, our a clinical study indicated that the natural history of discogenic low back pain was continuous and chronic[63]. This result indicates that most patients are expected to experience low back pain after a longer time interval, and their pain severity is expected to remain nearly the same. The elucidation of natural history of discogenic low back pain has important clinical significances for decision-making of treatments.

There are a multitude of treatments used in clinical practice to treat chronic low back pain, with little consensus amongst clinicians as to which is the best approach. Pharmacologic treatment usually includes analgesics, nonsteroidal anti-inflammatory drugs, and muscle relaxants, but the evidence for their efficacy is not compelling. In randomized trials, the differences in pain after a patient has taken nonsteroidal anti-inflammatory agents as compared with placebo have generally been in the minimally detectable range[64]. A meta-analysis revealed that opioids seem to have a small effect in improving function and relieving pain for the patients with chronic low back pain[65]. Long-term treatment with narcotics is generally discouraged, given the associated risks of tolerance and side effects. Physical therapy, exercise, manipulation, and back school seem to have some effects, but it is unknown if effects are sustained for the long term[64]. Exercise therapy by the McKenzie method is a popular treatment for low back pain among physical therapists. Clinical studies have indicated that the McKenzie method is slightly more effective than manipulation or is equal to strengthening training for patients with chronic low back pain[66,67].

If conservative treatment fails, then epidural injections are commonly performed for chronic discogenic pain. Epidural injections are administered by accessing the lumbar epidural space by multiple routes including interlaminar, caudal, and transforaminal[68-79]. Epidural procedures continue to be debated regarding their effectiveness, indications, and medical necessity. Recent systematic reviews indicated that effectiveness of epidural injections for treatment of discogenic low back pain was fair[80]. The underlying mechanism of action of epidurally administered steroid and local anesthetic injection is still not well understood. It is believed that the achieved neural blockade alters or interrupts nociceptive input, the reflex mechanism of the afferent fibers, self-sustaining activity of the neurons, and the pattern of central neuronal activities[80]. Further, corticosteroids have been shown to reduce inflammation by inhibiting either the synthesis or release of a number of pro-inflammatory mediators and by causing a reversible local anesthetic effect[81-85].

As alternative treatments, percutaneous treatments directed at altering the internal mechanics or innervation of the disc by heat (intradiscal electrothermal annuloplasty, IDET, and biacuplasty) have recently been advocated[7,86,87], but data supporting their use are controversial[86]. IDET was first used to treat discogenic low back pain in 1996, using a concection technology with a 5 cm active tip placed at the uncleoannuar junction. Two randomised trials have shown either no effect or benefit in only a small number of highly selected subjects[88-90]. Further, of the 6 observational studies[91-96], 4 studies showed positive results, one study showed negative results, and one study showed undermined results. Recent a systematic review evaluated these studied, and concluded that the evidence is fair for IDET[97]. Biacuplasty is one of the minimally invasive treatment methods. It creates heat across the posterior annulus using a cooled bipolar radiofrequency device[98]. The initial study results are promising[99,100], but the effectiveness needs to be evaluated further to use randomized controlled trials.

During recent decades, surgical fusion of the lumbar spine has been performed in increasing number on patients with chronic low back pain[4]. However, the reported results vary considerably in different studies, and the complication rate after fusion surgery in the lumbar spine is not negligible[101-105]. Consequently, artificial disc replacement has been proposed as a substitute for spinal fusion with the aim of treating back pain while preserving vertebral motion at the operated levels and protecting adjacent levels from undergoing degenerative changes, but so far, only several studies have been reported on the

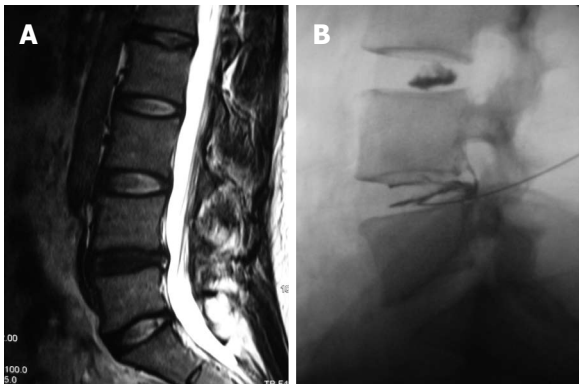

Figure 3 Magnetic resonance imaging and discography. A: A 35-year-old woman had a 5-year history of low back pain. Sagittal T2 weighted magnetic resonance imaging showed L4/5 disc degeneration with a high intensity zone in the posterior annulus fibrosus; B: Discography showed L4/5 disc disruption with exact pain reproduction. After discography, 10 mg methylene blue was injected into the painful disc through discographic needle. Low back pain was almost totally relieved. No recurrence was observed at a 12-mo follow-up interval.

results of lumbar disc prosthesis[106-108]. Recent a systematic review suggested that the spine surgery community should be prudent to adopt this technology on a large scale because harm and complications may occur after some years[109]. The results with longer follow-up need to be observed further.

Based on the recent insights into signal transduction mechanisms that might lead to the induction of pain by degenerative discs, it is conceivable that therapies aiming at disrupting pro-inflammatory signaling pathways and the pathway of nerve conduction might be successful in the foreseeable future. Such therapies might not have the ability to reverse the progressing tissue destruction which occurs with aging but may transform a symptomatic to asymptomatic disc degeneration and thereby greatly improve life quality of the affected patients[10]. Recently, a minimally invasive method, intradiscal methylene blue injection for the treatment of painful disc degeneration, had been reported (Figure 3)[110,111]. This successful outcome subsequently was demonstrated by the animal experiments which indicated that methylene blue indeed had destroyed the nerve endings or nociceptors and alleviated inflammatory response in the degenerated discs[112,113].

Recently, there has been a growing interest in developing strategies that aim to repair or regenerate the degenerated disc biologically. Treatments for degenerated discs have two main objectives: restoration of the disc' s structure and elimination of pain[114]. The benefits of biologically based treatments appear to be limited to restoring disc structure. Whether disc regeneration would result in pain relief remains unclear. That said recent data from animal studies have shown changes in cytokine expression following growth factor injection, indicating a possible mechanism for pain relief. Further, the first human clinical trial for growth factor injection therapy is currently underway and may shed light on the clinical outcome. Mesenchymal stem cells (MSCs) may also help relieve pain by reducing inflammation. A recent study indicates that MSCs can induce the production of anti-inflammatory cytokines[115]. However; additional studies are needed to elucidate the underlying mechanisms of pain relief.

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MINIREVIEWS

Bone morphogenetic protein in complex cervical spine surgery: A safe biologic adjunct?

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Abstract

The advent of recombinant DNA technology has substantially increased the intra-operative utilization of biologic augmentation in spine surgery over the past several years after the Food and Drug Administration approval of the bone morphogenetic protein (BMP) class of molecules for indications in the lumbar spine. Much less is known about the potential benefits and risks of the "off-label" use of BMP in the cervical spine. The history and relevant literature pertaining to the use of the "off-label" implantation of the BMP class of molecules in the anterior or posterior cervical spine are reviewed and discussed. Early prospective studies of BMP-2 implantation in anterior cervical spine constructs showed encouraging results. Later retrospective studies reported potentially "life threatening complications" resulting in a 2007 public health advisory by the FDA. Limited data regarding BMP-7 in anterior cervical surgery was available with one group reporting a 2.4% early (< 30 d) complication rate (brachialgia and dysphagia). BMP use in the decompressed posterior cervical spine may result in neurologic or wound compromise according to several retrospective reports, however, controlled use has been reported to increase fusion rates in select complex and pediatric patients. There were no cases of *de novo* neoplasia related to BMP implantation in the cervical spine. BMP-2 use in anterior cervical spine surgery has been associated with a high early complication rate. Definitive recommendations for BMP-7 use in anterior cervical spine surgery cannot be made with current clinical data. According to limited reports, select complex patients who are considered "high risk" for pseudoarthrosis undergoing posterior cervical or occipitocervical arthrodesis or children with congenital or traumatic conditions may be candidates for "off-label" use of BMP in the context of appropriate informed decision making. At the present time, there are no high-level clinical studies on the outcomes and complication rates of BMP implantation in the cervical spine.

Key words: Cervical spine; Bone morphogenetic protein; Bone morphogenetic protein

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DECADE OF BONE MORPHOGENETIC PROTEIN EMERGENCE IN THE UNITED STATES

Biological augmentation of spinal surgery procedures has substantially increased in the United States over the past decade with the advent of genetic engineering techniques and the Food and Drug Administration (FDA) approval and marketing of several synthetic products. A great deal of therapeutic potential has been associated with the "Bone Morphogenetic Protein" (BMP) class of molecules since the Nobel Prize nominated work of Marshall Urist in 1965 demonstrated their ability to transduce intracellular signaling pathways towards the genesis of bone and cartilage tissues[1]. Basic science studies laid the groundwork for later pre-clinical studies that demonstrated definitive evidence of rhBMP-2 induced os-

teoinduction in a small series of 11 humans[2]. The more recent foray of these powerful signal transduction agents into the clinical realm has brought to light both powerful efficacy and the potential for serious and even fatal complications.

In 2002, the FDA granted pre-market approval of rhBMP-2 (rhBMP-2 - Infuse Bone Graft, Medtronic Sofamor Danek, Memphis, TN) for use in adult patients undergoing single-level anterior lumbar interbody fusion (ALIF) from L2 to S1 for degenerative disk disease[3]. Two years later, a second subtype of recombinant BMP molecule was also approved by the FDA, BMP-7 (rhBMP-2 - OP-1 Putty, Stryker Biotech, Hopkinton, MA) as an alternative to autograft in patients requiring revision posterolateral (intertransverse) lumbar spinal fusion, for whom autologous bone and bone marrow harvest are not feasible or are not expected to promote fusion (patients with osteoporosis, smokers, and diabetes)[4].

Any new therapeutic procedure, technique, or medication will bring a finite number of associated complications. In the ensuing time period following the translation of these biological adjuncts into the operating room, a series of reports has sparked great concern about potential adverse sequelae. In July of 2010, a 33% higher concentration formulation of Medtronic's rhBMP-2 product featuring a compression-resistant matrix (AMPLIFY Matrix - 2.0 mg/cc compared to INFUSE 1.5 mg/cc) that was designed to induce *de novo* bone formation without iliac crest bone graft (ICBG) was rejected by the FDA due to possible increased cancer risks in susceptible individuals[5]. In 2011, secondary analysis of Medtronic-funded studies found an increased cancer risk associated with rhBMP-2 (AMPLIFY) in patients undergoing posterolateral lumbar fusion. Reports of increased retrograde ejaculation following ALIF procedures[6,7] and that complication rates associated with BMP are 10 to 50 times higher than the original estimates in industry-sponsored peer-reviewed publications have recently been publicized[6]. The ensuing media attention to these studies has resulted in a decline in the use of biologics in spine surgery applications[8].

Much less is known about the "off-label" use of the BMP class of molecules in the cervical spine. To understand the incidence and spectrum of reported complications associated with BMP use in the cervical spine, the relevant clinical studies reported in the literature are reviewed and discussed.

ANTERIOR CERVICAL SURGERY WITH BMP

The efficacy of rhBMP-2 use in the anterior cervical spine has been evaluated by several groups as "off-label" indications have been found in parallel with those approved by the FDA.

Prospective studies

An early pilot study in 2003, was designed as a prospective randomized trial comparing rhBMP-2 to cancellous autogenous ICBG inside a fibular allograft in 33 patients. All patients underwent plated anterior cervical discectomy and fusion (ACDF) for degenerative cervical disk disease[9]. At 2-years follow-up, both groups demonstrated solid fusion in all patients. Interestingly, the rhBMP-2 group had superior improvement in neck disability and arm pain scores. In this pilot study, anecdotal observation of two cases of heterotopic bone anterior to the graft in the rhBMP-2 group and one in the autograft group were made. Given the limited numbers of patients, conclusive statements on potential adverse events could not be made. In 2004, a second pilot study prospectively followed 20 patients that underwent ACDF with rhBMP-2 contained within a bioabsorbable spacer demonstrated bridging bone across the interspace in 100% of patients[10]. Buttermann confirmed these reports in a prospective nonrandomized consecutive series of 66 patients with either ICBG or BMP-allograft. Two patients in the ICBG group had pseudarthrosis compared to one patient in the BMP-allograft group at 2-3 year follow-up. However, 50% of the patients in the BMP allograft group had "neck swelling" presenting as dysphagia compared to 14% in the ICBG group[11].

Retrospective studies

Several retrospective studies raised concerns about the use of BMP in the anterior cervical spine. In 2005, Boakye *et al*[12] reported an uncontrolled retrospective report of good clinical outcomes and solid fusion with rhBMP-2 implanted inside of a polyetherehterketone (PEEK) spacer for single and multi-level ACDF in 24 patients. By 2006, retrospective reviews of 151 patients who underwent either anterior cervical corpectomy (n = 13) or ACDF (n = 138) augmented with high dose INFUSE (up to 2.1 mg/level) reported a complication rate of 23.2% due to hematoma requiring surgical evacuation or readmission due to swallowing/breathing difficulties or dramatic swelling in the absence of a hematoma[13]. A subsequent retrospective report of 69 patients confirmed the high complication rate associated with BMP-2 use in ACDF constructs with 27.5% having clinically significant swelling[14]. In 2007, retrospective reports of significantly more dysphagia following ACDF with rhBMP-2 and increased anterior soft tissue shadow for the first 6 wk postoperatively on lateral C-spine radiograph were accompanied by similar clinical outcomes at 2-years[15].

Radiographic reports

These early reports of excellent fusion rates were later accompanied by radiographic reports of endplate erosion and subsidence associated with rhBMP-2. In 2007, a prospective study of cervical interbody fusion with allograft and rhBMP-2 demonstrated significant subsidence of cervical interbody grafts of a mean height of 53% that occurred in more than half of the operative levels[16]. Further radiographic studies comparing polyetherehterketone (PEEK) cages and BMP for spinal fusion demonstrated an enhanced fusion rate with a concomitant

prevertebral soft-tissue swelling in patients who underwent ACDF. Radiographic evidence of a resorptive phase of BMP-2 resulting in endplate absorption has been reported by several groups to occur in 100% of patients undergoing ACDF[15,17,18].

FDA public health advisory

In March of 2007, a case report of a 54 year-old male presenting with neck swelling and difficulty swallowing 5 days after ACDF with rhBMP-2 resulting in respiratory distress and reintubation was published[19]. By July of that year, early "off-label" use of BMP in the cervical spine resulted in at least 38 reports of complications over the preceding 4 years[20]. This provided the impetus for the FDA to issue a public health advisory of "life-threatening complications" due to severe swelling and airway compromise. Many practitioners continue to implant BMP in the cervical spine despite this advisory in a select group of patients in the context of thorough patient education and informed decision making.

BMP use after the FDA advisory

Following the FDA advisory in 2007, reports of acute airway obstruction between postoperative days 2 and 7 remained a significant concern. Yaremchuk reported in 2010 a retrospective review of 260 patients who underwent cervical procedures augmented by BMP between 2004 and 2009. Patients treated with BMP had significantly longer hospital stays, higher hospital charges, a higher number of tracheotomies, unplanned intubations after surgery, dysphagia, dyspnea, respiratory failure, readmissions, intensive care unit admissions, and 90-d mortality rates. Despite these warnings, surgeons have advocated rhBMP-2 use in the anterior cervical spine in a controlled manner. A retrospective study by Tumialan *et al*[21] reported 200 patients that underwent one to four level ACDF with PEEK spacer, titanium plate, and rhBMP-2 reported a fusion rate of 100%, an incidence of clinically significant dysphagia of only 7%, and suggested that the incidence of dysphagia may be decreased by a lower dose of rhBMP-2 that is placed only within the PEEK spacer.

Anterior cervical surgery with BMP-7 (OP-1)

Data on the use of OP-1 in the anterior cervical spine is much more sparse than that of rhBMP-2. A PubMed database (http://www.ncbi.nlm.nih.gov/pubmed/) query for "BMP-7" or "OP-1", and "anterior cervical" yielded only one study in the literature at the present time. In 2009, surgeons in Australia reported early outcomes and complications (within 30 d) of a prospective consecutive cohort study of 123 patients who underwent ACDF with a controlled dose of OP-1 augmentation. They reported a 2.4% complication rate (transient brachialgia and dysphagia), no reoperations, and concluded that BMP-7 can be used safely in anterior cervical procedures. This report remains to be reproduced by other groups and long-term data on fusion and complication rates have yet to be reported.

POSTERIOR CERVICAL SURGERY WITH BMP

Therapeutic applications of rhBMP-2 in the posterior cervical spine avoid the putative inflammatory effects on critical anterior airway structures suggesting indications may be more plausible. However, there have been few reports on the safety and efficacy of the "off-label" use of BMP products in the posterior cervical spine. At the present time, there are no prospective studies on the use of BMP in posterior cervical spine procedures.

A potential role for OP-1 in posterior cervical spine surgery in patients considered to be high risk for psuedoarthrosis was examined in a 2007 invited submission of the American Association of Neurosurgical Surgeons Joint Section on Disorders of the Spine and Peripheral Nerves. This report by Furlan *et al*[22] was an uncontrolled prospective non-randomized study of 14 patients undergoing posterior cervical or occipitocervical spine surgery that resulted in no "allergic reactions" and no postoperative hematomas. In this patient population that included heavy smokers, patients with genetic disorders (mucopolysaccharidosis), rheumatoid arthritis, lupus, and previous nonunions, a fusion rate of 80% was reported at mean follow-up of 24 mo. All patients underwent MR imaging between 6 months and 1 year postoperatively and one patient who underwent posterior occipitocervical fusion demonstrated an asymptomatic linear opacification in the soft tissues representing heterotopic ossification.

In 2009, a retrospective evaluation of 77 patients undergoing posterior cervical arthrodesis with either rhBMP-2 absorbable sponge or ICBG demonstrated a trend towards more posterior cervical wound complications requiring treatment in the rhBMP-2 group (14.6%) *vs* the ICBG group (2.8%), however, this result did not reach statistical significance[23]. In 2011, Xu *et al*[24] reported a retrospective review of 204 patients that underwent posterior spinal fusion augmented with and without rhBMP-2 over a 4-year period and found at 2-year mean follow-up there was no significant difference between the two cohorts in duration of hospitalization, CSF leakage, infection, hematoma, C5 palsy, wound dehiscence, reoperation rates, or Nurick/ASIA scores. There were no patients in the rhBMP-2 group with instrumentation failure, however, a trend was observed towards increased rates of instrumentation failure in the non-BMP group due to 11 patients (7.1%) with this complication (P = 0.06). Patients receiving rhBMP-2 did have a significantly increased fusion rate (P = 0.01), however, they also had higher rates of recurrent/persistent neck pain (chi-square test P = 0.003, log-rank test P = 0.01)[24].

Case reports have suggested the potential for catastrophic neurological complications with rhBMP-2 use in the posterior cervical spine following laminectomy. Anderson *et al*[25] reported two cases of posterior cervical

decompression and instrumented fusion procedures resulting in a substantial decline in neurological status due to exuberant seroma formation causing cord compression at 5 d and 2 wk postoperatively.

