ISSN 2218-5836 (online)

World Journal of *Orthopedics*

World J Orthop 2016 February 18; 7(2): 74-148

Published by Baishideng Publishing Group Inc

WJO
World Journal of Orthopedics

A peer-reviewed, online, open-access journal of orthopedics

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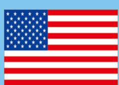

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World Journal of Orthopedics

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Monthly Volume 7 Number 2 February 18, 2016

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World Journal of Orthopedics (*World J Orthop*, *WJO*, online ISSN 2218-5836, DOI: 10.5312) is a peer-reviewed open access academic journal that aims to guide clinical practice and improve diagnostic and therapeutic skills of clinicians.

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

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NAME OF JOURNAL
World Journal of Orthopedics

ISSN
ISSN 2218-5836 (online)

LAUNCH DATE
November 18, 2010

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Monthly

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PUBLICATION DATE
February 18, 2016

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DOI: 10.5312/wjo.v7.i2.74

World J Orthop 2016 February 18; 7(2): 74-77
ISSN 2218-5836 (online)
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EDITORIAL

Bone and high-density lipoprotein: The beginning of a beautiful friendship

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Author contributions: Papachristou DJ conceived the general idea of the paper; Papachristou DJ and Blair HC wrote the paper.

Conflict-of-interest statement: The authors declare no conflict of interest.

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Received: July 5, 2015
Peer-review started: July 13, 2015
First decision: September 22, 2015
Revised: November 7, 2015
Accepted: December 1, 2015
Article in press: December 2, 2015
Published online: February 18, 2016

Abstract

There is a tight link between bone and lipid metabolic pathways. In this vein, several studies focused on the exploration of high-density lipoprotein (HDL) in the pathobiology of bone diseases, with emphasis to the osteoarthritis (OA) and osteoporosis, the most common bone pathologies. Indeed, epidemiological and *in vitro* data have connected reduced HDL levels or dysfunctional HDL with cartilage destruction and OA development. Recent studies uncovered functional links between HDL and OA fueling the interesting hypothesis that OA could be a chronic element of the metabolic syndrome. Other studies have linked HDL to bone mineral density. Even though at epidemiological levels the results are conflicting, studies in animals as well as *in vitro* experiments have shown that HDL facilitates osteoblastogensis and bone synthesis and most probably affects osteoclastogenesis and osteoclast bone resorption. Notably, reduced HDL levels result in increased bone marrow adiposity affecting bone cells function. Unveiling the mechanisms that connect HDL and bone/cartilage homeostasis may contribute to the design of novel therapeutic agents for the improvement of bone and cartilage quality and thus for the treatment of related pathological conditions.

Key words: High-density lipoprotein; Cartilage; Bone; Osteoarthritis; Osteoporosis

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Core tip: Recent evidence suggests that high-density lipoprotein (HDL) metabolic pathways are closely related to bone and cartilage homeostasis. In this editorial the authors briefly present the current knowledge concerning the mechanisms that link HDL and cartilage and bone metabolism and discuss the role of HDL result in the development of the most common bone

pathological conditions, osteoarthritis and osteoporosis. These data add to the appreciation of bone and lipid connection and pave the way towards the development of novel HDL-related strategies for the treatment of these diseases.

Papachristou DJ, Blair HC. Bone and high-density lipoprotein: The beginning of a beautiful friendship. *World J Orthop* 2016; 7(2): 74-77 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/74.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.74

It is now accepted that there is a strong connection between lipid metabolism and bone-cartilage homeostasis[1,2]. Indeed, it has been shown that lipid metabolic pathways differentially affect bone cells, leading to the development of pathological bone conditions, *via* both systemic and local phenomena. However, the molecular mechanisms that underline the bone-lipid connection have not been fully illuminated yet. The past few years several, epidemiological studies and studies on animal models focus on the implication of high density lipoprotein (HDL) in the development of bone-related diseases with emphasis to the most common bone pathologies, osteoarthritis (OA) and osteoporosis (OP).