A role for rhBMP-2 augmentation in the pediatric population for congenital and traumatic conditions has been supported by recent case reports. In 2007, a 4-mo-old infant with Down syndrome who suffered a high cervical spine injury due to craniovertebral instability and two previous failed arthrodesis attempts later underwent successful salvage fusion procedure with rhBMP-2 augmentation. The patient subsequently went on to fusion without a reported complication at 4 years follow-up[26]. The surgical challenges of occipitocervical stabilization in infants with complex trauma may also benefit from BMP-2 augmentation. Benzel *et al*[27] reported a case of a 12-mo-old female with traumatic atlanto-occipital dislocation after a motor vehicle accident that was stabilized by autologous rib graft, Mersilene suture, ethibond sutures as "cross-connectors" and rhBMP-2 augmentation with excellent alignment and modest but progressive neurological improvement by 12 wk.

CONCLUSION

Recombinant DNA technology has hastened the arrival of powerful biologically engineered molecules capable of intracellular signal transduction pathways into the operating theatre. Approval by regulatory agencies and the subsequent proliferation of these products to "off-label" indications such as the cervical spine has provided new clinical data and novel complications associated with their use. At the present time, widespread international utilization of BMP products has been self-limited by a prohibitively high cost. In the coming years, as proprietary patents expire and generic formulations become commercially available, an international dialogue in the academic community will aid in the understanding of not only the clinical efficacy of biologics, but also help to mitigate potential harm.

Several studies have reported excellent fusion rates and the avoidance of donor site morbidity with the use of rhBMP-2 in the anterior cervical spine. However, concomitant increased complication rates are reported that may involve catastrophic airway compromise. The soft-tissue complications may be dose dependent, with higher rates reported for higher concentrations by several authors.

Patients who are considered high risk for pseudoarthrosis undergoing posterior cervical or occipitocervical arthrodesis or children with complex congenital or traumatic conditions may be candidates for "off-label" use of BMP according to limited current reports. At the present time, there are no high level clinical studies of the outcomes, complication rates, safety and efficacy of BMP use in the cervical spine.

When painted with broad strokes, the powerful effects of BMP are implicated by several studies to result in increased complication rates in the cervical spine. In a comprehensive database review of the Scoliosis Research Society Morbidity and Mortality database of 55862 spinal fusion procedures, multivariate analysis demonstrated that anterior cervical spinal fusion with BMP remains a significant predictor of complications after adjusting for patient age and revision procedures[28].

In a retrospective cohort study of the Nationwide Inpatient Sample database (a sample of 20% of United States community hospitals) consisting of 328468 spinal fusion procedures, BMP use was associated with greater complications for anterior cervical fusions and greater hospital charges[29]. Nonetheless, in select complex cervical patients, the use of BMP in a controlled fashion may have benefits that outweigh the risks as supported by several authors[21,22,26,27].

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Unicompartmental knee prosthetization: Which key-points to consider?

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Abstract

Unicompartmental knee arthroplasty (UKA) has evolved into a suitable option for diseased knees that cannot be managed with arthroscopic treatment and at the same time are not good candidates for total knee replacement. Since meticulous execution of the surgical technique is essential to optimizing UKA outcome, some procedural key-points are mandatory. Templates (phantoms) are then used to size the required prosthetic component (using these radiographs. Arthritic varus (or valgus) knees with an asymptomatic patello-femoral joint are typically ideal for UKA. Metal-backed tibial components should be favourite instead of all-polyethylene tibial components to avoid polyethylene creep that may occur in fixed bearings. Moreover, a proper thickness of the polyethylene layer is mandatory, in order to avoid early failure.

Key words: Knee; Unicompartmental knee prosthesis; Procedure; Surgery

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UNICOMPARTMENTAL KNEE ARTHROPLASTY

Unicompartmental knee arthroplasty (UKA) has evolved into a suitable option for diseased knees that cannot be managed with arthroscopic treatment and at the same time are not good candidates for total knee replacement (TKR). On initial consideration, UKA has several potential advantages over TKR, namely preservation of bone stock, cruciate ligament conservation, and sparing of the contralateral compartment and the patello-femoral joint[1]. Since meticulous execution of the surgical technique is essential to optimizing UKA outcome[2], some procedural key-points are mandatory. Preoperatively, appropriate implant selection requires the use of weight-bearing radiographs of the affected knee to better delineate true varus or valgus features of the arthritic compartment. Templates (phantoms)[3] are then used to size the required prosthetic component (Figure 1) using these radiographs. Arthritic varus (or valgus) knees with an asymptomatic patello-femoral joint are typically ideal for UKA[4]. If there is concern regarding the cartilaginous condition of patello-femoral joint, magnetic resonance imaging and subsequent arthroscopic evaluations[5] are suggested prior to selecting the definitive prosthetic solution as skyline knee radiographs may not be an accurate reflection of the joint condition. If patello-femoral joint disease is present, a TKR should be performed as there is a high likelihood that revision after UKA will be is a more suitable option as progression of

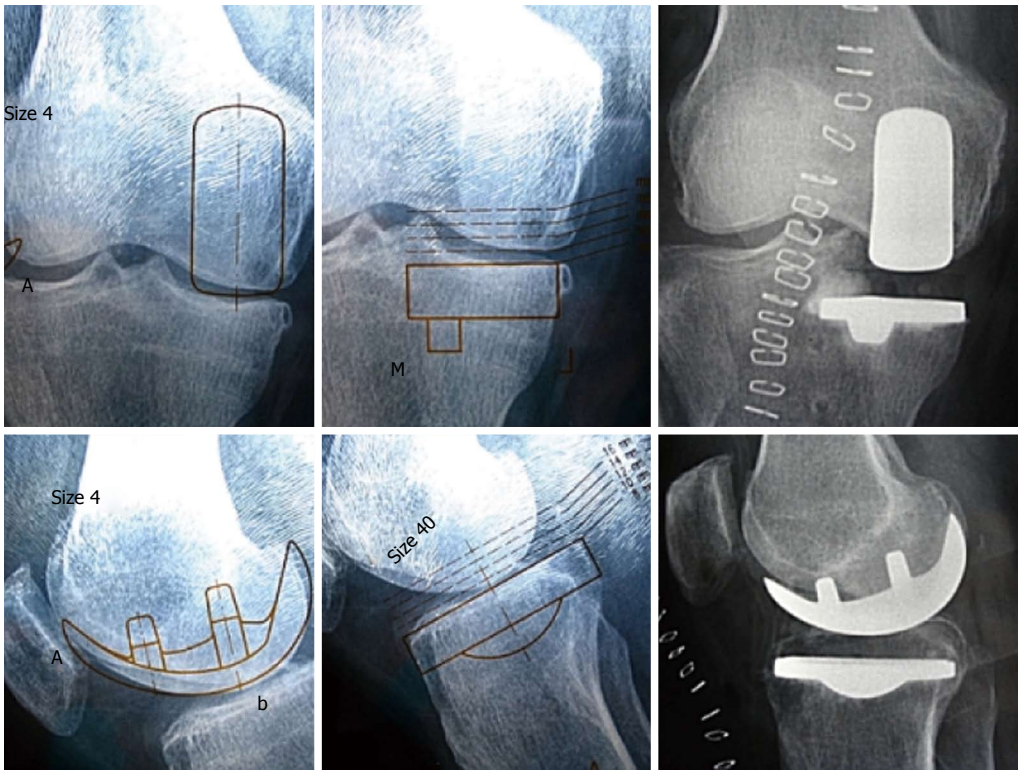

Figure 1 Example of a preoperative surgical plan of a medial unicompartmental knee arthroplasty right knee. Weight-bearing radiographs are templated against acetate phantoms. Immediate post-operation radiographs show correct positioning of the prosthetic implants.

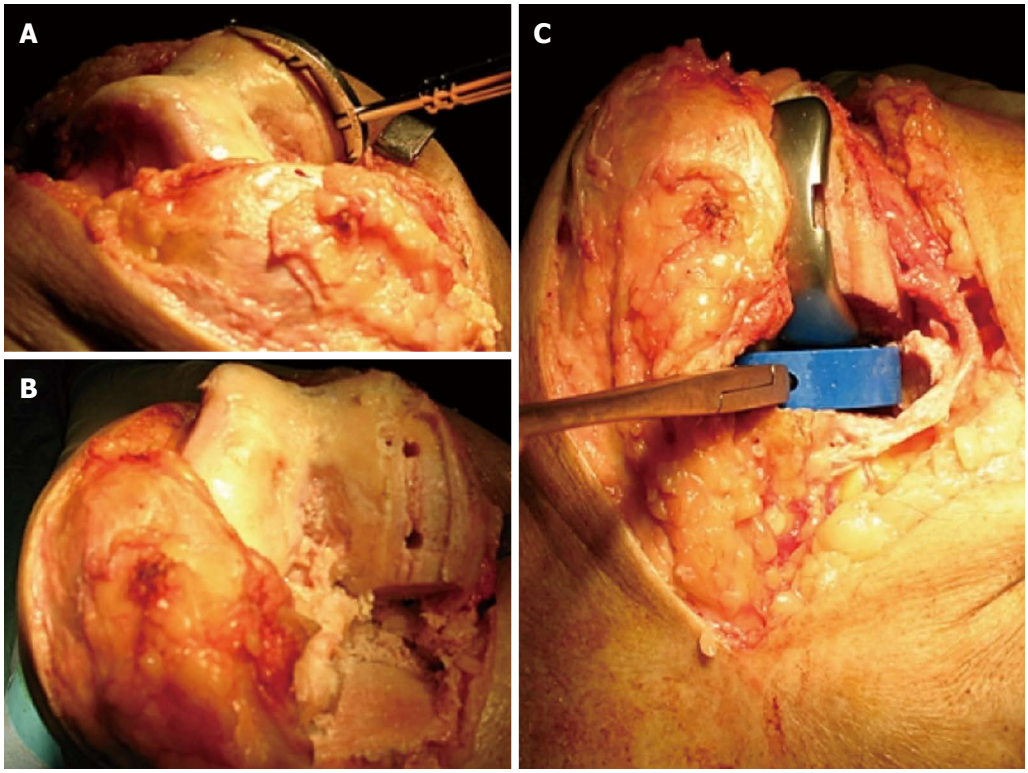

Figure 2 Knee bone cuts and positioning of trial components. A: A curved instrument available in different sizes allows to check the curvature of the condylus to prosthetize along with the amount of bone to remove; B: Femoral and tibial bony cuts. At this stage of the operation is essential to check eventual meniscal fragments, bony particulate and bony prominences that is made possible through a standard parapatellar approach; C: Femoral and tibial trials inserted with patella in place. Accurate trials size to choose definitive implants must be carefully checked.

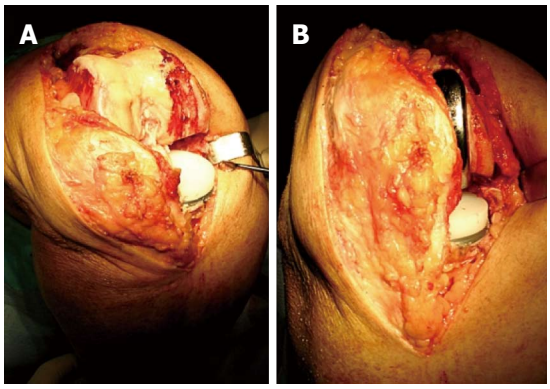

Figure 3 Cemented prosthetic components in place and patellar tracking assessment. A: Cemented tibial metal-back component in place with proper thickness of polyethylene insert; B: Cemented femoral and tibial components inserted along with patella in place. At this moment it is possible to verify ligament balance and patellar tracking.

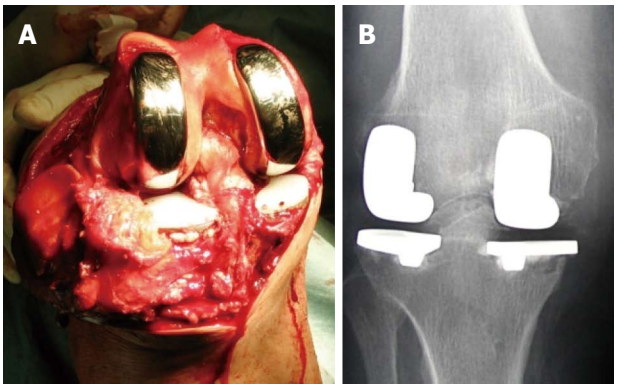

Figure 4 Bi-unicompartmental knee arthroplasty. A: In selected cases, bi-unicompartmental knee replacement is a feasible prosthetic solution that allows to maintain ligamentous compartments; B: This permits to have a more physiologic knee functionality, replacing only the affected parts of the articulation.

arthritis may involve not only the un-prosthetized contralateral compartment, but also the patello-femoral joint with progressive degeneration[6] and consequent surgical prosthesis revision. In general, metal-backed tibial components should be favourite instead of all-polyethylene tibial components to avoid polyethylene creep[7] that may occur in fixed bearings. Moreover, a proper thickness of the polyethylene layer is mandatory, in order to avoid early failure[8]. At the time of surgery, traditional Von Langenbeck's medial or lateral parapatellar surgical approach should be performed since the entire articulation (anterior and posterior compartments) should be evaluated to avoid leaving intra-articular bony particulate, residual sections of meniscus, posterior condylar bony cams, posteriorly extruded cement, and hidden osteophytes that may significantly contribute to implant failure[9] (Figure 2). Moreover, since all the three compartments are visualized, Von Langenbecks's approach allows thorough evaluation of ligament balance, avoiding over- and under-corrections, and permits a good assessment of patellar tracking (Figure 3). The same approach is mandatory in bi-unicompartmental knee replacement, an alternative prosthetic solution[10,11] that employs two unicompartmental prostheses and is utilizable in selected patients with asymptomatic patello-femoral articulation (Figure 4). In contrast, the use of minimally invasive approaches leads to reduced access to surgical landmarks[12] and is more likely to result in anatomic malalignment. Bent narrow Hohmann retractors are recommended instead of straight ones in order to minimize soft tissue stress during retraction and in a less invasive way protect the posterior neurovascular bundle during power-saw cutting of the condylus and the tibial plate. To conclude, it is also strongly suggested to use pulsed lavage irrigation to increase cement penetration and decrease both bone and poly-methyl-methacrylate debris particles[13,14] that may be responsible for third-body polyethylene abrasive wear.

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Common surgical complications in degenerative spinal surgery

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Abstract

The rapid growth of spine degenerative surgery has led to unrelenting efforts to define and prevent possible complications, the incidence of which is probably higher than that reported and varies according to the region of the spine involved (cervical and thoracolumbar) and the severity of the surgery. Several issues are becoming progressively clearer, such as complication rates in primary versus revision spinal surgery, complications in the elderly, the contribution of minimally invasive surgery to the reduction of complication rate. In this paper the most common surgical complications in degenerative spinal surgery are outlined and discussed.

Key words: Spine surgery; Complication; Failed back surgery; Instability; Disc herniation

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INTRODUCTION

Spine surgery has grown exponentially over recent decades, with fusion performed for degenerative conditions comprising the lion's share[1]. A recent evidence based review of the literature reported the overall rate of reported complications to be 16.4%[2]. The focus of this particular paper will be those complications that are related to the surgical operation; general medical complications and surgical wound infection are not included (Table 1). The conditions mentioned here are outlined briefly but in reasonable detail; a more elaborate report would be beyond the scope of this paper.

DURAL TEARS

Dural tears happen accidentally during spine surgery. The reported incidence varies from 15.9% in revision surgery[3] to 3.5% in primary lumbar discectomy[4]. These tears are usually the result of direct trauma or laceration, with the Kerrison punch being the instrument most commonly implicated[5]. Intraoperative technical difficulties that appear to predispose to accidental durotomies are dural scarring, adhesions and fibrosis, particularly in revision surgery, an eroded and thin dura as seen in long-standing spinal stenosis, and large disc herniations making dural retraction and nerve root dissection difficult[6].

When recognized intraoperatively, dural tears need to be made watertight to prevent cerebrospinal fluid (CSF) leaks. This is usually accomplished by direct suturing and/or the use of fibrin glue, in addition to muscle or fat graft to cover the area of the tear[3-5,7]. In a large retrospective series, primary repair was successful in the majority of cases, with only 1.8% requiring reoperation for a second defect repair[3]. Similarly, results from the Spine Patient Outcomes Research Trial (SPORT) study

show that incidental durotomy, although associated with increased operative time, blood loss and inpatient stay, does not impact long-term clinical outcome[8-10]. If unrecognized however, these tears can have significant consequences, such as CSF leakage and/or the development of fistulas or pseudomeningoceles. CSF leaks present with headache, nausea, vomiting, and/or photophobia as soon as patients assume an upright posture after surgery[7]. A pseudomeningocele is a CSF-filled cyst that develops from the dura tear. In addition to symptoms related to CSF leakage, compression from the cyst may also result in back pain or even nerve root compression[11,12]. The clinical diagnosis may be confirmed by magnetic resonance imaging (MRI) or computed tomography (CT) myelography. Treatment consists of bed rest, epidural blood patch or fibrin glue, percutaneous or open placement of subarachnoid drain and open direct repair of the dural tear[7,11,12]. As the incidence of iatrogenic CSF fistulas or pseudomeningoceles is between 0.02%-2%, there is limited available evidence on the long term outcome of patients presenting with this complication[7,11,12]. Nevertheless, it seems that open direct dural repair as soon as the dural tear is diagnosed provides the best outcomes[7].

RECURRENT DISC HERNIATION

A recurrent disc herniation is defined as the presence of herniated disc material at the same level and site in a patient that has experienced a pain free interval after discectomy. The reported incidence varies between 5%-23%[13-16]. The only risk factors that have consistently shown a strong association are diabetes mellitus[17,18] and the shape and size of the herniation[19]. Symptomatic recurrent herniations are much less common than radiographic ones (10.2% *vs* 23.1%)[16]. So, care must be taken before attributing the recurrence of low back pain or nerve root symptoms to the herniation. In addition, imaging of the post-operative spine can be difficult to evaluate. A mass lesion at the previously operated level should be differentiated between pseudomeningocele, scar tissue and recurrent disc herniation. Gadolinium-enhanced MRI appears to be the imaging modality of choice in such patients[14,20,21], although intraoperative findings are not in agreement with imaging results in up to 33% of cases[22]. Once the diagnosis is made, treatment options are similar to primary herniations, i.e. conservative (pharmacological modalities, physiotherapy) or surgical. Although revision surgery on the spine is generally associated with poorer outcomes and higher rates of complications, repeat discectomies appear to be an exception, with most authors reporting results similar to those of primary discectomies[15,22-24].

INSTABILITY

Clinical spinal instability is defined as the loss of the spine's ability to maintain its patterns of displacement under physiologic loads. There is no initial or additional neurologic deficit, no major deformity, and no incapacitating pain[25]. Causes of instability are degenerative[26,27] erosion of structures by neoplastic disease[28], trauma[29], spondylolisthesis[30] and iatrogenic (post-laminectomy)[31,32]. In the post-operative patient, instability is most commonly seen after laminectomy without fusion, although even simple discectomy may be complicated by this condition. Clinically, patients may present with low back pain with or without radicular symptoms. Radiographic criteria for spinal instability include translation and angulation of one vertebra relative to another in standing and in flexion-extension radiographs, with Posner's radiographic criteria showing the best correlation with clinical findings and surgical outcomes[25,33,34]. The treatment of post-operative spinal instability is either bracing or instrumented spinal fusion, with surgery exhibiting superior results[34,35].

Table 1 Surgical complications in spinal surgery

Complications
Dural tears
Instability
Junctional kyphosis
Recurrent disc herniation
Pseudarthrosis (non-union)

PSEUDARTHROSIS (NON-UNION)

Pseudarthrosis refers to a failure in osseous union of the intended spinal fusion. Although pseudarthrosis is not always correlated with symptoms or poor results[36,37], most authors agree that a solid fusion results in better clinical outcomes and certainly mitigates any need for reoperation[38-40]. Radiographic confirmation is required to make the diagnosis; signs include a cleft in the fusion mass, failure of incorporation of bone graft, progressive resorption of bone graft, loosening and/or breakage of implants and progressive deformity[41]. Pseudarthrosis can be further graded by the Lenke classification, in the case of posterolateral fusions[42], or by the Brantigan, Steffee, Fraser classification, in cases where PLIF cages are used[43]. Radiography however is dreadfully unreliable in detecting non-union (its accuracy ranges from 82%-68%[44,45]) when compared to surgical exploration. Flexion-extension views may be helpful in detecting instability in the fused segments, although their value in the lumbar spine has been questioned[46,47]. Helical CT scanning has demonstrated better accuracy[48,49] although surgical exploration remains the "gold standard"[50]. When the diagnosis has been made, the decision to operate or not should be made on an individual basis. A period of close observation, during which bracing and activity limitation are employed is certainly reasonable early on, in the hope that delayed union, rather than non-union, will ultimately occur. In the symptomatic patient who shows evidence of pseudoarthrosis later on, revision surgery is warranted. It has been shown that pseudoarthrosis repair can lead to improved clinical results[39,44], although this revision surgery carries a significant risk of recurrent non-union and a persistently poor outcome[39,40,51]. When surgically treat-

ing pseudarthrosis, it is important to remember that better graft material than that used in the index procedure should be used in an optimized environment. This means aggressive removal of fibrous tissue, extensive decortication where appropriate, use of autologous bone, (preferably iliac crest), use of biological modifiers such as electrical stimulation or BMP, replacement of implants when anchorage is questionable, conversion to circumferential fusion whenever possible and if necessary, extension of the fusion and correction of alignment[52,53].

JUNCTIONAL KYPHOSIS

Junctional kyphosis can occur at either end of an instrumented spinal fusion as a result of the increased mechanical demands in the zone adjacent to the fusion. In its strict definition, this occurs when the sagittal Cobb angle between the last instrumented vertebra and two vertebrae further away from this is greater than 10° or when postoperatively there is an increase in the same angle by ⩾ 10°[54]. Incidence appears to be greatest at the proximal end of long fusions, with reported rates ranging from 26%-43%[55-57] while distal junctional kyphosis occurs in 21.7%-30.2% of patients overall[58,59]. Although specific risk factors have not yet been identified in an evidence based manner, most authors argue that normalization of global sagittal alignment would prevent the development of junctional failure[59-61]. Junctional kyphosis is a radiographic sign which does not always produce symptoms and which shows no correlation with clinical outcomes in most studies[55,56,59,62]. As such, treatment should be reserved for those patients who are symptomatic or where there is obvious deformity. There is a single study in the literature addressing treatment of symptomatic proximal junctional kyphosis. The corrective procedures performed were Smith-Petersen osteotomies in the majority of cases, with rib osteotomies and vertebral column resection in exceptional cases[63]. Reported results were good with a minimum follow-up of two years.

NEUROLOGICAL COMPLICATIONS

The occurrence of a post-operative neurological deficit is probably the most dreaded of all spinal complications. Despite its notoriousness, the reported incidence is only 0%-2% in most reports[64]. Injury to the nervous elements can either be direct at the time surgery, such as laceration, traction or compression of an exiting nerve root, or indirect, due to disruption of blood supply or compression. Notably, injury to the peripheral nerves may occur due to improper patient positioning, with resulting nerve palsies. Direct injury can be caused by trauma from surgical instruments of from misplacement of screws and/or hooks[65]. Disruption of the blood supply usually happens during correction of spinal deformity. The use of intraoperative neurophysiological monitoring has reduced the occurrence of neurological complications, with the Stagnara wake-up test still being used in cases with increased risk of postoperative neurological deficits[66]. Compression occurs intraoperatively from cotton patties, fat grafts or dura sealing products. In these cases, deficits will manifest immediately after surgery. Compression can also be caused from a mass lesion, such as hematoma, pseudomeningocele, epidural abscess or recurrent disc herniation. The presentation of neurologic symptoms will be insidious and almost certainly never in the immediate post-operative period.

A meticulous neurologic examination as soon as the patient wakes from surgery is of critical importance to distinguish deficits that occur intraoperatively from those that develop in the early post-operative period. The significance of this baseline examination is emphasized by the fact that imaging of the post-operative spine so soon after surgery will often be of limited value. Determining the cause of the neurological lesions depends on recollection of intraoperative events by the surgeon and his team, timing of presentation of symptoms and imaging findings, if any. Depending on the cause, management varies from patiently monitoring the course and progress of any deficits to immediate surgical exploration and correction of the underlying cause.

CONCLUSION

Surgical complications in spine surgery are not uncommon. Their significance can be minor, noticeable only as mere radiographic findings, or catastrophic, presenting with pain, neurological symptoms and progressive deformity. We chose not to include adjacent segment disease (ASD) in this overview. In our view, ASD constitutes the natural progression of the disease that was originally treated with surgery or perhaps a manifestation of wrong level selection and under-treatment. Hopefully, as our understanding of spinal pathologies becomes clearer and our therapeutic arsenal more sophisticated, the rate of complications will decrease further, minimizing the risks and distress to patients.

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Polymethylmethacrylate bone cements and additives: A review of the literature

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Abstract

Polymethylmethacrylate (PMMA) bone cement technology has progressed from industrial Plexiglass administration in the 1950s to the recent advent of nanoparticle additives. Additives have been trialed to address problems with modern bone cements such as the loosening of prosthesis, high post-operative infection rates, and inflammatory reduction in interface integrity. This review aims to assess current additives used in PMMA bone cements and offer an insight regarding future directions for this biomaterial. Low index (< 15%) vitamin E and low index (< 5 g) antibiotic impregnated additives significantly address infection and inflammatory problems, with only modest reductions in mechanical strength. Chitosan (15% w/w PMMA) and silver (1% w/w PMMA) nanoparticles have strong antibacterial activity with no significant reduction in mechanical strength. Future work on PMMA bone cements should focus on trialing combinations of these additives as this may enhance favourable properties.

Key words: Polymethylmethacrylate; Bone cement; Cement nanoparticle; Vitamin E additive; Arthroplasty; Artificial joint fixation; Post-operative infection; Mechanical weakness; Fat additive; Antibiotics

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INTRODUCTION

Bone cement, or polymethylmethacrylate (PMMA), has been used in surgical fixation of artificial joints for over 50 years. The primary function of bone cement is to transfer forces from bone to prosthesis. This review explores the development of bone cements, the role of bone cement additives, identifies applications and discusses future directions.

HISTORICAL BACKGROUND

The pioneering work on PMMA technology is widely credited to German chemist Dr. Otto Rohm. He patented the PMMA product Plexiglass in 1933, which was used in submarine periscopes and airplane canopies[1], leading to an exponential increase in demand and interest during the pre-war and war era. Kulzer (1936) was at the forefront of mouldable cement technology after discovering that the dough formed by mixing ground PMMA powder and a liquid monomer hardens when benzoyl peroxide is added and the mixture heated to 100 ℃ in a stone mould[2]. The first clinical use of this PMMA mix-

ture was in an attempt to close cranial defects in monkeys in 1938. Surgeons used the heat stable polymer Paladon 65 to close cranial defects in humans. The material was assembled in plates in the laboratory and later moulded in the surgical suite[2].

The era of modern PMMA bone cements stems from the patent by Degussa and Kulzer (1943), describing how MMA polymerizes at room temperature if a co-initiator, such as a tertiary aromatic amine, is added[2]. Dental surgeons were the first to use this technology for dental fixatives and fixtures.

The first bone cement use in orthopaedics is widely credited to English surgeon, Dr. John Charnley, who used "dental acrylic" in 1958 for total hip arthroplasty[3]. Initial clinical results were poor for mechanical and biological reasons, related to both cement and loading surface[2]. Dr. Charnley developed a new product called "bone cement" (Plexiglass) which had more adaptable biological characteristics[4] and which he marketed aggressively to the global orthopaedic community. American orthopaedic surgeons trained with Dr. Charnley at the Wrightington Hospital in the 1960's and 1970's to learn his pioneering technique[5]. When returning to America, these surgeons often took bags of bone cement with them, an illegal trade which was only eliminated in the mid-1970's after the Food and Drug Administration approved the use of bone cement technology in the United States[5]. This material still had many shortcomings. Over the last two decades, additives have been developed to address these shortcomings[6].

PMMA PROPERTIES AND ADDITIVES

Mechanical weakness

A common complication of cemented arthroplasty is loosening of the cemented prosthesis. Mechanical weakness in the bone cement, primarily attributed to the addition of barium sulphate and zirconium oxides (for radiological detection), increases the risk of loosening[7]. Stabilisation of the bone cement matrix improves the transfer of load across the cement-prosthesis interface, reducing the likelihood of crack formation in the cement. Various additives such as steel fibres, glass fibres, carbon fibres and titanium fibres have been developed to improve mechanical strength[8-10]. Rubber toughened cement (PMMA matrix interspersed with rubber particles; Moeseley Rubber Co. Pvt. Ltd., United States) has 167% greater fracture toughness (the structural strength to withstand further cracking in fractured materials) than non-reinforced control (PMMA), although compressive strength and elasticity are compromised (raw data not available)[11]. PMMA reinforced with embedded continuous stainless steel coil (2.5 turns of coil; distal tip of prosthesis) significantly increases compressive stress 4.5-fold (control *vs* reinforced; 0.039 ± 0.001 MPa *vs* 0.009 ± 0.001 MPa) and tensile stress 4.5-fold (control *vs* reinforced; 4.272 ± 0.015 MPa *vs* 0.95 ± 0.005 MPa) on 3-dimensional finite element computational analysis[12]. This reinforcement increases mechanical strength, thus decreasing the likelihood of fracture formation. The use of additives with rubber toughened cements and stainless steel coils may improve other properties and needs to be investigated.

Interface integrity

The long-term stability of cemented hip arthroplasty is also dependent on the integrity of the bone-cement interface. Interface integrity is related to the strength of bonding and the degree of cement penetration (extent of interdigitation into bone). Increased migration behavior and micromotions of the prosthesis and bone cement are a result of abrasion. The production of wear particles from roughened metallic surfaces and from the PMMA cement promotes local inflammatory activity, resulting in chronic complications to hip replacements[13]. Lower bone cement viscosity affects the mechanical strength of the connection, giving an immediate limitation to the benefits of certain water-based additives, like antibiotics, in comparison to those in powder form[14]. The addition of an amphiphilic bonder, such as glutaraldehyde, may lead to significant improvements in the longevity of cemented metal stems[13,15]. Strength is maximized by increasing the amount of trabecular bone in the cement[16]. Interface integrity should be the optimal outcome of any additive trial. Powder based additives should generally be preferred to their water based counterparts, with greater importance placed on ensuring increased trabecular bone in cement matrix and/or amphiphilic bonders.

Osteoconduction

Osteoconduction refers to a process in which the three-dimensional structure of a substance is conducive to the on growth and/or ingrowth of newly formed bone. Bone growth on an implant surface depends on the action of differentiated bone cells; pre-existing pre-osteoblasts/osteoblasts activated by trauma or recruited from primitive mesenchymal cells by osteoinduction[17,18]. Bone conduction is dependent on the conditions for bone repair as well as the biomaterial used and its reactions[19]. More than 60% by weight of bioactive ceramic powders should be added to PMMA powders to achieve satisfactory osteoconductive properties after setting[20].

Thermal reduction

The polymerisation of bone cement is an exothermic process that can cause tissue necrosis. The high peak curing temperatures of acrylic bone cements is a major concern that needs to be addressed. The use of oxygen plasma increases the maximum curing temperature of bone cement. For example, 100 W of oxygen plasma applied to PMMA powdered polymer (Sigma-Aldrich Chemie, Germany) increases the maximum temperature from 83.48 ± 7.35 ℃ to 96.50 ± 4.52 ℃ (no reported significance)[21]. This is explained by the catalytic activity in polymerization, which results in more rapid heat release. A number of additives have also been tested for

their potential effects on heat reduction. PMMA bone cement modification with 1-dodecyl mercaptan (DDM, Acros Organics, United States) lowers peak temperatures by 4-6 ℃ (no reported significance), possibly by acting as a chain stopping agent[21]. Endothermic reactions involving ammonium nitrate (Acros Organics United States) also help to reduce temperatures (73.64 *vs* 96.5 ℃; no reported significance). Zeolites (ZSM-5, Acros Organics, United States) further improve the exothermic profile of bone cements, reducing temperature from 90.12 to 86.9 ℃ with DDM, and from 73.64 to 72.66 ℃ with ammonium nitrate (no reported significance)[21]. In addition to limiting PMMA toxicity, the antioxidant N-Acetylcysteine (NAc) has also been shown to significantly reduce heat release in a dose dependent manner[22]. The maximum polymerization temperature was 42.6 ℃ with 1.00% (w/w) NAc, compared to 57.0 ℃ in the absence of NAc.

Radio-opacifying additives

Ceramic particles, such as barium sulfate and zirconia (zirconium oxide), are incorporated into bone cement to allow visualization through X-ray imaging[23]. They have an adverse influence on the biocompatibility of PMMA, leading to mechanical weakness[23-25]. Barium sulfate ($BaSO_4$; Horii Pharmaceutical, Osaka, Japan) at 10% w/w monomer has a compressive load test strength of 85(± 5) MPa[26]. Increasing concentrations of $BaSO_4$ (20%; 30%; 40% w/w monomer) reduce this strength (86 ± 4 MPa; 87 ± 8 MPa; 69 ± 10 MPa), although only the reduction between 30% and 40% is statistically significant ($P < 0.02$)[26]. The 10% w/w monomer has a fracture load of 88 ± 10 MPa in the three point bending load test, and this strength reduces in proportion to increasing barium concentration[26]. Furthermore, impact load testing of 10% w/w monomer reveals a strength of 3.1 ± 0.9 kJ/m^2, which is the same as for the 20%, 30% and 40% w/w monomers ($P < 0.01$)[26]. Thus, increasing concentrations of barium sulfate (10%-40%) reduce mechanical strength of cement. Additionally, conventional barium sulfate (Reade Materials; Providence, RI, United States) promotes poor osteoblast (bone forming cells) function at the surface of PMMA, in human osteoblast cell culture lines (CRL-11372), as seen by scanning electron microscopy and atomic force microscopy[25]. Kobayashi *et al*[27] analysed the effect of barium concentrations in PMMA additives (10%, 30% wt and empty control; Simplex® and Spineplex®, Stryker Instruments) in animal models at 12 and 90 d. Higher concentrations of barium sulfate were associated with stronger foreign body reaction at 90 d, suggesting lower levels of biocompatibility at higher concentrations. Further work is needed weighing the benefit of higher cement visualization against the lower biocompatibility at higher $BaSO_4$ concentrations in humans.

Iodine-containing acrylic bone cement has comparable biocompatibility to the barium sulfate-containing equivalent, while maintaining its useful radiopaque properties[28]. Analysis suggested that there was no significant difference in mechanical strength (fracture toughness and four-point loading test) between iodine and barium sulfate based cements.although further work needed to assess clinical application of iodine based cement[28].

Table 1 Exothermic activity of polymethylmethacrylate mixed with nano-MgO (12.8 nm) *vs* polymethylmethacrylate control[25]

	1 s	1 min	2 min	10 min	107 min
PMMA (℃)	44.98	45.82	50.10	52.5	47.85
PMMA and nano-MgO (℃)	39.65	40.36	46.99	48.85	44.10

PMMA: Polymethylmethacrylate.

The use of ceramic nanoparticles, such as magnesium oxide (MgO; 12.8 nm; Sigma Aldrich; St. Louis, MO, United States) and $BaSO_4$ (80-500 nm; Reade Materials; Providence, RI, United States), improves osteoblast adhesion (PMMA + nanoMgO 3.25 cells/mm^2; PMMA + nano$BaSO_4$ 3.6 cells/mm^2; cell density on adhesion assay and fluorescence microscopy) compared to conventional PMMA (2.6 cells/mm^2), although this improvement is not statistically significant ($P < 0.1$)[25]. The addition of nano$BaSO_4$ (100 nm; Sachtleben, Duisburg, Germany) to PMMA (CMW1 bone cement; DePuy Orthopaedics Inc., Warsaw, IN, United States) at 10% w/w has no significant difference on uniaxial compression strength ($P = 0.08$) or uniaxial tensile strength (ultimate stress and elastic modulus; $P = 0.3$ and $P = 0.4$ respectively)[29]. The addition of nanoMgO (at 10% w/w per total PMMA cement) also reduces the exothermic nature of *in vitro* PMMA solidification (Table 1), thus minimizing tissue necrosis[25]. Overall, nanoMgO and nano$BaSO_4$ improve osteoblast adhesion, with nanoMgO minimizing tissue necrosis and nano$BaSO_4$ having no impact on mechanical strength. Further work is needed to fully assess the mechanical parameters of nanoMgO and the exothermic activity of nano$BaSO_4$.

Organobismuth compounds also have radio-opaque properties that have been tested in bone cement. One particular study found that 5%, 10%, 15% and 20% (w/w) bismuth salicylate in bone cement with a 2/1 solid/liquid ratio [MMA, 1% (v/v) dimethyl-4-toluidine, 1.25% (w/w) benzoyl peroxide, Merck] had higher radiopacity than standard admixtures containing barium sulphate (Merck)[30]. Furthermore, 10% bismuth salicylate preparations had a higher percentage of injectability than their 10% barium sulphate counterpart (85.89% *vs* 81.90%; no reported significance)[30]. The addition of contrast agents, such as gadolinium and manganese, to produce a signal-inducing bone cement formulation has also been useful for magnetic resonance imaging. Gadolinium in gadoterate meglumine-water cement (Dotarem 0.5 mmol/mL; Laboratory Guerbet, Paris, France, 12 g PMMA and 5 mL MMA) had a higher contrast-to-noise ratio (CNR) in air than the manganese-containing cement (5 mL $MnCl_2$ solution, 100 mg/L deionised water) with a maximum CNR of 157.5 in a fast T1W turbo-spin echo sequence[31].