HDL is a vital constituent of the lipoprotein transport system, regulating plasma and tissue lipid matabolism and homeostasis. Apolipoprotein A1 (ApoA1), the lipid transporter ATP-binding-cassette transporter A1 (ABCA1) and the plasma enzyme LCAT are required for the biosynthesis and maturation of HDL. Plasma ApoA-1 is a 243-residue protein, which synthesis takes place primarily in the liver and intestine. ApoA-1 is one of the major apolipoproteins of HDL, since it is responsible for the formation of discoidal HDL particles that mature and become spherical by the action of LCAT[3,4]. LCAT is synthesized and then secreted primarily by the liver catalyzing the esterification of free cholesterol of lipoproteins by transferring a fatty-acyl group from the C-2 position of lecithin to the 3-hydroxyl group of cholesterol. ApoA1 facilitates LCAT activation in plasma[4].

Several lines of evidence associate reduced HDL levels with the development of OA. Indeed, it is now well received that OA is strongly connected to cardiovascular and metabolic pathologies namely hypertension hypercholesterolemia, diabetes type 2, which in turn are associated to altered fat metabolism[5]. Further to support this notion, recent epidemiological data propose that patients with OA have significantly reduced HDL levels compared to healthy individuals. Regrettably, however, the molecular mechanisms that link HDL to cartilage degeneration are still vague. A recent research work has shown that the OA patients have greatly reduced expression of ApoA1 in hyaline or articular cartilage, suggesting that ApoA1-depended HDL reduction affects hyaline cartilage homeostasis[6]. In addition, a very interesting *in vitro* study that used cartilage and synovial membrane joint cells from patients with OA having undergone joint replacement therapy, showed that ApoA1 has the ability to induce the expression of interleukin-6 (IL-6), mouse matrix metalloproteinase-1 (MMP-1) and MMP-3 by primary chondrocytes and fibroblast-like synoviocytes *via* the toll-like receptor 4 receptor. The authors proposed that the lipid metabolic profile is deregulated in the synovial fluid of OA patients and that apoA-1 exhibits pro-inflammatory properties responsible for the symptoms associated with OA[7]. Aiming at further investigating the HDL-OA connection, Collins-Racie *et al*[6], showed that LXR signaling is implicated in the pathobiology of OA. The liver X receptors (LXRα/NR1H3 and LXRβ/NR1H2) are oxysterol-activated transcription factors of the nuclear receptor family that regulate the homeostasis of cholesterol at both cellular and whole-body level and have robust anti-inflammatory functions. They also demonstrated that that the expression levels of LXRα and -β, as well as the expression levels of the LXR target genes ABCG1 and apolipoproteins D and E were altered, a finding implying that the LXR signaling cascade is dysfunctional in degenerated OA cartilage. Importantly, they propose that use of LXR signaling modulators as therapeutic alternative to standard joint glucocorticoid injections[6]. In the same vein Tsezou *et al*[8], studied the expression of genes that regulate cholesterol efflux in human OA chondocytes. In harmony with previous reports having demonstrated that distorted lipid metabolism is critically involved in OA they demonstrated that the expression of ABCA1, ApoA1, and LXRα and LXRβ genes that control cholesterol efflux is greatly reduced in OA compared to normal chondrocytes. Moreover they showed that treatment of osteoarthritic chondrocytes with the LXR agonist TO-901317 resulted in the enhancement of the ApoA1 and ABCA1 expression and cholesterol efflux[8].