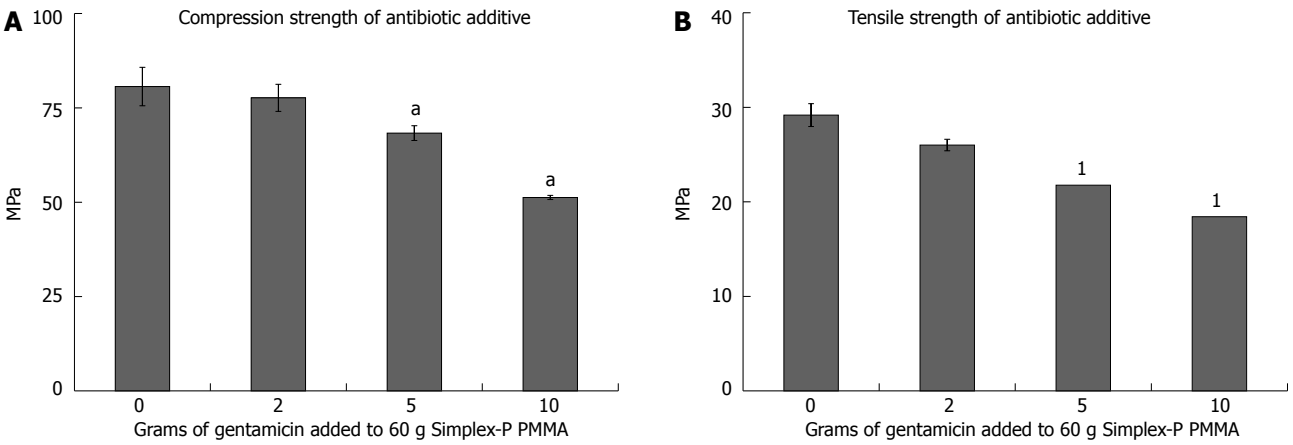

Figure 1 Mechanical strength of antibiotic (gentamicin) additives[38]. A: Compression strength, [a]$P < 0.05$ *vs* 0 g addition of Gentamicin; B: Tensile Strength, [1]invalid result as cements failed to fracture in a non-brittle manner.

Antibiotic additives

There is a high incidence of post-operative infections (0.25%-2.0%) in individuals receiving total joint replacements[32]. In cases where PMMA is used this rate increases to 13%[33]. Use of antibiotic-loaded bone cement for prophylaxis and prosthesis related infections has been documented since the 1970s, with erythromycin one of the earliest additives used[34,35]. Despite achieving clinical efficacy, erythromycin was found to diffuse poorly from the cement matrix into surrounding bone[34,35]. Aminoglycosides, such as gentamicin and tobramycin have since become popular additives for bone cements, due to their broad spectrum activity and low allergy profiles[36,37].

One study found that addition of gentamicin (2/60 g cement) did not significantly alter compressive or diametral tensile strength compared to control PMMA (Simplex-P; Figure 1). However, higher gentamicin levels of 5/60 g or 10/60 g, significantly reduced compressive strength ($P < 0.05$), although results for tensile strength could not be interpreted[38]. Although higher doses of gentamicin mean greater antibiotic availability, the mechanical properties of the additive are adversely affected.

Another study compared four antibiotics (sodium oxacillin, sodium cefazolin powder, gentamicin powder and gentamicin sulphate aqueous solution; 40 mg/mL of PMMA mixture), evaluating them for compressive (80, 70 and 65 MPa; 2g gentamicin powder, 250 mg aqueous gentamicin and 800 mg aqueous gentamicin solution respectively) and diametral tensile strength (27, 23 and 15 MPa; 2 g gentamicin powder, 250 mg aqueous gentamicin and 800mg aqueous gentamicin solution respectively) in comparison to control PMMA (Simplex-P)[39]. Powered gentamicin (2/40 g) made no statistically significant difference to compressive or diametral tensile strengths whereas aqueous forms produced weakened bone cements, as result attributed to the water in the mixture[39]. We recommend use of 2/60 g, or less, of antibiotic in powdered form. This lowers post-operative infection rates while only causing modest reductions in compressive (< 5% reduction) and tensile (< 5% reduction) strength.

Vancomycin has also been used as a bone cement additive, with concentrations less than 5% having no effect on the mechanical properties of the bone cement[40,41]. However, this has been found to be less efficacious than similar concentrations of tobramycin and gentamicin[37,42]. Interestingly, when used in combination with tobramycin, a synergistic effect appeared[43,44], with a 68% greater elution of tobramycin ($P = 0.024$), and 103% greater elution of vancomycin from the bone cement ($P = 0.007$), compared to controls containing only one antibiotic[43].

Vitamin E additives

The polymerisation process utilises a redox system, comprising benzoyl peroxide (BPO) as an initiator and *N,N*-dimethyl-4-toluidine (DMT) as an activator. This produces benzoate and amine free radicals which are thought to induce local inflammation and alter macrophage activity[45]. Vitamin E is a free radical "scavenger" in the oxidative process[46]. Mixed Vitamin E (MVE) additive (1 part liquid MVE: 1.8 part solid cement) shows increased cytocompatibility (as measured by total cellular DNA, cellular proliferation and differentiation *vs* control PMMA group) and decreased exothermic activity (peak temperature: 15% wt MVE-MMA 53 ℃ *vs* PMMA 76 ℃), reducing the likelihood of bone necrosis. However, setting time is increased (20.7 min 15% wt MVE-MMA mixture *vs* 12.2 min PMMA control), which exposes the operative site to the environment for longer[46]. Compositions of > 25% wt MVE-MMA have no effect on compressive strength, but significantly reduce tensile strength (Figure 2), although this still remains within the range for clinical usage[46]. The use of 15% vitamin E yields a lower compressive strength compared to additive concentrations of 10% and 20% (Figure 2), though this could be attributed to experimental error. Greatest clinical scope exists for 10% vitamin E additives as they have a positive effect on free radical oxidation and exothermic activity, with only modest reduction (< 5%) in tensile strength.

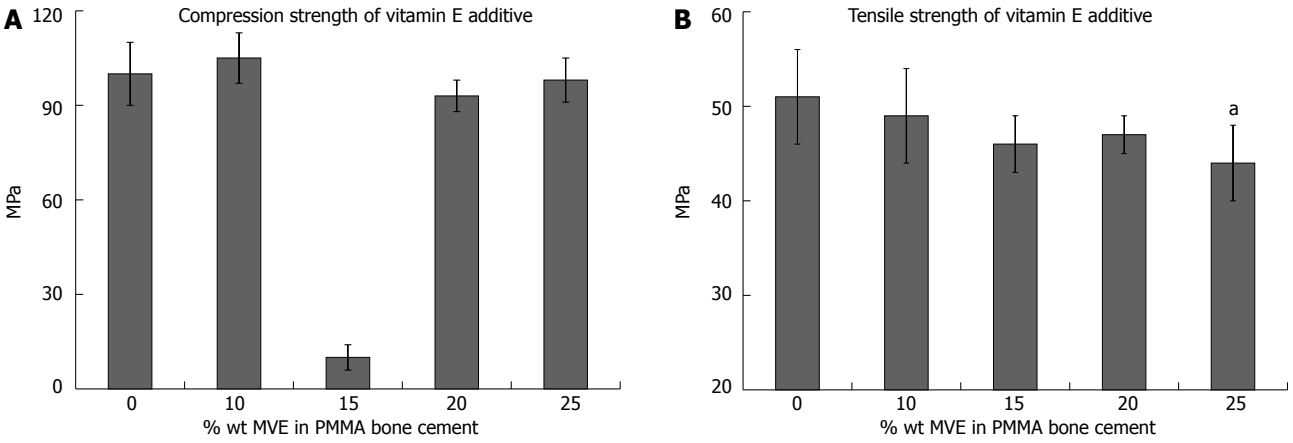

Figure 2 Mechanical strength of vitamin E additives[46]. A: Compression strength, great reduction at 15% appears to be an anomaly, but requires further review; B: Tensile strength, $^{a}P < 0.05$ *vs* 0%.

Table 2 Diametral tensile strength of polymethylmethacrylate and MMA:AA: MA co-polymer mixtures[47]

PMMA quantity (g)	MMA:AA:AMA quantity (g)	MMA:AA:AMA ratio	Tensile strength (Mpa)
20	0	-	31.3 ± 9.0
19	1	80:20:10	39.3 ± 3.0
17	3	80:20:10	36.2 ± 4.7
19	1	70:30:10	33.1 ± 4.2
17	3	70:30:10	26.6 ± 6.1

PMMA: Polymethylmethacrylate.

Monomer and nanoparticle additives

The co-polymer [poly (methylmethacrylate-acrylic acid-allylmethacrylate) or poly (MMA-AA-AMA); MMA, Kanton Chemical Co. Japan; AA, Alfa Aesar, Ward Hill, MA, United States; AMA, Acros Organics, Morris Planes, NJ, United States] reduces bone cement shrinkage (a problem in traditional compositions) as it absorbs body fluids and swells to compensate for shrinkage. An MMA:AA:AMA ratio of 80:20:10 resulted in improved mechanical strength (Table 2). In contrast, 70:30:10 did not yield any significant improvements, possibly due to increased acrylic acid concentration[47]. Co-polymerisation with MMA:AA:AMA also resulted in improved fracture toughness, due to a roughened surface, as identified with scanning electron microscopy. Further, cross-linked poly (MMA-AA-AMA) copolymer is able to induce bone ingrowths at the interface of bone and copolymer[48].

Bone cement composites have been trialed with nanoparticle additives, such as multi-walled carbon nanotubes and nano-sized titanium fibers. While there were measurable improvements in the flexural strength and bending capacity by 12.8% and 3.7% respectively, adverse effects on surrounding cell *in vitro* biocompatibility were observed[9] At the optimal concentration of 1% by wt, nano-titania fibers-give a significant increase in fracture toughness (67%), flexural strength (20%) and flexural modulus (22%), compared with control PMMA cement, while retaining handling properties and *in vitro* biocompatibility[9].

Recently, nanoparticles have been trialed *in vitro* as bactericidal agents. PMMA (DePuy International Ltd., UK and Biomet, Merck, Germany) with and without gentamicin was loaded with chitosan (CSNP, CarboMec Inc) and quaternary ammonium CS derived nanoparticles (QCSNP) at weight ratios of 15% and 30%, and then examined for their antibacterial (*Staphylococcus aureus* and *Staphylococcus epidermidis*, analysed by sphectrophotometry), mechanical (tensile and three point bending test, Young's and bending modulus) and cytotoxic properties (3T3 mouse fibroblast assay)[49]. Bone cement mixed with CSNP and QCSNP significantly ($P < 0.05$) decreased cell count for both strains (500 to 200 CFU/cm^2 for CSNP; 500 to 40 CFU/cm^2 for QCSNP)[49]. Cytoxicity assay and mechanical testing showed no significant difference between CSNP, QCSNP and control PMMA[49]. Further *in vivo* assessment of CSNP and QCSNP as potential bone cement additives is suggested for future studies.

Silver ions (AgNP) inactivate enzymes vital to bacteria and disable the mechanism for bacterial DNA replication[50]. Clinical application is limited by the difficulty of incorporating and dispersing AgNP into acrylics. *In situ* generation of AgNP (University of Texas Health Science Center, Texas) has been trialed[51]. Silver benzoate (AgBz; 1.0% w/w of total monomer; Sigma Aldrich) was blended with PMMA and extra benzoyl peroxide (B; 0.5%, 1.0%, 1.5% and 2.0% w/w; Sigma Aldrich) and diamethyl-p-toludine (D; 0.5, 1.0, 1.5 and 2.0% w/w; Sigma Aldrich) added. AgNP released silver ions *in vitro* for over 28 d (analysed by Atomic Absorption Spectrometry), inhibited 99.9% of bacterial growth at 48 h (*Acinetobacter baumannii, Pseudomonas aeruginosa, Proteus mirabilis and Staphylococcus aureus*; *in vitro* antimicrobial assay) and showed a continued antibacterial effect against *P. aeruginosa* for over 28 d (1.5B: 0.5D 1% AgBz, 1B: 1D 1% AgBz and 0% AgBz; 4.8, 6.3 and 0 mm inhibition; long term antimicrobial assay)[51]. However, AgNP (1%) mixtures have reduced mechanical strength (three point bending flexural test) compared to controls. Further work is needed to assess optimum loading, other mechanical properties and long term antimicrobial activity against other bacterial strains.

Table 3 Summary of polymethylmethacrylate bone cement additives

Additive	Summary
Gentamicin	Reduces post-operative infection rates. Powdered format (2/60 g or 2/40 g) shows no significant impact on mechanical strength, however increased gentamicin concentration decreases mechanical strength
Vitamin E	Improves cement cytocompatibility and reduces peak temperature. 10% vitamin E concentration does not significantly affect mechanical strength. Increasing concentrations associated with increased setting time and decreased mechanical strength
Polymer MMA:AA:AMA	Reduces bone cement shrinkage and improves fracture toughness. 80:20:10 significantly improves mechanical strength *vs* control
NanoMgO and NanoBaSO$_4$	Improves osteoblast adhesion, nanoMgO (12.8 nm) minimizes tissue necrosis and nanoBaSO$_4$ (100 nm) improves mechanical strength
Barium sulfate	Allows radiological identification of cement. 10% concentration is not associated with significant decrease in mechanical strength *vs* control. As concentration increases, mechanical strength decreases
Chitosan nanoparticles	*In vitro* studies show significant antibacterial activity against *S. aureus* and *S. epidermidis* with no significant difference in cytoxicity and mechanical strength *vs* control PMMA
Silver nanoparticles	AgNP (1%) has strong and continued antibacterial activity (against *A. baumannii*, *P. aeruginosa*, *P. mirabilis* and *S. aureus*) but with reduction in mechanical strength. Nanosilver (5-50 nm) has antibacterial activity against *S. epidermidis*, MRSE and MRSA with no significant difference in cytotoxicity *vs* control

PMMA: Polymethylmethacrylate; MRSE: Methicillin-resistant *S. epidermidis*; MRSA: Methicillin-resistant *S. aureus*.

Nanosilver (5-50 nm; 0.1%, 0.5% and 1.0% w/w monomer) mixed with PMMA (Coripharm, Dieberg, Germany), PMMA mixed with 2% w/w gentamicin sulphate (Schering-Plough, Brussels, Belgium) and PMMA control were compared for antimicrobial activity (on microplate proliferation assays) against *S. epidermidis*, methicillin-resistant *S. epidermidis* (MRSE) and methicillin-resistant *S. aureus* (MRSA)[52]. PMMA control had no antimicrobial effect, whereas 1% Nanosilver and 2% gentamicin loaded cements completely inhibited *S. epidermidis*. Furthermore, 1% Nanosilver completely inhibited MRSA and MRSE growth whereas gentamicin had no effect. This may be due to gentamicin resistance in tested strains[52]. The antimicrobial effect of Nanosilver was dose dependent, with higher concentrations of Nanosilver having higher antimicrobial effect. *In vitro* cytotoxicity was not significantly different (human osteoblast quantitative elusion testing and qualitative growth) between Nanosilver and PMMA controls[35]. Further, biocompatibility (measured by human osteoblast on growth) was similar between Nanosilver and the control group.

FUTURE APPROACHES

The focus of bone cement research is better mechanical quality, curing time and biocompatibility. Biomaterials, such as calcium phosphates and hydroxyapatite, more efficiently induce bone growth. Advances in the biocompatibility of PMMA bone cements might be achieved by introducing osteogenic agents, such as bone morphogenic proteins or transforming growth factors, to cement surfaces that contact the surrounding bone[53].

PMMA for vertebroplasty has greater stiffness than vertebral cancellous bone, causing higher incidences of fracture of neighboring vertebral bodies[54]. More porous bone cement has been developed by introducing an aqueous phase in PMMA cements, which is released *in vivo* with powder particles and thus increases risk of embolism. Beck and Boger (2009) showed that delaying the addition of the aqueous phase to acrylate mixture minimizes the amount of particles released[54].

CONCLUSION

As demonstrated in this review, there are many bone cement additives, none of which is perfect as strength often being adversely affected with minor additions of an additive (Table 3). There is scant data focusing on the effect of combining various additives. We suggest that this approach may yield bone cements that display the beneficial properties of each additive, while still maintaining structural integrity. Low index (< 15%) vitamin E and low index (< 5 g) antibiotic impregnated additives should be investigated further. These target inflammatory and infective pathologies, respectively, related to long term failure in bone cements, with only modest reductions in mechanical strength of the cement matrix. Mechanical strength and interface integrity should be improved through the use of rubber-toughened cements, amphiphilic bonders and/or increasing trabecular bone concentration in the cement matrix. Chitosan (15% w/w PMMA) and silver (1% w/w PMMA) nanoparticles have strong antibacterial activity with no significant reduction in mechanical strength. The field of nanoparticle technology holds promise.

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BRIEF ARTICLE

Longitudinal evaluation of time related femoral neck narrowing after metal-on-metal hip resurfacing

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Abstract

AIM: To track the short-term neck narrowing changes in Birmingham metal-on-metal hip resurfacing (MOMHR) patients.

METHODS: Since 2001, the Center for Hip and Knee Replacement started a registry to prospectively collect data on hip and knee replacement patients. From June 2006 to October 2008, 139 MOMHR were performed at our center by two participate surgeons using Birmingham MOMHR prosthesis (Smith Nephew, United States). It is standard of care for patients to obtain low, anteriorposterior (LAP) pelvis radiographs immediately after MOMHR procedure and then at 3 mo, 1 year and 2 year follow up office visits. Inclusion criteria for the present study included patients who came back for follow up office visit at above mentioned time points and got LAP radiographs. Exclusion criteria include patients who missed more than two follow up time points and those with poor-quality X-rays. Two orthopaedic residency trained research fellows reviewed the X-rays independently at 4 time points, *i.e.*, immediate after surgery, 3 mo, 1 year and 2 year. Neck-to-prosthesis ratio (NPR) was used as main outcome measure. Twenty cases were used as subjects to identify the reliability between two observers. An intraclass correlation coefficient at 0.8 was considered as satisfied. A paired *t*-test was used to evaluate the significant difference between different time points with $P < 0.05$ considered to be statistically significant.

RESULTS: The mean NPRs were 0.852 ± 0.056, 0.839 ± 0.052, 0.835 ± 0.051, 0.83 ± 0.04 immediately, 3 mo, 1 year and 2 years post-operatively respectively. At 3 mo, NPR was significantly different from immediate postoperative X-ray ($P < 0.001$). There was no difference between 3 mo and 1 year ($P = 0.14$) and 2 years ($P = 0.53$). Femoral neck narrowing (FNN) exceeding 10% of the diameter of the neck was observed in only 4 patients (5.6%) at two years follow up. None of these patients developed a femoral neck fracture (FNF).

CONCLUSION: Femoral neck narrowing after MOMHR occurred as early as 3 mo postoperatively, and stabilized thereafter. Excessive FNN was not common in patients within the first two years of surgery and was not correlated with risk of FNF.

Key words: Hip joint; Arthroplasty; Complications; Hip resurfacing; Femoral neck narrowing

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INTRODUCTION

Metal-on-metal hip resurfacing (MOMHR) was approved in the United States by the Food and Drug Administra-

tion in May 2006, buoyed by promising survivorship data from the United Kingdom[1]. This technique, primarily due to its bone conserving nature, has become an alternative to total hip arthroplasty in younger patients. Femoral neck narrowing, potentially posing as a risk factor for femoral neck fracture, is a complication unique to this type of arthroplasty; though at present, there is no consistent evidence showing correlation between neck narrowing and neck fracture after MOMHR.

The incidence of neck narrowing after MOMHR was reported from 77% to 98%[2-3]. Although the exact etiology of neck narrowing is still unknown, possible contributing factors for neck narrowing may include stress shielding, damage to the blood supply, bone necrosis in the residual femoral head, alteration in hip biomechanics or secondary to wear debris[5-12].

Spencer's study showed-neck narrowing after resurfacing may stabilize after 2 years[2]. Shimmin demonstrated that the mean time to fracture after MOMHR is 3 to 4 mo, while Cooke *et al* reported that bone mineral density is significantly decreased at 3 mo postoperatively and recovers back to normal thereafter[13,14]. As a result of this data it is unclear when exactly neck narrowing occurs and whether or not it had any impact as a risk factor for early femoral neck fracture with MOMHR. Thus the purpose of this study was to more closely evaluate the changes that occur in the femoral neck in MOMHR patients. We measured neck narrowing radiographically immediately after surgery and at 3 mo, 1 year and 2 years postoperatively. We hypothesized that neck narrowing occurs early after MOMHR and then stabilizes long before the 2 year time point.