In our further effort to explore the involvement of HDL-related metabolic pathways in the pathogenesis of OA we examined the effect of HDL deficiency and impaired maturation on OA development using ApoA1 and LCAT knock out, as well as wild-type mice. Both animal groups were fed both chow (standard) and Western-type (high-fat) diet. Our findings were intriguing. Indeed, we found that the $LCAT^{-/-}$ mice developed marked diet-induced obesity in comparison to the C57BL/6 and $ApoA1^{-/-}$ groups that were fed Western-type diet. Notably, both the LCAT and the ApoA1 knockout mice developed OA, even though the latter were not obese. These novel findings raise the challenging possibility that alterations in HDL rather than increased mechanical stimulation due to excess body weight most probably result in the development of OA in mice. Moreover, histomorphometrical analysis revealed that the bone marrow from $LCAT^{-/-}$ and $ApoA1^{-/-}$ mice contained remarkably enhanced number of fat cells, compared to the other groups adding to the prevailing notion that bone marrow fat is functionally involved in the pathobiology of cartilage destruction, most plausibly *via* the production and secretion of adipokines, such as leptin, adiponectin and resitin[8]. Definitely, the role of HDL metabolic pathways in the development of OA warrants further investigation; however, the vast majority of the existing research data point towards a protective role of HDL against diet-induced OA and suggest that OA probably represents another facet of the metabolic syndrome[5,9].

Recent data suggest that serum HDL levels and bone mass are connected. Nevertheless, whether this association is positive or negative, is not clear. Indeed, in a relative recent review article on human subjects Ackert-Bicknell very nicely describe a large number of epidemiological studies exploring the link between HDL and bone mineral density. He proposed the that the inconsistent results that were presented are attributed to a number of parameters including age, dietary habits, sex, endocrine status and genetic background[10]. It seems that the research data are clearer in molecular, *in vitro* and animal model studies. Indeed, studies in mice have shown that specific genes such as *APOE, PPARγ, ESR1, IL-6* that regulate both BMD and HDL exhibit chromosomal co-localization[10]. In addition, studies on transgenic mice uncovered specific genes that regulate both BMD and HDL serum levels. One of these genes is apolipoprotein E (apoE) that is involved in HDL metabolic pathways. The role of apoE in bone regulation is very intriguing. Indeed, a few years ago an animal model study showed that apoE deficiency is associated with increased bone mass and elevated osteoblastic function, whereas bone resorption is not affected[11]. Interestingly, however, a few years later the same group showed that when stressed with diabetogenic high-fat diet, the apoE deficient mice develop decreased bone mass and lower body weight[12]. In addition, these animals display lower serum glucose, insulin and leptin levels compared to the control group. Less is know about the role of apoE in osteoclast function. A recent *in vitro* study unveiled that apoE halts osteoclast differentiation and proposed that this effect is possibly mediated through the inhibition of the RANL-dependent nuclear factor κB activation and the c-Fos and NFATc1 induction[13]. Genetic analyses in mice also demonstrated that human apoE isoforms have different effects on bone mass and bone turnover. More specifically, Kim *et al*[14], showed that human apoE2 strongly influences trabecular (but not cortical) bone metabolism in knock-in mice and highlighted the possibility that apoE ε2 allele might serve as a genetic risk factor vertebral fractures in humans[15].

Scavenger receptor class B type Ⅰ is the product of *Scarb1* gene, and its major function is the uptake of cholesteryl esters of HDL by the liver and other tissues. The implication of *Scarb1* in bone metabolism has very recently started to be investigated. However, the results generated seem to be very interesting. Using static and dynamic histomorphometric analyses, Martineau *et al*[16] showed that *Scarb1* deficiency results in augmented bone mass that was more evident in the trabecular bones of 2 mo old female mice[14]. In symphony with the histomorphometry data, *in vitro* assays revealed that the expression levels of the osteoblastic transcription factor *Osx/Sp7* were enhanced, whereas the mRNA levels of the cavelin 1, a gene that halts osteoblastic progenitor differentiation, were reduced. Notably, the number of TRAP-positive surface remained unaffected in these KO mice. In an effort to further explore the role Scarb1 in osteoblastogenesis, the same group performed a series of *in vitro* assays on mesenchymal stem cells obtained from Scarb1 deficient and wild-type mice and concluded that the enhanced osteogenic function that was observed in the Scarb1 knock-out mice can be attributed to stimulation of the Wnt signaling cascade[16].