MATERIALS AND METHODS

This study was a retrospective longitudinal evaluation of prospectively collected patients' data from the Center for Hip and Knee Replacement Registry. From June 2006 to October 2008, 139 MOMHR were carried out at our center by two senior surgeons using the Birmingham MOMHR prosthesis (Smith Nephew, Memphis, TN, United States). All operations were performed using a modified enhanced posterior soft tissue repair approach[15]. The components were fixed using an uncemented hydroxyapatite porous coated cobalt chrome acetabular component and a cemented femoral component. As a part of our standard of care, all patients had low anterior-posterior (LAP) pelvis radiographs immediately after MOMHR procedure and were advised follow-up X-rays at 3 mo, 1 year and 2 years post-operatively. All radiographs were taken with great toes in contact to maintain consistent femoral rotation.

Inclusion criteria for the present study were all patients who came back for follow up office visit at the above mentioned time points and obtained LAP radiographs. Exclusion criteria included patients who missed more than two follow up time points and those with poor-quality X-rays. Symmetry of the trochanter was evaluated qualitatively on all follow up radiographs to ensure identical femoral neck version. We had function follow up of all 139 MOMHR. None of them had femoral neck fracture or revision at 2 years time point. Seventyone hips were excluded due to lack of proper X-rays; 68 hips (61 patients) fulfilled the inclusion criteria and were included into the study. Out of these 49 (72%) were in men and 19 (28%) were in women. The mean age at the time of surgery was 50.6 ± 9.6 years, the average body mass index was 29.4 ± 5.2 kg/m^2. The primary preoperative diagnosis was osteoarthritis in 53 (78%), osteonecrosis in 11 (16.2%), dysplasia in 2 (3%) and inflammatory arthritis in 2 (3%).

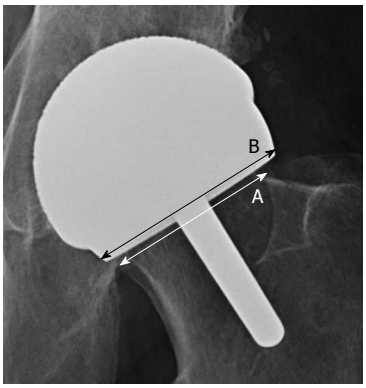

Figure 1 Radiograph showing measurement of Femoral Neck and Prosthesis. A: Neck-to-prosthesis ratio was calculated by dividing the femoral neck diameter at the prosthesis; B: Neck-to-prosthesis ratio was calculated by the diameter of the prosthesis at the opening edge.

Neck-to-prosthesis ratio, as described by Spencer *et al*[2], was used as the main outcome measure. "A" is the diameter of the femoral neck exactly at the prosthesis; "B" is the diameter of the implant exactly at the level of its opening edge (Figure 1). By dividing A by B the neck-to-prosthesis ratio was calculated. The means of the ratios between the two observers was taken for statistical analysis. Neck narrowing was indicated by reduced ratio (A/B) over the period of time. Femoral neck narrowing greater than 10% was considered significant.

Two independent observers reviewed the X-rays at 4 time points, *i.e.*, immediately after surgery, 3 mo, 1 year and 2 year. All the measurements were performed using Centricity Enterprise Web V3.0 (2006 GE Medical System) digital radiographic software. Twenty cases were used as subjects to calculate an intraclass correlation coefficient which evaluates the intra-observer and inter-observer reliability between the two observers (a value more than 0.8 was considered significant). After ensuring good reliability the remaining patients' X-rays were analyzed.

Statistical analyses were performed using SPSS 12.0 (SPSS for Windows, Rel. 12.0.0, 2003; SPSS Inc, Chicago, Ill). A paired *t*-test was used to evaluate the significant difference between different time points. A two-sided *P*-value < 0.05 was considered to be statistically significant.

RESULTS

Intraclass correlation coefficient calculated to analyze the reliability of the intraobserver and interobserver radiological measurements of diameters of femoral neck and

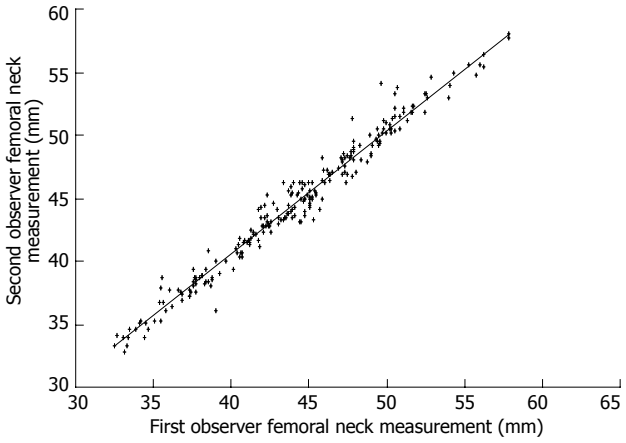

Figure 2 Inter-rater reliability comparison graph of paired femoral neck measurements.

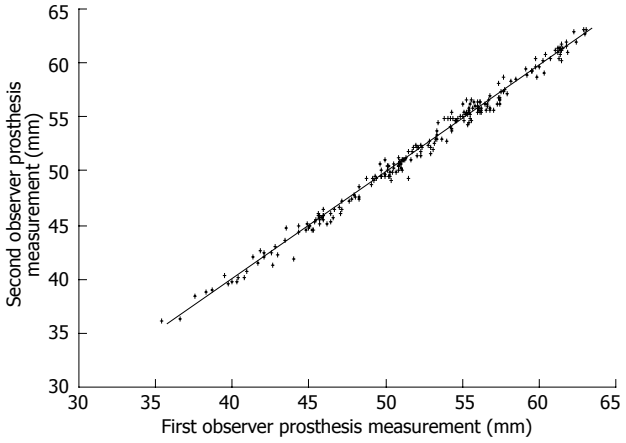

Figure 3 Inter-rater reliability graph of paired prosthesis measurements.

the femoral component showed significant degree of correlation (correlation coefficient = 0.924; 95%CI of 0.903-0.941) (Figures 2 and 3).

The neck-to-prosthesis ratios (NPRs) were 0.852 ± 0.056 immediately after surgery, 0.839 ± 0.052 at 3 mo, 0.835 ± 0.051 at 1 year and 0.83 ± 0.04 at 2 years post-operatively (Figure 4). When comparing to the immediate postoperative NPRs, the percent change was 1.9 ± 3.2 (0.05%-12.6%) at 3 mo, 1.9 ± 4.4 (0.1%-17%) at 1 year, and 3.6 ± 4.8 (0.07%-20%) at 2 years post-operatively. At 3 mo, femoral neck narrowing (FNN) was observed in 74% (48) of hips, which was significantly different from immediate postoperative X-ray ($P < 0.001$). Out of these 48 hips 23 were in men and 15 in women. There was no difference between neck to prosthesis ratio between 3 mo and 1 year ($P = 0.14$) and between 1 year and 2 years ($P = 0.53$). Excessive FNN, *i.e.*, narrowing that exceeded 10% of the diameter of the neck, was observed in only 4 patients at two years follow up. None of these patients developed a femoral neck fracture.

DISCUSSION

This aim of this study was to evaluate the short term

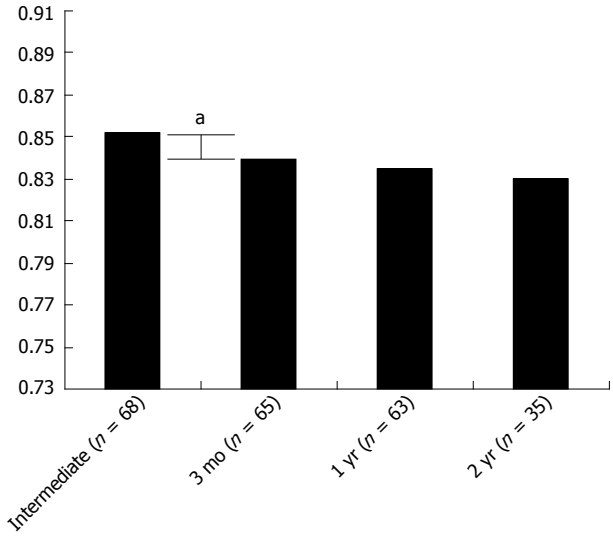

Figure 4 Neck-prosthesis ratio at follow-up (a) indicates significant change in neck-to-prosthesis ratio from immediate postoperative to 3 mo postoperatively.

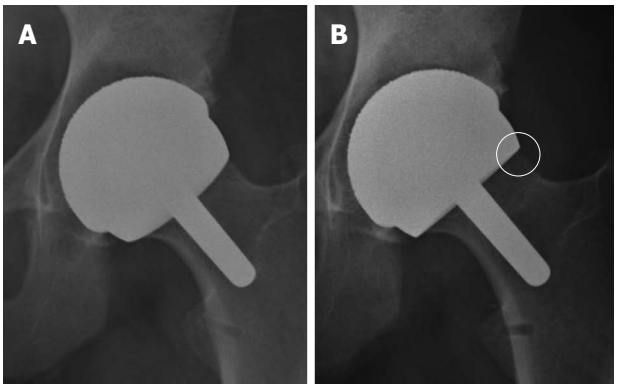

Figure 5 Femoral neck narrowing after Birmingham metal-on-metal hip resurfacing prosthesis occurs as early as 3 mo postoperatively and the neck-to-prosthesis ratio stabilizes thereafter. A: Immediate postoperative X-ray; B: Cirle showing neck narrowing at 3 mo postoperatively.

FNN after MOMHR. To the best of our knowledge, this is the first longitudinal evaluation of time related FNN after MOMHR focusing on short term outcome. Previous studies have focused on neck narrowing at 2 years or more, and their results have consistently reported absence of significant neck narrowing after 2 years post-operatively[1-4,16]. Spencer *et al*[2] reported that neck narrowing occurs within the first 2 years after surgery with no significant progression observed to a follow up of 7 years. Hing *et al*[4] showed that there was no statistically significant difference between the neck diameter at 3 years and 5 years indicating that thinning had stabilized previous to the 3 years time point. Joseph *et al*[3] also found no significant neck thinning after 2 years. Results of our study demonstrate that FNN after Birmingham MOMHR prosthesis occurs as early as 3 mo postoperatively and the NPR stabilizes thereafter (Figure 5). Our results of early neck narrowing may be supported by observations of Cooke *et al*[14] who found that bone mineral

density changes after resurfacing are mainly confined to femoral neck and that it reduces by 3 mo post-operatively but is recovered to normal by 12 mo with no significant change thereafter.

The incidence of neck narrowing in our cohort was 74% (48 hips). This was similar to what Hing *et al*[4] observed (125 hips; 77%) in their study on 163 Birmingham Hip Resurfacing arthroplasties but was less than that reported by Spencer *et al*[2] who found neck narrowing in 90% of prosthesis at 2 years post operatively. It is possible that the uncemented implant used in that study may result in a different loading pattern as compared to BHR. Joseph et al. did a comparative study examining both the Cormet 2000 in 35 cases and Birmingham Hip Resurfacing in 26 cases[3]. They observed neck narrowing in 98 % (60/61) of cases but found no statistical difference in the measurements between the two implant types. We also noticed that 15 out of 19 female had neck narrowing, while only 23 out of 49 male did ($P = 0.017$). One of the possible reason might be the femoral neck of female was significantly narrower than male. In our group the femoral neck diameter were 44.0 ± 3.5 mm and 37.7 ± 3.6 mm for male and female respectively. While the stem diameter of the femoral component is the same in spite of the size of the component, these results in the stem to neck ratio in female are greater than male. However, further researches were needed to investigate the effect of femoral neck diameter on neck narrowing.

Although the exact etiology of neck narrowing is still unknown, possible contributing factors for neck narrowing may include stress shielding, damage to the blood supply, bone necrosis in the residual femoral head, alteration in hip biomechanics or secondary to wear debris.

In the current literature, bone remodeling secondary to stress shielding after hip resurfacing has been studied by several finite element analyses[7-9]. Although bone remodeling is a feature of normal bone metabolism, hip resurfacing may result in stress shielding with resorption and narrowing of the femoral neck resulting from altered load. We believe that this resorption stabilizes by 3 mo; however, it requires further investigation.

Changes in blood supply to femoral head after hip resurfacing is controversial. Steffen *et al*[5] demonstrated compromised blood supply to the femoral head during hip resurfacing. Also, notching of the femoral neck during surgery has been shown to cause a reduction in blood flow of 50%[6]. In the retrieval analysis of failed Birmingham or Cormet resurfacing, Little *et al*[17] observed evidence of osteonecrosis in all but one case at revision. However, Howie *et al*[18] and Campbell *et al*[19] reported that retrieved femoral head maintained good blood supply and that avascular necrosis of femoral head is not a common cause of failure of resurfacing. The reason for this difference in observation may be attributed to different histological criteria used for determining osteonecrosis. It is still unclear if changing of blood supply plays a role in neck narrowing.

It has been shown that metal-on-metal articulations if malpositioned cause increased wear rates[10]. This wear induced debris can cause an inflammatory reaction and subsequent osteolysis which leads to neck thinning[10-12]. Also, in some patients hypersensitivity due to metal ion release may be a cause of neck thinning[20].

Although the clinical significance of neck narrowing is still unknown, the main concern is whether it could be predictive of future risk of femoral neck fractures. There is no consistent evidence in the literature showing that neck narrowing can lead to fracture. Shimmin did a national review of 3497 Birmingham hips which were inserted by 89 surgeons. Fracture of the femoral neck occurred in 50 patients, an incidence of 1.46%. They also found out that the mean time to fracture was 15.4 wk postoperatively. In our cohort, though we observed a 74% rate of neck narrowing, we did not have any fracture cases and therefore, we were not able to evaluate if there is correlation between neck narrowing and fracture.

We note the limitations of this study. First, as in all previous studies, we did not assess FNN in the sagittal plane. Computed tomography scan or roentgen stereophotogrammetric analysis may provide more accurate information; however, routine use of these methods on every resurfacing patient was not performed for this investigation. Our measurements were recorded using digital radiographs which may have improved our accuracy compared to previous studies done using a conventional radiography[1,2,16]. To reduce errors, all observations were made twice by two independent observers and all values were expressed as ratios. Similar to previous studies, we showed that this method of measuring neck-prosthesis ratio is statistically reliable. We had an intraclass correlation coefficient of 0.924. Second, this is a retrospective study. Only 68 out of 139 patients fulfilled the inclusion criteria. Although 96% (65/68) and 93% (63/68) patients had 3-mo and 1-year data, only 51% (35/68) had 2-year data. Selection bias may affect the result. Thirdly, the sample size of this study is relatively small. Potentially, this study could be under powered.

In conclusion, our study shows that neck narrowing occurs as early as 3 mo after MOMHR and is generally not progressive for up to 2 years as was previously believed. This pattern of early neck narrowing may be explained by bone adoption to initial stress shielding of the neck below the implant. Further study is required to determine the exact cause of this early neck narrowing. In our study, thinning of the femoral neck did not progress to any adverse clinical consequences and we are currently unsure of its clinical significance. It still remains to be seen whether patients with FNN may be more susceptible to femoral neck fracture.

COMMENTS

Background

Metal-on-metal hip resurfacing (MOMHR) was approved in the United States by the Food and Drug Administration in May 2006, buoyed by promising survivorship data from the United Kingdom. This technique, primarily due to its bone conserving nature, has become an alternative to total hip arthroplasty in younger patients. Femoral neck narrowing, potentially posing as a risk factor for

femoral neck fracture, is a complication unique to this type of arthroplasty.

Research frontiers

The incidence of neck narrowing after MOMHR was reported from 77% to 98%. Although the exact etiology of neck narrowing is still unknown, possible contributing factors for neck narrowing may include stress shielding, damage to the blood supply, bone necrosis in the residual femoral head, alteration in hip biomechanics or secondary to wear debris. As a result of this data it is unclear when exactly neck narrowing occurs and whether or not it had any impact as a risk factor for early femoral neck fracture with MOMHR.

Innovations and breakthroughs

This study was to more closely evaluate the changes that occur in the femoral neck in MOMHR patients. The authors measured neck narrowing radiographically immediately after surgery and at 3 mo, 1 year and 2 years postoperatively. The authors hypothesized that neck narrowing occurs early after MOMHR and then stabilizes long before the 2 year time point.

Applications

This pattern of early neck narrowing may be explained by bone adoption to initial stress shielding of the neck below the implant. In this study, thinning of the femoral neck did not progress to any adverse clinical consequences and we are currently unsure of its clinical significance. It still remains to be seen whether patients with femoral neck narrowing may be more susceptible to femoral neck fracture.

Peer review

The manuscript is very interesting and can be accepted with minor corrections that are reported through the text.

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BRIEF ARTICLE

Incidence and analysis of radial head and neck fractures

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Abstract

AIM: To investigate several complications like persistent radial head dislocation, forearm deformity, elbow stiffness and nerve palsies, associated with radial head fractures.

METHODS: This study reviewed the clinical records and trauma database of this level Ⅰ Trauma Center and identified all patients with fractures of the radial head and neck who where admitted between 2000 and 2010. An analysis of clinical records revealed 1047 patients suffering from fractures of the radial head or neck classified according to Mason. For clinical examination, range of motion, local pain and overall outcome were assessed.

RESULTS: The incidence of one-sided fractures was 99.2% and for simultaneous bilateral fractures 0.8%. Non-operative treatment was performed in 90.4% (*n* = 947) of the cases, surgery in 9.6% (*n* = 100). Bony union was achieved in 99.8% (*n* = 1045) patients. Full satisfaction was achieved in 59% (*n* = 615) of the patients. A gender related significant difference (*P* = 0.035) in Mason type distribution-type Ⅲ fractures were more prominent in male patients *vs* type Ⅳ fractures in female patients-was observed in our study population.

CONCLUSION: Mason type Ⅰ fractures can be treated safe conservatively with good results. In type Ⅱ to Ⅳ surgical intervention is usually considered to be indicated.

Key words: Elbow; Radial head; Radial neck; Fracture; Children; Adult

Core tip: To investigate several complications like persistent radial head dislocation, forearm deformity, elbow stiffness and nerve palsies, associated with radial head fractures. An analysis of clinical records revealed 1047 patients suffering from fractures of the radial head or neck classified according to Mason. Non-operative treatment was performed in 90.4% (*n* = 947) of the cases, surgery in 9.6% (*n* = 100). Full satisfaction was achieved in 59% (*n* = 615) of the patients. A gender related significant difference (*P* = 0.035) in Mason type distribution-type Ⅲ fractures were more prominent in male patients *vs* type Ⅳ fractures in female patients-was observed in our study population.

Kovar FM, Jaindl M, Thalhammer G, Rupert S, Platzer P, Endler G, Vielgut I, Kutscha-Lissberg F. Incidence and analysis of radial head and neck fractures. *World J Orthop* 2013; 4(2): 80-84 Available from: URL: http://www.wjgnet.com/2218-5836/full/v4/i2/80.htm DOI: http://dx.doi.org/10.5312/wjo.v4.i2.80

INTRODUCTION

Fractures of the radial head are common and account for one third of all fractures of the elbow and approximately 1.5%-4% of all fractures in adults[1-3]. As much as 85% of these fractures occur between the third and sixth decade of age. According to the literature the mean age is between 45 and 45.9 years, and in an average, female patients are 7 to 16.8 years older than male patients[4-8]. Injury mechanism is a fall on the outstretched arm with the elbow in pronation and partial flexion, or in a rare case, direct trauma[1,6,7,9]. In children the incidence for radial head and neck fractures is up to 1.3%[10].

Radial fractures can be classified by the Mason-Johnston classification[11,12]. According to this classification, radial head fractures can be divided in to 3 types: a type I fracture is a nondisplaced fracture, a type Ⅱ fracture is a displaced fracture, and a type Ⅲ fracture is a comminuted fracture. Johnston added a fourth type: a radial head fracture with dislocation of the elbow[7,11,12].

Thus, the aim of this study was to analyze the epidemiology of radial head and neck fractures, specifically to describe age distribution, male female ratio, and the influence of fracture types and stabilization technique on the overall outcome, seen in this Level I Trauma Center between 2000 and 2010.

MATERIALS AND METHODS

Study population

In a ten year period, 1047 non-selected trauma patients where included in our study at a Level I Trauma Center, Department auf Trauma Surgery, Medical University of Vienna, Austria. Data were collected prospectively and evaluated retrospectively, in our computerized patient record's database. We collected data on all victims admitted to the hospital with diagnosed radial head and neck factures, but only patients with complete data and follow up have been included into the present study.

Members of the Department of Trauma Surgery did data collection and an independent member of the Department not involved in the study did a random cross check to exclude possible errors. Internal revision board (IRB) approval was not requested due to the fact that it is a retrospective data study only. The study was conducted according to the principles of Good Clinical Practice (GCP) and Good Laboratory Practice (GLP) to the best of our knowledge. Collected data included variables such as age, gender, mechanism of injury, method of treatment, and clinical and radiological outcome after treatment. We generated two subgroups, juvenile fractures of the radial head and neck (< 18 years), and fractures in adults. Exclusion criteria for this study were missing pertinent clinical or radiographic data of follow-up monitoring leading to incomplete dataset. Treatment methods were depending on the fracture type and the physicians' choice. Radial head prosthesis was implanted in patients with comminuted fractures, if the salvage of the radial head was not possible. For clinical examination, range of motion, local pain, and bony union were assessed routinely.

Table 1 Description of studypopulation *n* (%)

Total	1047 (100)
Male	499 (47.7)
Female	548 (52.3)
Age (range), yr	36 (2-95)
Follow up (wk)	3 (0-350)
Children	77 (7.4)
Adults	970 (92.6)
Left	501 (47.9)
Right	538 (51.4)
Utriusque	8 (0.8)

Clinical and radiographic examination

For analysis of incidence and outcome of radial head a neck fractures, all records of follow-up monitoring were meticulously reviewed for each patient. Follow-up monitoring included patient's accurate clinical and radiographic examination in our outpatient clinic at admittance and at each follow-up visit. Radiographic assessment included standard radiographs (antero-posterior and lateral view). Additional radiocapitellar views or computer tomography (CT) scans were performed if the standard finding was doubtful. Radiologic scoring was performed according to Johnston's modification of the Mason classification[11,12].

Statistical analysis

For statistical analyses we used the SPSS software package (SPSS, Chicago, IL, United States). Medians and Interquartile rages are shown for continuous variables unless otherwise stated. Discrete variables are presented as counts and percentages. The nonparametric Mann-Whitney *U* test was used for continuous variables and the χ^2 test for discrete variables. A two-tailed *P* value less than 0.05 was considered statistically significant.

RESULTS

During the ten-year study period, 1047 trauma patients met the inclusion criteria. The mean age was 36 years (range 2 to 95), 499 (47.7%) were males and 548 (52.3%) were females, 970 (92.6%) patients were adults, 77 (7.4%) were children. (Table 1) In our study population a total of 859 (82.1%) fractures type I, 149 (14.2%) type Ⅱ, 28 (2.7%) type Ⅲ and 11 (1.1%) type Ⅳ have been observed. (Table 2) In 538 patients (51.4%) the radial head fracture or neck fracture was on the right side, and 501 cases (47.9%) had the fracture on the left side. In 8 cases (0.8%) a simultaneous bilateral fracture was observed. Mean follow up was 3 wk (range 0 to 350). 71 (6.6%) had follow-up less than one week, 267 (25.5%) had follow-up of exactly one week.

We divide our total patient population in two subgroups: adults and children to analyse our treatment results. In the children group 69 (90%) cases were treated

Table 2 Distribution of fracture types I-IV in our study population *n* (%)

Mason		Male	Female
Type Ⅰ	859 (82.1)	409 (47.6)	450 (52.5)
Type Ⅱ	149 (14.2)	67 (45.0)	82 (55)
Type Ⅲ	28 (2.7)	20 (71.4)	8 (28.6)
Type Ⅳ	11 (1.1)	3 (27.3)	8 (72.7)

conservatively compared to 8 (10%) cases treated with surgery. In comparison to those findings, in the adult group 91% (n = 880) cases were treated conservative compared to 9% (n = 90) cases treated with surgery.

In the total study population, 11 prostheses (1%) were implanted. In seven cases cemented radial head prostheses, in three cases bio prostheses and in one case total elbow prosthesis were implanted.

In eight cases sensitivity impairment was observed in type Ⅰ fractures, treated conservatively. Those patients were from the geriatric study pool and had full function on the affected extremity. Two patients, both type Ⅲ, developed a non-union, one after stabilization with a T-plate, and one after open reduction in the first procedure and transfixation during the revision surgery. In one case, type Ⅲ, a palsy of the ulna nerve occurred after closed reduction. Synostosis was observed in a type Ⅲ fracture, treated with a prosthesis. Re-osteosynthesis was indicated in one case, because the primary screw fixation was locking the range of motion (ROM) in the elbow joint. After re-osteosynthesis the patient gained full ROM without pain. Luxation after initial treatment occurred in two cases, one in a type Ⅰ fracture, stabilized with a T-plate, and in the second case, a type Ⅲ fracture, treated with a prosthesis of the radial head. No death or amputation occurred in our study population.

A gender related significant difference (P = 0.035) in Mason type distribution was observed in our study population. type Ⅲ fractures were more prominent in male patients (n = 20, 71.4%) *vs* type Ⅳ fractures in female patients (n = 8, 72.7%).

A significant difference in type Ⅱ distribution was observed between children and adults. While 26% of the children (n = 20) type Ⅱ fracture, only 13% of the adult subgroup (n = 129) suffered from the same fracture type (P = 0.004). Correlating with age revealed that within children younger than ten years, only half of the patients suffered from type Ⅰ (53%, n = 17), and type Ⅱ (40.6%, n = 13) (P < 0.001). In the children older than ten years, and adults, type Ⅰ was predominant. 84% (n = 38) in children from 11 till 18 years, and 83% (n = 804) in the adult subgroup (P < 0.001).

Median ROM (flexion/extension) according to Mason classification was: type Ⅰ 135 [interquatile range (IQR) 105-150], type Ⅱ 130 (IQR 108-150), type Ⅲ 130 (IQR 108-150) and type Ⅳ 140 (IQR 110-150). For the total study population 77% (n = 802) gained ROM > 100°, 22% (n = 225) ROM 50°-100°, and 2 (n = 20) < 50°. Median ROM (internal/external rotation) was 94% (n = 985) > 100°, 4% (n = 43) 50°-100°, and 2% (n = 19) < 50°. Total pain distribution at the end of follow up was non 59.3% (n = 621), mild 37.6% (n = 394) and severe in 3.1% (n = 32) (P = 0.031).

Different forms of conservative treatment did not influenced time of immobilization and pain at the end of follow-up. (Table 3) 75% of patients treated with surgery reported no pain at the end of follow-up compared to 57% of patients, treated conservatively (P = 0.03) (Table 4). No influence according to Mason classification could be observed.

DISCUSSION

In our study, we aimed to investigate the effect of fracture type and stabilization technique on overall outcome. Additionally we also looked at possible gender related influences. Due to the limited range of follow up, we believe that the total number of 1047 included cases over a period of ten years allows a warrantable analysis of our study population.

Incidence of fracture types according to Mason was comparable to findings in the already published literature[7,13]. The average age in years for specific fracture types (Ⅰ-Ⅳ) in the adult subgroup was similar to those numbers published by Duckworth *et al*[13]. For the distribution of fracture types in the children subgroup, we could detect similar results compared to Kaas *et al*[7]. The number of observed simultaneous bilateral fractures during an inclusion period of ten years is in accordance with previous published data[14]. Haematoma aspiration was performed in a total of 23 cases (2%), but no significant influence on pain and functionality could be observed. This is in contrast to the finding by Ditsios *et al*[1], postulating that haematoma aspiration leads to a imminent decrease in pain for the patient.

Our results demonstrate a statistical significance for the male female ratio in both subgroups. In current publications male-female ratio of 2:3, with female patients being significantly older is reported[4]. We found a full satisfactionary outcome after 3 wk on average in 59% (n = 615) of the patients, after radial head and neck fractures.

The assessment of longitudinal stability is a basic step before deciding the most suitable surgical option and to avoid complications[15]. If open reduction and internal fixation fails to achieve a satisfactory result, resection arthroplasty and radial head prosthesis are additional options, but both are linked with poorer outcome results[3,15-17]. Despite the fact that numerous papers have been published dealing with the optimal treatment of radial head fractures, no consensus or general accepted guideline exists[16,18-23].

There are several limitations of the current study we have to mention in relation to our results. The first and most gravid is the fact that the study was retrospectively performed. Also some critical readers may esteem the long inclusion duration of ten years as limitation. The fact that the study population represents a wide range of

Table 3 Immobilization time in conservative treatment

	Type Ⅰ				Type Ⅱ				Type Ⅲ				Type Ⅳ
	n	Median	Min	Max	*n*	Median	Min	Max	*n*	Median	Min	Max	*n*
Cast upper arm	256	1	1	6	51	2	1	6	0				0
Cast lower arm	7	2	2	4	1	2	2	2	0				0
Dorsale splint	7	4	1	4	1	1	1	1	0				0
Elastic bandage	3	1	1	3	4	2	1	3	0				0
Filmulin bandage	526	1	1	12	34	1	1	8	1	3	3	3	0
Gilchrist	0	0			1	2	2	2	0				0
Cork splint upper arm	0	0			1	3	3	3	0				0
Cork splint lower arm	1	1	1	1	0				1	1	1	1	0
Mitella	8	1	1	1	0				0				0
Non	9	0	0	0	3	0	0	0					0
Surgery	10				53				26				11

Table 4 Summary treatment strategies and pain *n* (%)

	Total	Surgery	Pain non	Pain mild	Pain severe
Type Ⅰ	859 (82.1)	10	3 (30)	7 (70)	0
Type Ⅱ	149 (14.2)	53	41 (77.4)	10 (18.9)	2 (3.8)
Type Ⅲ	28 (2.7)	26	21 (80.8)	4 (15.4)	1 (3.8)
Type Ⅳ	11 (1.1)	11	10 (90.9)	1 (9.1)	
		Conservative			
Type Ⅰ		849	488 (57.5)	335 (39.5)	26 (3.1)
Type Ⅱ		96	57 (59.4)	36 (37.5)	3 (3.1)
Type Ⅲ		2	1 (50)	1 (50)	
Type Ⅳ		0			

age and heterogeneity in the accident cause and fracture type may also be seen as a disadvantage. Several surgeons, attendings and residents, performing the surgeries might also influence the results. We also want to mention the special patient population when it comes to suicidal jumps and motor vehicle accidents, with people of challenging social background that might have an influence on the outcome, compliance and follow up. Also the inclusion of extreme fracture cases with severe soft tissue trauma may have an influence on our results. Despite these limitations we believe that the results justify our conclusion, even if further prospective clinical trials have to be conducted to approve our findings.

Conservative treatment is the primary goal. Mason type I fractures can be treated safe conservatively with good results[1,12,24]. In type Ⅱ to Ⅳ surgical intervention is usually considered to be indicated[23]. A gender related significant difference ($P = 0.035$) in Mason type distribution was observed in our study population. type Ⅲ fractures were more prominent in male patients ($n = 20$, 71.4%) *vs* type Ⅳ fractures in female patients ($n = 8$, 72.7%). Different forms of conservative treatment did not influence the pain at the end of follow-up. 75% of patients treated with surgery reported no pain at the end of follow-up compared to 57% of patients, treated conservatively ($P = 0.03$).

The decision which of the described techniques should be used in a patient can still be considered a fine line, and has to be based on the individual case and surgeons experience.

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COMMENTS

Background

To investigate several complications like persistent radial head dislocation, forearm deformity, elbow stiffness and nerve palsies, associated with radial head fractures.

Research frontiers

Radial fractures can be classified by the Mason-Johnston classification.

Innovations and breakthroughs

Fractures of the radial head are common and account for one third of all fractures of the elbow and approximately 1.5%-4% of all fractures in adults. As much as 85% of these fractures occur between the third and sixth decade of age. According to the literature the mean age is between 45 and 45.9 years, and in an average, female patients are 7 to 16.8 years older than male patients. Injury mechanism is a fall on the outstretched arm with the elbow in pronation and partial flexion, or in a rare case, direct trauma. In children the incidence for radial head and neck fractures is up to 1.3%.

Applications

An accurate classification of radial head fractures is the first step in successful treatment.

Peer review

The manuscript is an interesting one. It summaries a 10 year prospective study related to an important population suffering radial head and neck fractures.

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BRIEF ARTICLE

Bipolar hemiarthroplasty for femoral neck fracture using the direct anterior approach

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Abstract

AIM: To evaluate whether walking ability recovers early after bipolar hemiarthroplasty (BHA) using a direct anterior approach.

METHODS: Between 2008 and 2010, 81 patients with femoral neck fracture underwent BHA using the direct anterior approach (DAA) or the posterior approach (PA). The mean observation period was 36 mo. The age, sex, body mass index (BMI), time from admission to surgery, length of hospitalization, outcome after discharge, walking ability, duration of surgery, blood loss and complications were compared.

RESULTS: There was no significant difference in the age, sex, BMI, time from admission to surgery, length of hospitalization, outcome after discharge, duration of surgery and blood loss between the two groups. Two weeks after the operation, assistance was not necessary for walking in the hospital in 65.0% of the patients in the DAA group and in 33.3% in the PA group ($P < 0.05$). As for complications, fracture of the femoral greater trochanter developed in 1 patient in the DAA group and calcar crack and dislocation in 1 patient each in the PA group.

CONCLUSION: DAA is an approach more useful for BHA for femoral neck fracture in elderly patients than total hip arthroplasty in terms of the early acquisition of walking ability.

Key words: Direct anterior approach; Bipolar hemiarthroplasty; Posterior approach; Femoral neck fracture; Muscle presentation; Walking ability

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INTRODUCTION

The direct anterior approach (DAA) is an intermuscular approach to reach the hip joint using the distal part of the Smith-Petersen approach without muscle detachment[1-3]. This approach has been reported to be useful in total hip arthroplasty (THA) for hip osteoarthritis due to it facilitating recovery of walking ability early after the operation[2,4-8]. When bipolar hemiarthroplasty is performed for femoral neck fracture in the elderly, early recovery is important to prevent a decrease in activities of daily living (ADL)[9-11]. Therefore, assuming that walking ability recovers early after bipolar hemiarthroplasty using DAA, we performed a prospective study on the usefulness of DAA in comparison with the posterior approach (PA).

MATERIALS AND METHODS

Between January 2008 and January 2010, 81 patients with femoral neck fracture underwent bipolar hemiarthroplasty using DAA or PA, and 79 of them were included as subjects after excluding patients with a pathological fracture. The patients were alternately assigned to the DAA group or PA group in the order they were hospitalized. The mean observation period was 36 mo (24-48 mo). As for the prosthesis type, the Centrax/Accolade TMZF (β titanium alloy: titanium-molybdenum-zirconium-iron) stem (Stryker) was used in all patients (Figure 1). Surgery was performed as soon as possible after admission. Anticoagulants/antiplatelet drugs were not suspended. The operators were 6 surgeons with 2-8 years clinical experience in the orthopedic department. The author (Baba T) played the role of a teaching assistant in all operations.

DAA was performed employing the method of Oinuma *et al*[2] using the distal part of the Smith-Petersen approach in the supine position on a standard surgical table. The fascia of the tensor fasciae latae muscle was incised at a site about 2 cm laterally to the skin incision to prevent lateral femoral cutaneous nerve injury and the intermuscular space between the tensor fasciae latae muscle and sartorius muscle was bluntly entered. The anterior articular capsule was exposed, incised and resected as much as possible to expose the femoral head. For stem insertion, the surgical table was extended so that the hip joint could be extended to 15°. The superior and posterior portions of the articular capsule were partly incised so that the greater trochanter could be elevated with a retractor. Finally, the size and stability were confirmed under fluoroscopy during the operation. PA was performed in the lateral recumbent position. The gluteus maximus muscle was divided along muscle fibers and short external rotators were detached. A T-shaped incision was made in the articular capsule and the femoral head was resected. Finally, the short external rotators and the articular capsule were sutured to the original position as much as possible.

In both groups, full weight bearing was permitted from the day after the operation. In the DAA group, no abduction pillow was applied. The PA group used an abduction pillow during rest on the bed for about 2 wk. An antibiotic was administered at the time of the introduction of anesthesia and at 3 hourly intervals thereafter (total of 3 times) on the day of the operation and twice a day for the subsequent 4 d. The drain was removed 2 d after the operation and fondaparinux as an anticoagulant for deep veins was administered at an appropriate dose according to the body weight and renal function for 14 d. The patients visited the hospital for examination 1 mo after discharge and underwent plain X-ray examination and clinical evaluation at 3 monthly intervals for 1 year and at 6 monthly intervals thereafter. When they were transferred to another hospital to continue rehabilitation, they visited our hospital 1 mo after the transfer and the subsequent schedule was the same as above.

The age, sex, body mass index (BMI), time from admission to surgery, length of hospitalization, outcome after discharge, walking ability, duration of surgery, blood loss and complications were compared.

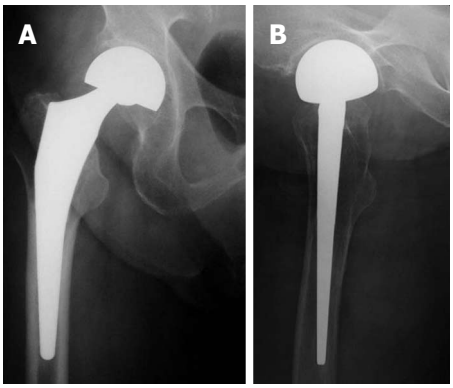

Figure 1 Since the anteroposterior width of Accolade TMZF stem is narrow and rasping of the greater trochanter is not necessary, this stem could be readily used for the direct anterior approach. Anteroposterior and lateral views on X-ray radiography after bipolar hemiarthroplasty.

Table 1 Demographic characteristics of patients

	DAA	PA	*P* value
Sex (male:female)	7:33	8:31	NS[1]
Age (yr)	76.7 ± 7.3	74.9 ± 7.7	NS[2]
BMI (kg/m^2)	20.6 ± 3.6	21.6 ± 3.0	NS[2]
Time from admission to surgery	2.9 ± 2.5	2.9 ± 2.0	NS[2]

There was no significant difference in the age, sex, BMI, time from admission to surgery. Values are the mean ± SD. [1]χ^2 test, [2]Student's *t*-test. BMI: Body mass index; DAA: The direct anterior approach; PA: The posterior approach; NS: Not significant.