As mentioned previously, studies have shown that HDL deficiency results in the congregation of lipoblasts in the bone marrow of mice. It is also accepted that bone marrow accelerates osteoclastogenesis, while stunts osteoblastogenesis. These data spark the question whether HDL may have an implication in the pathogenesis of other bone pathological conditions, including neoplastic bone diseases. Since bone marrow microenvironment possesses a cardinal role in the development of bone metastasis we are tempted to speculate that HDL may have a protective role towards metastatic bone disease a hypothesis that definitely merits further exploration. In addition, the tight link between bone and fat raises the challenging possibility that the development of drags that will effectively target lipid-specific metabolic pathways may enhance osteoblast function, improving bone quality.

Collectively, gradually accumulating research evidence suggests that HDL serves as a requirement for normal cartilage and bone function and that it most probably has a protective role against the development of degenerative and metabolic conditions such as OA and OP. Nevertheless, additional epidemiological, molecular, and *in vitro* studies in animal models are needed to substantiate this hypothesis. Furthermore, the role of other molecules that are tightly involved in the HDL metabolic pathways (such as ABCA1), should be carefully examined. Except from HDL-C levels, HDL functionality should also be determined in bone diseases. Indeed, mounting evidence supports the notion that the functionality of HDL particles is plausibly more significant than simply HDL-C levels in plasma and in many instances the anti-inflammatory and anti-oxidant properties of HDL cannot be evaluated only by the determination of HDL-C plasma levels[17].

Unfolding the molecular mechanistic events that connect HDL and bone metabolism may pave the way towards the development of HDL-directed therapies that could add to the armamentarium against bone-related diseases.

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P- Reviewer: Canavese F, Maheshwari AV, Sakamoto A
S- Editor: Ji FF **L- Editor**: A **E- Editor**: Liu SQ

World Journal of Orthopedics

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DOI: 10.5312/wjo.v7.i2.78

World J Orthop 2016 February 18; 7(2): 78-81
ISSN 2218-5836 (online)
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EDITORIAL

Controversies in management of slipped capital femoral epiphysis

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Author contributions: All authors equally contributed to this paper with conception and design of the study, literature review and analysis, drafting and critical revision and editing, and final approval of the final version.

Conflict-of-interest statement: No potential conflicts of interest. No financial support.

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Received: May 29, 2015
Peer-review started: June 1, 2015
First decision: August 4, 2015
Revised: November 2, 2015
Accepted: November 24, 2015
Article in press: November 25, 2015
Published online: February 18, 2016

Abstract

The traditional treatment of the hip with a slip of the capital femoral epiphysis has been an *in situ* fixation using a single screw. This has the sanctity of a long term result. Recent literature stresses the outcomes of failure to restore the upper femoral alignment and on the basis of the poor results makes a plea for capital realignment. This being a recent development, it lacks the support of long term follow up and it remains to be seen if this is a better alternative of managing displaced and unstable slipped capital femoral epiphysis. The authors look at some of the available literature on the subject to highlight these controversies and their implications for orthopedic surgeons. Other controversies pertain to contralateral fixation, duration of immobilization and amount of weight bearing after an *in situ* fixation.

Key words: Slipped capital femoral epiphysis; Fixation *in situ*; Femoral head realignment; Osteoplasty; Dunn osteotomy

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Core tip: This article discusses the current controversies around the treatment of slipped capital femoral epiphysis (SCFE). Newer surgical techniques have brought with them controversies as to the best form of management of different types of SCFE. The authors highlight the current status of management in the light of publications on the above subject.