Statistical analysis

Continuous data were analyzed using Mann-Whitney *U* test and Student's *t*-test and data grouped into categories were analyzed with the chi-squared test. A $P < 0.05$ was considered significant.

RESULTS

The DAA group consisted of 40 patients (7 males and 33 females) with a mean age of 76.7 ± 7.3 years. The PA group consisted of 39 patients (8 males and 31 females) with a mean age of 74.9 ± 7.7 years. Two patients in the DAA group died of liver cancer and myocarditis and 1 in the PA group died of renal failure. These deaths were not associated with the femoral neck fracture. The other patients were followed up to the final evaluation time point. There was no significant difference in the age, sex and BMI between the two groups (Table 1). Surgery was performed 2.9 d (mean) after admission in both the DAA group and the PA group. Surgery was performed within 2 d after admission in 24 of the 40 patients in the DAA group and 23 of the 39 patients in the PA group.

The mean hospitalization period was 29.9 (14-50) d in the DAA group and 29.3 (17-58) d in the PA group, showing no difference. Therefore, the place of residence

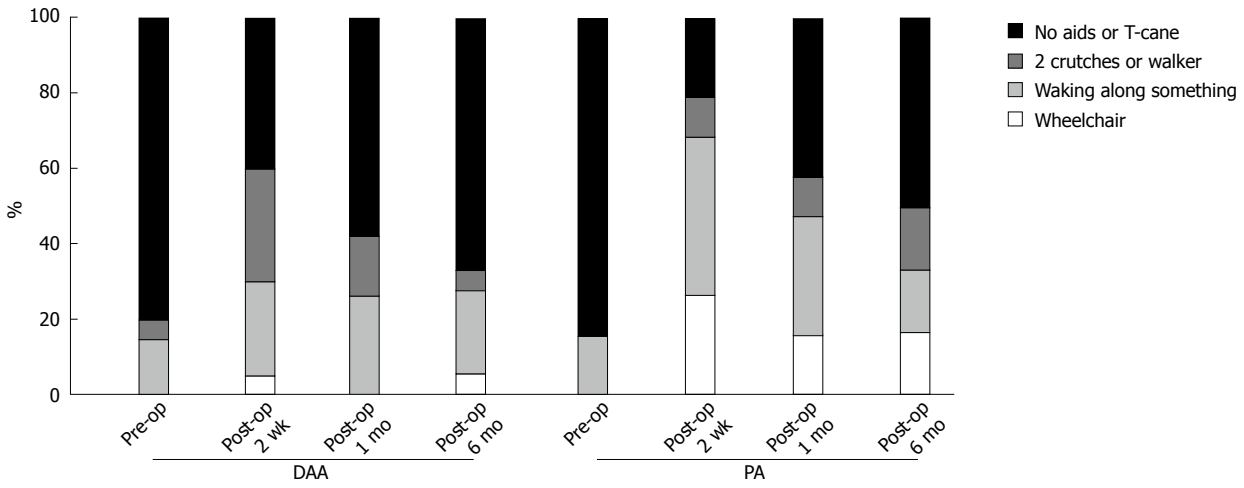

Figure 2 Walking ability before injury and after the operation. DAA: Direct anterior approach; PA: Posterior approach; op: Operation.

at the time of injury and the place to which the patient was discharged from our hospital were investigated. In the DAA group, the former and latter were home and home, respectively, in 38 patients and a facility and facility in 1, and home and a rehabilitation hospital in 1. Of the 40 patients, 39 were discharged to the place of residence before injury. In the PA group, the former and latter places were home and home, respectively, in 21 patients and home and a rehabilitation hospital in 18. Of the 39 patients, only 21 were discharged to the place of residence before injury. Walking ability before injury and after the operation was classified into the following 4 categories: unaided walking (including walking using a T-cane because in our hospital we instruct patients to use a T-cane even when unaided walking is possible), walking using two crutches (including walkers for the elderly), walking along something (assisted walking) and use of a wheelchair (Figure 2). Two weeks after the operation, assistance was not necessary for walking in the hospital (unaided walking, walking using a T-cane, walking with 2 crutches) in 65% (26/40) of the patients in the DAA group and in 33.3% (13/39) in the PA group (Mann-Whitney *U* test; $P < 0.05$). After 6 mo, unaided walking or walking using a T-cane was possible in 67.5% (27/40) in the DAA group and in 66.6% (26/39) in the PA group, without a significant difference between the two groups. The duration of surgery was 65.3 ± 39 min in the DAA group and 76.7 ± 33 min in the PA group. The intraoperative blood loss was 121 ± 82 g in the DAA group and 146 ± 56 g in the PA group. Warfarin was administered in 3 patients in the DAA group and Bayaspirin in 3 in the DAA group and 5 in the PL group but these drugs were not suspended during the perioperative period.

As for complications, fracture of the apex of the femoral greater trochanter developed in 1 patient in the DAA group and calcar crack in 1 patient and dislocation in 1 in the PA group. Neither infection of the superficial layer or deep area nor fatal deep venous thrombosis was observed. No special treatment was performed for the fracture of the apex of the femoral greater trochanter. The calcar crack was reinforced by wiring as much as possible. The fracture of the apex of the femoral greater trochanter or calcar crack did not delay the initiation of weight bearing after the operation, presenting no special clinical problems.

DISCUSSION

To improve ADL for femoral neck fracture in the elderly, we paid attention to DAA as an intermuscular approach. Excellent results of THA using DAA have been reported[12-14]. DAA is advantageous for the early postoperative recovery of muscle strength and is associated with a low dislocation rate. However, it has also been reported that muscle strength 6-12 mo after the operation does not differ between DAA and other approaches[4,15]. Since THA is mostly performed for hip osteoarthritis, the long-term recovery of muscle strength is important and the advantage of DAA (early recovery of muscle strength) is not so marked. Rather than this advantage, the low dislocation rate may be useful for THA. On the other hand, in bipolar hemiarthroplasty in the elderly, it is important to use methods that: (1) does not induce dislocation, even in patients such as dementia patients with difficulty in recognizing contraindicated limb positions; and (2) facilitate early regaining of walking ability without a decrease in the preoperative muscle strength rather than the long-term recovery of muscle strength. In addition, less invasive, safe and accurate surgical methods may reduce peri- and postoperative complications, contributing to ADL improvement. Therefore, we performed this study, comparing two groups who were treated by DAA as an intermuscular approach or PA as an approach with muscle detachment using the same prosthesis system and who were similar in age and sex and the waiting period. As a result, the DAA group clearly showed a better walking ability early after the operation.

Dislocation after bipolar hemiarthroplasty is one of the complications, although the reported dislocation rate varies from 1.5% to 13.4%[16-20]. Risk factors of dislocation include difficulty in recognizing dislocation-inducing limb positions due to dementia and mental/neurological

disorders, decreased muscle strength due to hemiplegia or Parkinson's disease, and frequent falling. These risks cannot be avoided because this fracture mainly occurs in elderly people. Concerning the difference in the dislocation rate between surgical approaches, many studies have shown that the anterior approach is advantageous in reducing dislocation in THA[1,3], whereas Sierra RJ *et al*[18] reported no association between the dislocation rate after bipolar hemiarthroplasty and the surgical approach. In our study, dementia and Parkinson's disease were observed in 5 and 1 patient, respectively, in the DAA group and 3 and 3 patients, respectively, in the PA group. The number of high-risk patients for dislocation was similar between the two groups but two episodes of posterior dislocation occurred in a patient with dementia in the PA group. After using a hip abduction orthosis, this patient did not develop dislocation. Dislocation-inducing limb positions in the PA group may involve a higher risk in bipolar hemiarthroplasty in elderly patients than in THA because patients have difficulty in adequately understanding these positions. Since dislocation-inducing limb positions after an operation using DAA rarely occur during ADL, few instructions regarding such positions are necessary.

Oinuma *et al* described patients appropriate for implantation of a THA by DAA system as: (1) females; (2) without obesity; (3) with osteoarthritis excluding Crowe 3 and 4; and (4) showing a wide range of motion[21,22]. When these criteria are applied to bipolar hemiarthroplasty, femoral neck fracture frequently occurs in females without deformation showing a normal range of motion. In our DAA group, the mean BMI was 20.1 and there were few obese patients. These conditions are appropriate for the use of DAA. In particular, using DAA, stem manipulation on the femoral side is considered to be difficult. However, since femoral neck fracture was not accompanied by flexion contracture or deformation, anterior transfer of the femur was straightforward in bipolar hemiarthroplasty compared with THA. Fracture of the apex of the greater trochanter in our study was clearly a surgical manipulation problem and adequate attention should have been paid to osteoporotic bone. Due to the surgical technique, it is necessary to select stems not occupying the medullary cavity and preserving the greater trochanter. Long straight stems are difficult to insert using DAA. The Accolade TMZF stem (Stryker) used in this study has a tapered wedge achieving stem fixation on the medial and lateral sides of the femoral medullary cavity in a wedge shape[23]. Since the anteroposterior width of the stem is narrow and rasping of the greater trochanter is not necessary, this stem could be readily used for DAA. Concerning tapered wedge fixation in patients with frail medullary cavity shapes or bone, the stem alignment tends to be flexed but this presents no clinical problems and satisfactory mid-term results have been reported[24,25]. Indeed, there were no clinical problems associated with the use of the Accolade stem in our patients.

In conclusion, DAA is an approach more useful for bipolar hemiarthroplasty for femoral neck fracture in elderly patients than THA in terms of the early acquisition of walking ability due to muscle preservation and the low dislocation rate.

COMMENTS

Background

The direct anterior approach (DAA) is an intermuscular approach to reach the hip joint using the distal part of the Smith-Petersen approach without muscle detachment. This approach has been reported to be useful in total hip arthroplasty (THA) for hip osteoarthritis due to it facilitating recovery of walking ability early after the operation.

Research frontiers

When bipolar hemiarthroplasty is performed for femoral neck fracture in the elderly, early recovery is important to prevent a decrease in activities of daily living.

Innovations and breakthroughs

Assuming that walking ability recovers early after bipolar hemiarthroplasty using DAA, the authors performed a prospective study on the usefulness of DAA in comparison with the posterior approach (PA).

Applications

DAA is an approach more useful for bipolar hemiarthroplasty for femoral neck fracture in elderly patients than THA in terms of the early acquisition of walking ability due to muscle preservation and the low dislocation rate.

Peer review

The authors treated femoral neck fracture cases treated bipolar hemiarthroplasty and compared between groups using the DAA and the group using the PA. The manuscript is neat. The concluded that DAA useful in elderly patients than PA in terms of the early acquisition of walking ability due to muscle preservation and anesthetic management during surgery in the supine position.

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CASE REPORT

Combined distal tibial rotational osteotomy and proximal growth plate modulation for treatment of infantile Blount's disease

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Abstract

Infantile Blount's disease is a condition that causes genu varum and internal tibial torsion. Treatment options include observation, orthotics, corrective osteotomy, elevation of the medial tibial plateau, resection of a physeal bar, lateral hemi-epiphysiodesis, and guided growth of the proximal tibial physis. Each of these treatment options has its disadvantages. Treating the coronal deformity alone (genu varum) will result in persistence of the internal tibial torsion (the axial deformity). In this report, we describe the combination of lateral growth modulation and distal tibial external rotation osteotomy to correct all the elements of the disease. This has not been described before for treatment of Blount's disease. Both coronal and axial deformities were corrected in this patient. We propose this combination (rather than the lateral growth modulation alone) as the method of treatment for early stages of Blount's disease as it corrects both elements of the disease and in the same time avoids the complications of proximal tibial osteotomy.

Key words: Infantile Blount's disease; Tibia vara; Growth modulation; Eight plate; Hemi-epiphysiodesis; Rotational osteotomy; Genu varum; Lateral tension plate; Distal tibial osteotomy; External rotation osteotomy; Guided growth

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INTRODUCTION

Infantile tibia vara (infantile Blount's disease) is an orthopedic condition that affects young children causing varus deformity of the knee. The treatment of this condition differs according to the degree of involvement of medial proximal tibial physis. Multiple treatment options had been described for this condition[1-10]. These included observation; orthotic[4]; corrective osteotomy (acute or gradual correction)[3,5-9,10,11]; elevation of the medial tibial plateau[2,12,13]; resection of a physeal bar[1]; lateral hemi-epiphysiodesis[14]; and guided growth of the proximal tibial physis[8].

Infantile Blount's disease causes marked varus deformity that originates from the proximal tibial physis. The pathology of infantile Blount's disease involves internal tibial torsion as an element of the condition[15]. Treatment of Blount's disease should address all the elements of the disease; otherwise the child will be left with partially uncorrected deformity. Some of the surgical techniques used to treat infantile Blount's disease focus only on the coronal deformity (genu varum deformity) and does not treat the axial (internal tibial torsion) part of the disease[2,8,12-14].

There has been increasing interest in treating infantile Blount's disease by guide growth modulation[8]. The

principle of guided growth modulation depends on inhibiting the growth on the lateral aspect of the proximal tibial physis while allowing the medial part of the physis to continue growing resulting in correction of the genu varum deformity. This will not result in correction of the internal tibial torsion that is part of the pathology of infantile Blount's disease[8].

In this case report, we describe a novel method to treat infantile Blount's disease by combining a proximal lateral tibial growth modulation with distal tibial osteotomy to achieve both full correction of the deformity and decrease the risks of complications to the patient.

CASE REPORT

Three years old girl, Hispanic, morbidly obese, presented to the outpatient clinic with the bilateral severe genu varum deformity. Clinical examination showed that the child has bilateral internal tibial torsion of about 30 degrees bilaterally. The radiographs showed affection of the medial proximal growth plate (Langenskiold stage 2). The mechanical axis of the right side was 3.6 cm medial to the center of the knee and the mechanical axis of the left side was 3.2 cm medial to the center of the knee. The angle between the mechanical axis of the femur and the mechanical axis of the tibia (mechanical tibio-femoral angle) was 20° varus on the right side and 17° varus on the left side. The girl had the diagnosis of bilateral infantile tibia vara with bilateral internal tibial torsion (Figure 1).

The child underwent surgery to perform lateral proximal tibial growth modulation by inserting lateral tension band plate (eight plate) (Orthofix, Lewisville, Texas) (reversible plate hemi-epiphyiodesis) to correct the varus deformity. In addition, distal external rotation osteotomy of the tibia and fibula was performed to bring the foot to 5° external rotation compared to the knee axis. The external rotation osteotomy was done at the level of the distal tibia and fibula (junction proximal ¾ with the distal ¼). After rotation of the distal part, 3 crossing K-wires were passed across the osteotomy to stabilize it. Bilateral above knee casts were applied and patient was instructed to be non weight bearing for 6 wk on wheel chair (Figure 2).

Ten months later, follow up of the patient shows that she had full correction of both the varus deformity and the internal rotation deformity that was previously present. The radiographs showed correction of the varus deformity of the knee. The mechanical axis on the right side is 0.4 cm medial to the center of the knee and on the left side was 1.1 cm lateral to the center of the knee. The angle between the mechanical axis of the femur and mechanical axis of the tibia (mechanical tibio-femoral angle) was 0° on the right side and 7° valgus on the left side. The osteotomy side distally was completely healed. The 8 plates were removed bilaterally (Figure 3).

Consent was obtained from the mother to publish the case of her daughter.

DISCUSSION

Infantile Blount disease is a condition affecting the medial part of the proximal tibial physis. The condition is usually referred to as "infantile tibia vara" describing the frontal plane deformity; nevertheless, patients with infantile Blount disease have also internal tibial torsion deformity as well[15].

Tibial osteotomy is usually the standard of treatment for these children. The correction after tibial osteotomy can be done acutely with internal or external fixation. Acute correction carries the risk of compartment syndrome, under and overcorrection of the deformity[16-19]. A prophylactic anterior compartment fasciotomy and insertion of a drain is recommended for patients with Blount disease who are undergoing acute deformity correction to decrease the chance of compartment syndrome[20]. Gradual correction by external fixator lead to more accurate correction of the deformity with less chance of compartment syndrome, however, external fixators are usually not very well tolerated by the children due to their marked obesity and need to have bilateral fixators applied simultaneously in most cases. Another inherent problem with proximal tibial osteotomy to treat infantile tibia vera is that it is usually done away from the center of the deformity as the center of rotation and angulation (CORA) in cases of Blount disease lies at (or very close to) the level of the proximal tibial physis. Most of osteotomies are performed distal to the correct CORA because fixing very proximal osteotomies (at the level of the physis) is very technically challenging. This will result in displacement of the mechanical axis. Osteotomies done away from the CORA requires translation with the angular correction otherwise it will lead to shift of the mechanical axis of the limb[21].

Recently, there has been growing interest in using guided growth in treating early cases of infantile Blount's disease[8,22]. The procedure has the advantage of being minimally invasive, gradual correction with minimal risk and avoiding most of the complications of osteotomies. Also, the correction will occur at the center of deformity (CORA) avoiding any deviation of the mechanical axis of the corrected limb. The patient is followed until his/her mechanical axis of the limb reaches neutral alignment (or slight valgus) and then the tether (plate or staples) is removed. The tether is applied to the proximal lateral growth plate of the tibia, and it is not necessary to restrict the growth of the proximal fibular physis. Using the guided growth to treat early stages of infantile Blount disease will gradually correct the varus deformity but should theoretically have no influence on the internal tibial torsion. This will cause incomplete correction of the deformity and persistence of negative foot progression angle.

A recent retrospective study described the use of lateral tension plate to treat infantile Blount's disease[8]. Twelve children (18 limbs) had treatment of infantile Blount disease with application of lateral proximal tibial tension band plates. The success rate of growth manipulation in

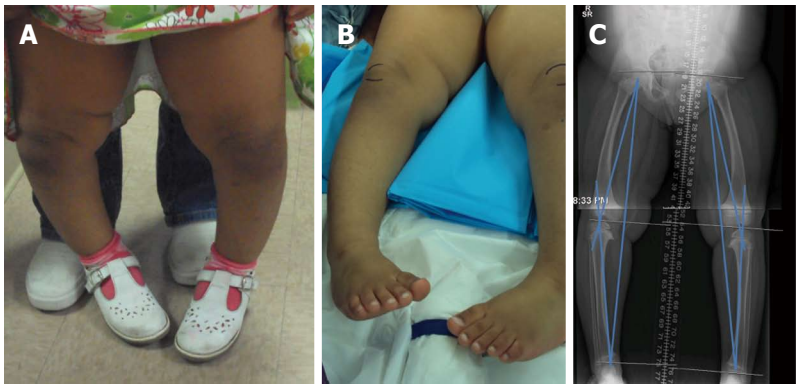

Figure 1 The girl had the diagnosis of bilateral infantile tibia vara with bilateral internal tibial torsion. A: 3 years old girl, standing showing genu Varum; B: Pre operative clinical picture showing the marked internal rotation of both lower extremities. Note the relation between the feet direction and the patella (outlined by skin marker); C: Pre operative radiograph showing the gneu varum, mechanical axis deviation and the proximal medial tibial physeal changes.

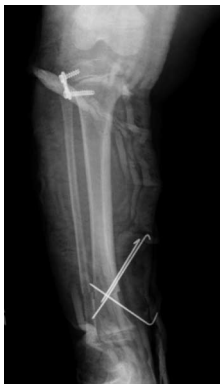

Figure 2 Immediate post operative radiograph for the right leg showing application of the lateral plate to proximal tibial growth plate and distal tibial/fibular osteotomy fixed by 3 K wires.