Johari AN, Pandey RA. Controversies in management of slipped capital femoral epiphysis. *World J Orthop* 2016; 7(2): 78-81 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/78.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.78

Slipped capital femoral epiphysis (SCFE) is a common condition faced by an orthopaedic surgeon. In 1962, Watson-Jones[1] lamented that "the treatment of displacement of upper femoral epiphysis is not a very happy chapter in the history of orthopaedic surgery". The litany of complications associated with this condition is long. In recent years, improvements in understanding of the stability status, imaging techniques, and fixation methods

Table 1 Classification of physeal stability

Duration of symptoms	
Acute	Less than 2 wk
Chronic	More than 2 wk
Acute on chronic	Duration of symptoms for more than 2 wk but with sudden deterioration of symptoms
Ability to walk	
Stable	Patient is able to walk
Unstable	Patient is unable to walk

have led to significant changes in this outlook.

Currently, the treatment of SCFE depends on many factors like remaining growth potential of the physis (open or closed), the stability of the slip (stable or unstable), severity of the deformity, presence of femoroacetabular impingement (FAI) and confidence of the surgeon with various surgical options.

Immediate goals of management of an acute SCFE are threefold: (1) pain relief; (2) maintenance of an epiphyseal-femoral neck relationship that will avoid further slip progression; and (3) acceleration of epiphyseodesis so that risk of repeat slippage is eliminated. Long term goals include avoidance of complications that could lead to significant premature secondary degenerative joint disease.

Despite numerous studies and clinical trials, the cause for avascular necrosis (AVN) in SCFE is not very clear. Various hypothesis have been suggested for the cause of AVN; mechanical instability of the physis being one of them. However, the presence of instability at the physis cannot be assessed directly. Two clinical classifications have been suggested (Table 1) to predict the instability at the physis; One depending on the duration of symptoms[2,3] and the other depending on the patient's walking ability[4].

In situ fixation with pins or screws is the recommended method of treatment for stable and chronic slips whereas, lots of controversies persist regarding the treatment of unstable or acute cases including the timing of intervention and the method of reduction. Also, physeal stability confirmed by clinical methods did not always matched with intraoperative findings at surgery. Ziebarth *et al*[5] compared the clinical classifications with the intraoperative findings. Classifying SCFE by the duration of symptoms had a low specificity of 44% and a sensitivity of 82%. Based on the eligibility to walk, the sensitivity was a low 39% and specificity was 76%. Ziebarth *et al*[5] concluded that the current clinical systems are not accurate to judge physeal stability in SCFE.

In situ central single screw fixation without any attempt for reduction has become the current treatment of choice for stable SCFE[6]. The surgeons who support this, insist that even though the proximal femoral anatomy is not restored with this treatment, the proximal femur has remodeling potential, especially for patients who are young[7-9]. Others believe that in unreduced epiphysis FAI leads to mechanical derangement of the hip and development of secondary osteoarthritis[10,11]. They believe in restoring the anatomy of the hip joint[12,13] by a combination of surgical dislocation of hip and a modified Dunn procedure[10,11]. Ziebarth *et al*[14] treated forty patients of slipped capital epiphysis with modified Dunn procedure and recommended it as a safe treatment option[15]. However, up to 17% risk of AVN is reported in all studies of Dunn's osteotomy. Even, addition of surgical dislocation of hip does not decrease the rate of AVN of femoral head as suggested by Alves *et al*[16] (2012) and Anderson *et al*[17] (2013). The authors recommend an *in situ* fixation followed by a later osteochondroplasty if felt necessary on a longer follow up.

Even though there is risk of avascular necrosis in unstable slip, reduction in these cases is feasible[18]. Some recent studies have reported good results of open reduction in unstable slips[14,19]. On the other hand there have been other reports, notably that of Sankar *et al*[20] with a 26% osteonecrosis and a 41% overall rate of substantial complications.

Another controversy is the number of screws for fixing the unstable SCFE. Biomechanical studies support the use of two screws as it provides more stable fixation when compared to a single screw. However, most surgeons prefer using a single screw due to the risk of epiphyseal perforation and subsequent chondrolysis with the use of two screws[21].