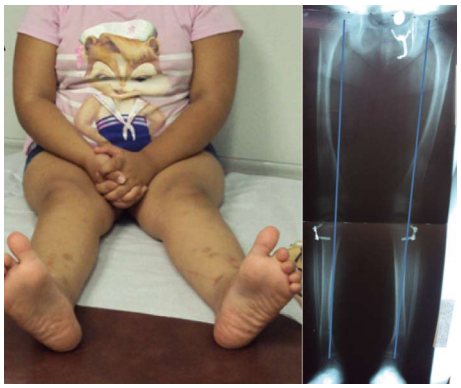

Figure 3 Ten months post operative showing. A: Correction of both the genu varum and the internal rotation of the leg (clinical picture); B: Correction of the varus deformity and healing of the osteotomy sites (radiograph).

this group was 89%. Despite this high success rates, the authors stated that in 3 patients (25% of the population), there was persistence of a significant internal tibial torsion.

We propose a combination of the lateral growth modulation with distal tibial/fibular rotational osteotomy that can effectively and safely correct both elements of the pathology of the Blount's disease. The application of lateral tether will correct the varus deformity and the distal external rotation osteotomy will correct the internal tibial torsion.

The advantages of this combination are the following: (1) It has the advantage of using growth tethering which is: The deformity is corrected at CORA which is biomechanically the best option. The deformity is corrected gradually with a chance to monitor the effect of treatment and obtain the exact desired amount of correction; (2) The internal rotation deformity will be corrected and not left without treatment; and (3) The external rotation osteotomy is done in a safer area (distally rather than proximally) with less concern regarding development of compartment syndrome[23,24].

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CASE REPORT

Biepicondylar fracture dislocation of the elbow joint concomitant with ulnar nerve injury

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Abstract

In this article, we present a case of humeral biepicondylar fracture dislocation concomitant with ulnar nerve injury in a seventeen year-old male patient. Physical examination of our patient in the emergency room revealed a painful, edematous and deformed-looking left elbow joint. Hypoesthesia of the little finger was also diagnosed on the left hand. Radiological assessment ended up with a posterior fracture dislocation of the elbow joint accompanied by intra-articular loose bodies. Open reduction-Internal fixation of the fracture dislocation and ulnar nerve exploration were performed under general anesthesia at the same session as surgical treatment of our patient. Physical therapy and rehabilitation protocol was implemented at the end of two weeks post-operatively. Union of the fracture lines, as well as the olecranon osteotomy site, was achieved at the end of four months post-operatively. Ulnar nerve function was fully restored without any sensory or motor loss. Range of motion at the elbow joint was 20-120 degrees at the latest follow-up.

Key words: Elbow injury; Fracture dislocation; Biepiconylar humeral fracture; Ulnar nerve injury

Core tip: Elbow joint posterior fracture-dislocations accompanied by neurovascular injuries are generally require surgical intervention. In this article, we present a case of humeral biepicondylar fracture dislocation concomitant with ulnar nerve injury in a seventeen year-old male patient. We obtained a successful clinical result by applying open reduction-internal fixation of the fracture dislocation and ulnar nerve repair at the same session as surgical treatment of this case. Although elbow fracture-dislocations with neurovascular complications are rarely seen, assessment of the neurovascular status in emergency room should always be a crucial part of physical examination which may affect the clinical result of the treatment.

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INTRODUCTION

Elbow joint is the second most common site of upper extremity dislocations in young adults[1]. Mechanism of injury in posterior elbow dislocation is generally described as falling on an outstretched hand[2]. Recent studies in the literature have shown that elbow joint is

more likely to dislocate when it is in slightly abducted and flexed position. Posterior dislocation of the elbow joint occurs when compressive forces are directed on to the outstretched hand through the radius and ulna, along with the valgus stress at the elbow joint[3]. These biomechanical forces also contribute to associated fractures at the dislocated joint. Sport related injuries are the etiology in 10%-50% of all elbow dislocations. More than 90% of the cases are posterior dislocations. Isolated cases can be successfully treated with closed reduction; however, dislocations accompanied by fractures or neurovascular injuries are more prone to different complications and generally require surgical intervention[1-3].

In this article, we present a case of humeral biepicondylar fracture dislocation concomitant with ulnar nerve injury in a seventeen year-old male patient.

CASE REPORT

Seventeen year-old male patient was admitted to the emergency department after falling on to left arm. Physical examination of the patient in the emergency room revealed a painful, edematous and deformed-looking left elbow joint. Hypoesthesia of the little finger was also diagnosed on the left hand. Radiological assessment ended up with a posterior fracture dislocation of the elbow joint accompanied by intra-articular loose bodies (Figure 1). Closed reduction in the emergency room was failed and surgical treatment was planned for the patient. Under general anesthesia, the patient was admitted to the operation table in prone position. A pneumatic arm tourniquet was applied and then sterile dressing of the left upper extremity was set. Following a twenty centimeters long skin incision, ulnar nerve was explored and total disruption of the nerve was diagnosed (Figure 2).

V-shaped olecranon osteotomy was applied in order to achieve open anatomic reduction of the distal humeral joint surface as well as the removal of the loose bodies inside the joint. Lateral collateral ligament (LCL) was ruptured with avulsion fracture of the lateral epicondyle (Figure 2). Fixation of the lateral epicondyle together with the LCL was carried out by using a headless screw. A nerve stimulator was used to explore and find out the distal end of the ulnar nerve. Following release of the two ends, microsurgical repair with anterior transposition was applied for disrupted ulnar nerve. Medial collateral ligament (MCL) was also ruptured with avulsion fracture of the medial epicondyle. Fixation of the medial epicondyle together with the MCL was achieved by using a headless screw. Plate and screw fixation was chosen for olecranon osteotomy site (Figure 2).

Following wound closure, a posterior long arm splint was applied. Physical therapy and rehabilitation protocol was implemented at the end of two weeks post-operatively. Active and passive stretching exercises were put into practice following a 3-wk passive ROM rehabilitation program. Galvanic current electrotherapy nerve stimulation was also applied at the same time.

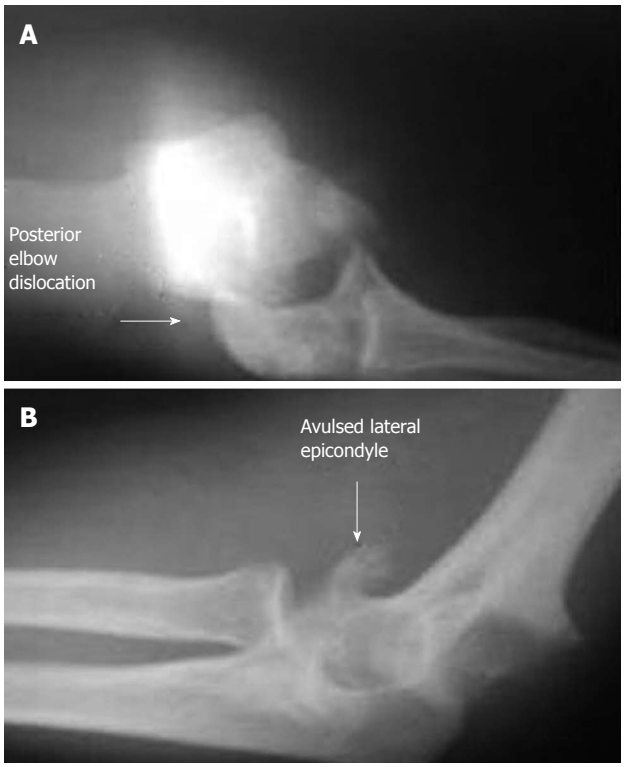

Figure 1 Pre-operative posterior elbow fracture dislocation with avulsed medial and lateral epicondyle fracture radiography.

Union of the fracture lines, as well as the olecranon osteotomy site, was achieved at the end of forth months post-operatively and the plate was removed after one year (Figure 3). Ulnar nerve function was fully restored with minimally hypoesthesia and no motor loss. Finger co-ordination was fully recovered and the reduced grip strength was improved at the end of six months. Disability of the Arm-Shoulder-Hand (DASH) Score was used to evaluate healing status during the post-operative follow-up period. Quick DASH score was measured as 27.5 at the end of 1 year.

Range of motion at the elbow joint was between 20 to 120 degrees and there was not sensory or motor loss except slight hypoesthesia of the fourth and fifth fingers by the end of one year post-operatively (Figure 4).

DISCUSSION

Stability of the elbow joint is supplied by the primary and secondary stabilizers playing role in different stages of motion. Main primary stabilizer is the anatomical structure of the ulnohumeral joint. Coronoid process is especially the most important part of this anatomical structure. Secondary stabilizers are the radial head, joint capsule, and the origins of flexor and extensor tendons[4]. Fracture dislocation of the elbow joint is often accompanied by disruption of one or more bony stabilizers, and thus pathophysiology of the elbow fracture dislocation is complicated. Generally, the stability of the joint cannot be secured by closed reduction because of the impaired

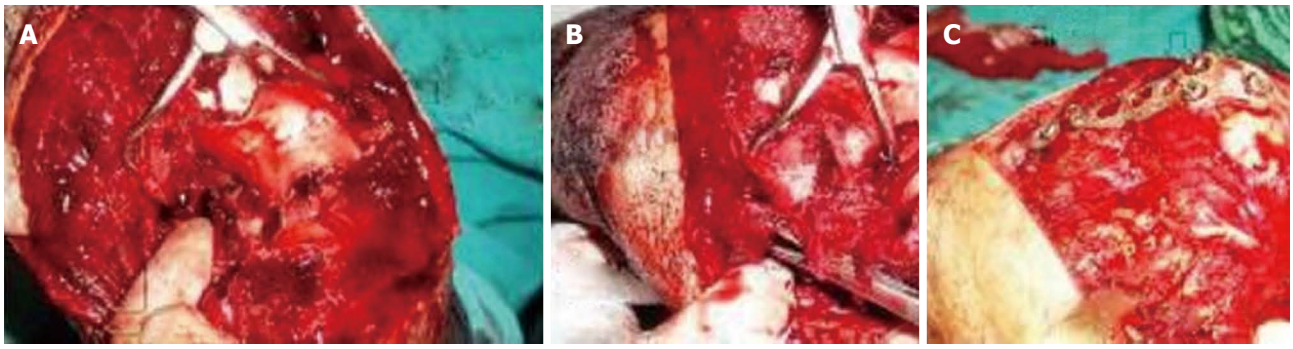

Figure 2 Intra-operative view. A: Avulsed medial epicondyle and lateral epicondyle with osteotomized olecranon; B: Avulsed medial epicondyle with nervus ulnaris; C: Plate and screw fixation of olecranon and repaired nervus ulnaris.

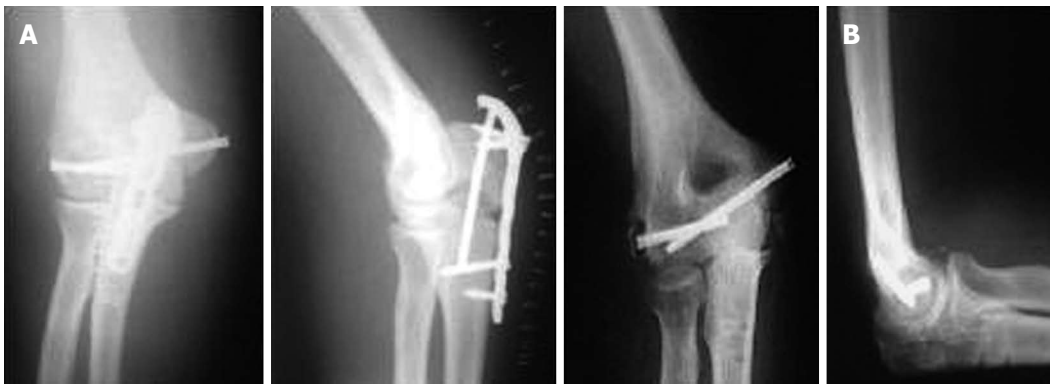

Figure 3 Early post-operative radiography with olecranon plate. A: Union of the fracture lines, as well as the olecranon osteotomy site, was achieved at the end of forth months post-operatively; B: Elbow radiography after removal olecranon after one year.

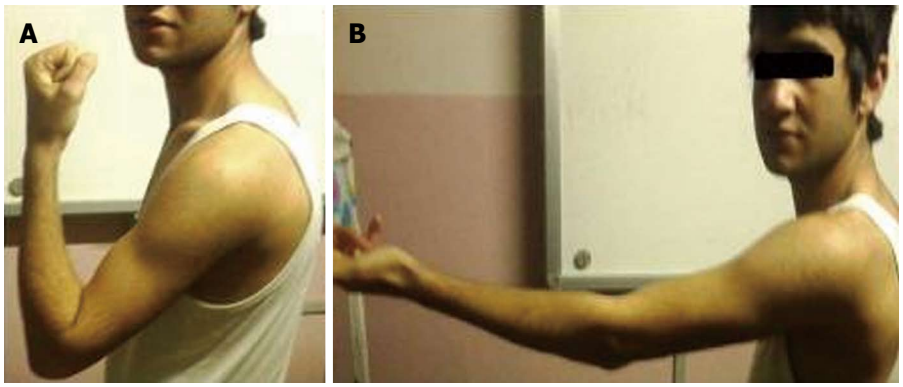

Figure 4 Elbow range of motion after one year. A: Fully restored flexion; B: Only 20 degrees extension disability.

function of these bony fragments which are very small in size but play crucial role in the biomechanical stability[5].

Biepicondylar fracture dislocation of the elbow joint was reported by several authors in the literature[6-9]. Bono *et al*[10] presented a case of intraosseous median nerve entrapment following posterior elbow dislocation in a seven year-old child. Abu Jayyap *et al*[11] reported biepicondylar fracture dislocation with complete radial nerve transection. In another study, median nerve entrapment and ulnar nerve palsy following elbow fracture dislocation in a child was discussed[12]. Acute ulnar nerve entrapment following closed reduction of a posterior fracture dislocation of the elbow joint was also highlighted as a potential risk in the literature[13]. Our patient had biepicondylar fracture dislocation of the elbow concomitant with complete ulnar nerve disruption.

Twelve months clinical outcome of our case was evaluated by the use of DASH scale. This scale is a 30-item self-report questionnaire which was developed to evaluate the functional status and symptoms of the patients with musculoskeletal disorders of the upper extremity[14]. Validity and reliability of this questionnaire in Turkish were tested and used in different studies. The scale is scored between 0 to 100 points and the higher scores indicate a

high level of disability[15]. DASH score of our case was measured as 27.5 at the end of one year.

In conclusion, we obtained a successful clinical result by applying open reduction-internal fixation of the fracture dislocation and ulnar nerve repair at the same session as surgical treatment of the case. As far as we could reach, we did not find any similar case reported in the literature. Although a few article can be considered close to our case report in the literature. We believe that although elbow dislocations with neurovascular complications are rarely seen, assessment of the neurovascular status in the emergency room should always be a crucial part of physical examination which may affect the clinical result of the treatment.

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Best approach for the repair of distal biceps tendon ruptures

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Abstract

The preferred treatment of distal biceps tendon ruptures is by operative repair. However, the best approach for repair (single *vs* double incision) is still subject of debate. Grewal and colleagues recently presented the results of a randomized clinical trial evaluating two different surgical approaches for the repair of distal biceps tendon ruptures. Despite the fact that this article currently presents the highest level of evidence for the surgical repair of distal biceps tendon ruptures, we have some comments on the study that might be interesting to discuss. We think that some of the results and conclusions presented in this study need to be interpreted in the light of these comments.

Key words: Distal biceps tendon; Elbow; Operation technique; Repair; Rupture

Core tip: The preferred treatment of distal biceps tendon ruptures is by operative repair. However, the best approach for repair (single *vs* double incision) is still subject of debate. Despite the fact that this article currently presents the highest level of evidence for the surgical repair of distal biceps tendon ruptures, we have some comments on the study that might be interesting to discuss. We think that some of the results and conclusions presented in this study need to be interpreted in the light of these comments.

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TO THE EDITOR

With great interest we have read the article of Grewal and colleagues[1]. We have however, some comments on this trial and think that the conclusions of this article should be interpreted in this light. The preferred treatment of distal biceps tendon ruptures is by operative repair[2,3]. A systematic review by Chavan *et al*[4] showed that refixation of the distal biceps tendon is best done with a cortical button. However, the best approach for repair (single *vs* double incision) is still subject of debate. Grewal *et al*[1] recently presented the results of the largest randomized clinical trial evaluating two different surgical approaches for the repair of distal biceps tendon ruptures. In this great piece of research were 91 acute distal biceps tendon ruptures randomized between a single incision repair with use of suture anchors (n = 47) or double incision repair with use of transosseous drill holes (n = 44). The postoperative treatment protocol was identical for both groups. Primary outcome measure was the American Shoulder and Elbow Surgeons elbow score and secondary outcome measures included number of complications, elbow range of motion, elbow strength, Patient Rated Elbow Evaluation and Disabilities of

Arm, Shoulder and Hand scores. After two years were outcome measure questionnaires completed by 91% of the patients. One patient in the single incision group had died. Six patients (three in both groups) were lost to follow up. Both at short term (3-6 mo) and long term (12-24 mo) there was no difference in mean outcome scores. The final isometric flexion strength was significantly better in the double incision technique. In addition, there were significantly more (minor) complications seen in the single incision group (predominately because of transient neuropraxias of the lateral antebrachial cutaneous nerve in this group). Despite the fact that this article currently presents the highest level of evidence for the surgical repair of distal biceps tendon ruptures, we have some comments on the study that might be interesting and relevant for the readers to be discussed.

Besides the difference in approach, there is also a difference in fixation technique used between both groups. This raises the question whether the presented differences between the groups (number of complications and especially the isometric flexion strength) is related to different approach used, or to the difference in fixation technique used. The article of Grewal *et al*[1] suggests the first, though it can not be ruled out that the latter might be of even or greater importance. Previous studies[4,5] concluded that suture anchor repair is a stronger fixation technique than transosseous drill holes.

Current study does not mention whether or not the biceps ruptures were complete or partial. If partial ruptures were included, the question rises whether or not these are divided equally between both groups. Since more dissection is required in complete ruptures, this might reasonably result in more complications.

The technique of drilling the holes is not described in detail; it is for example not clear in which direction the drill holes were made for both groups. This is of importance since drilling in the wrong direction can cause injury to the posterior interosseous nerve[6].

The authors found more transient neuropraxias of the lateral antebrachial cutaneous nerve in the single incision group. This might be caused by more traction on the nerve during the single incision surgical approach. However, the single incision group represents more patients that are operated after 2 wk (38%) *vs* the double incision group (25%). It is of interest whether this difference is significantly, as longstanding ruptures often need more dissection and possible more retraction of the soft tissues. From other part of the body we also know that that chronic pathology is more difficult to treat than acute ones[7].

In conclusion, we think that Grewal and colleagues performed an excellent study, which represents a major contribution to the "distal biceps tendon reconstruction literature". However, we think some of the results and conclusions presented in this study need to be interpreted with care. We hope that the authors can present some more information based on the above-mentioned comments in order to enrich the common knowledge in the repair of distal biceps tendon ruptures.

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

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

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

Patent (list all authors)

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

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