Confusion also remains regarding the type of corrective osteotomy (intracapsular/extracapsular) and it's timing for both stable and unstable SCFE[21]. Although most surgeons accept that cervical osteotomy is a more successful method of gaining anatomical correction, they opt for treatment by subtrochanteric (Southwick *et al*[21] 1967) or intertrochanteric (Griffiths[22] 1976) osteotomy because of lower risks of iatrogenic ischemic changes. However these osteotomies fail to restore the abduction power and rotational balance of the hip leading to postoperative Trendelenburg gait. These distal osteotomies also fail to correct the intraarticular incongruity of the hip in cases with a severe slip, leaving the features which lead to early degenerative arthritis. They also create a residual anatomical deformity of the proximal third of femur which may well prejudice any future need for total hip replacement. However, some recent studies report good outcome from these osteotomies[23].

Cervical osteotomy, by contrast, fulfills the requirements of successful operative treatment, by achieving an anatomical reduction. It therefore reduces the long term risk of osteoarthritis and produces a good postoperative functional result without surgical shortening[17,24,25].

According to Loder *et al*[26], there is not enough clinical evidence to prove the superiority of surgical dislocation and osteoplasty over pinning *in situ* for stable SCFEs. They also mention that there is not enough evidence to support the widespread use of surgical dislocation and capital realignment in stable SCFE and suggests further research especially in a large cohort of patients.

Also, there is controversy regarding fixation of contralateral normal hip. The supporters argue for fixation of the opposite hip in all patients in view of high incidence of contralateral slip[15]. Another group of surgeons recommend fixation of contralateral normal hip only in selective patients due to the risk of possible theoretical complications[27]. We prefer to avoid unnecessary fixation of the contralateral hip in all cases and suggest fixation of the opposite hip only if risk factors for contralateral slip is present. These are, young age at primary diagnosis, severe slip at primary diagnosis, presence of endocrine disorders like adiposogenital dystrophy, juvenile hypothyroidism and presence of nonspecific obesity. We also fix the contralateral normal hip if patient is on growth hormone therapy. Finally, in those cases where for social and/or geographical reasons the patient is not expected to comply with a protocol of continued regular clinical and radiological observation, prophylactic fixation is considered.

Post-operative protocol is also debated. Controversy remains regarding the timing of bearing weight in stable SCFE. Most of the surgeons prefer to be more careful and delay full weight bearing for several weeks. They recommend longer duration of bed rest and protected weight bearing after surgery. On the other hand, few orthopaedic surgeons recommend a shorter bed rest and allow total weight bearing for mild stable SCFE without any reported complication. This area needs more research to favor early weight bearing this being more comfortable from the patient point of view.

Furthermore, many aspects of treatment are not discussed such as the timing of treatment, (particularly in the management of unstable and severe slipped epiphyses), the use of capsular decompression and implant removal. As these aspects of management do not influence the final outcome significantly, they are not addresses by majority of the orthopedic surgeons. Literature also is unclear about their effect on final outcome and further studies to prove their significance is recommended.

Thus, the management of SCFE remains controversial. There are several areas where knowledge is lacking, and where multi-centric studies could be focused to identify the most effective method of management. Long-term prospective studies, employing both contemporary treatment methods and contemporary outcome measures, are needed to guide improved treatment selection and results for future patients with SCFE.

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P- Reviewer: Anand A, Baldwin K, Martinelli N, Solomon LB
S- Editor: Ji FF **L- Editor**: A **E- Editor**: Liu SQ

WJO World Journal of Orthopedics

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Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
DOI: 10.5312/wjo.v7.i2.82

World J Orthop 2016 February 18; 7(2): 82-93
ISSN 2218-5836 (online)
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REVIEW

Biomechanics of the anterior cruciate ligament: Physiology, rupture and reconstruction techniques

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Author contributions: Domnick C, Raschke MJ and Herbort M performed the research and wrote the paper.

Supported by A Research Fellowship from the Faculty of Medicine, Westphalian Wilhelms University Muenster to Domnick C.

Conflict-of-interest statement: There are no conflicts of interest to declare.

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Received: June 1, 2015
Peer-review started: June 5, 2015
First decision: August 16, 2015
Revised: September 5, 2015
Accepted: December 1, 2015
Article in press: December 2, 2015
Published online: February 18, 2016

Abstract

The influences and mechanisms of the physiology, rupture and reconstruction of the anterior cruciate ligament (ACL) on kinematics and clinical outcomes have been investigated in many biomechanical and clinical studies over the last several decades. The knee is a complex joint with shifting contact points, pressures and axes that are affected when a ligament is injured. The ACL, as one of the intra-articular ligaments, has a strong influence on the resulting kinematics. Often, other meniscal or ligamentous injuries accompany ACL ruptures and further deteriorate the resulting kinematics and clinical outcomes. Knowing the surgical options, anatomic relations and current evidence to restore ACL function and considering the influence of concomitant injuries on resulting kinematics to restore full function can together help to achieve an optimal outcome.

Key words: Biomechanics; Anterior cruciate ligament; Joint pressure; Anterior cruciate ligament rupture; Graft fixation; Anterior cruciate ligament reconstruction

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Core tip: This review of literature summarizes the influences and mechanisms of the physiology, rupture and reconstruction of the anterior cruciate ligament on kinematics and clinical outcomes. The major focuses are on the resulting joint kinematics after rupture and reconstruction and on biomechanics of graft fixation.

Domnick C, Raschke MJ, Herbort M. Biomechanics of the anterior cruciate ligament: Physiology, rupture and reconstruction techniques. *World J Orthop* 2016; 7(2): 82-93 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/82.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.82

INTRODUCTION

Biomechanics is one major key to the function, stability and aging process of joints. The knee is a major and complex joint. Its stability and motion are basically controlled by ligaments such as the anterior cruciate ligament (ACL)[1].

The ACL is a central ligament of the knee. The main functional role of the ACL is to provide stability against anterior tibial translation (ATT) and internal rotation. An acute ACL rupture is a common orthopedic trauma, with an estimated incidence of 78 per 100000 persons and a mean age of 32 years in Sweden and an estimated incidence of up to 84 per 100000 persons in the United States[2,3].

A common and frequent injury mechanism is non-contact combined valgus- and internal-rotation trauma[2,4]. Therefore, ACL injuries are often associated with other ligamentous injuries, such as a (partial) rupture of the medial collateral ligament (MCL) or the menisci. In addition, compression of the lateral condyle with a bone bruise or chondral lesion is often associated with the injury due to the valgus trauma. Persistent instability of the knee may be associated with long-term degenerative lesions. Surgical treatment of the ACL in the context of other injured structures and reconstruction of the intact joint kinematics are suggested to be the keys to a good clinical outcome[5,6].

ANATOMY

The ACL has its origin at the medial area of the lateral femoral condyle and inserts into the center of the eminentia of the tibia plateau next to the anterior horn of the lateral meniscus. The structure of the ACL has been described as two functional bundles: The anteromedial (AM) and the posterolateral (PL) bundle[7]. These two bundles have been associated with different roles in anteroposterior and complex-rotational stabilization of the joint[8-10]. The femoral origin was described as oval shaped with a longitudinal diameter of 18 mm and a width of approximately 11 mm[11,12]. The AM bundle is inserted deep in the intercondylar notch directly in front of the intercondylar line and the edge of the chondral bone. The femoral insertion of the PL bundle is located at anterior of the AM bundle, also bordering the edge of the chondral bone. The tibial insertion of the AM bundle is located close to the anterior horn of the lateral meniscus at approximately the first 30% mark of a virtual sagittal line crossing the tibial plateau, while the PL bundle inserts slightly posterolateral to the AM bundle at approximately 44% of the virtual sagittal line[9,13]. The anatomy of the ACL and functional bundles has been biomechanically evaluated in many studies[8-10,14], and surgical techniques have evolved as a result. Due to the oval shape of the femoral condyles, the position of the joint axis varies during flexion in the sagittal plane[15]. The oval/flat structure of the ACL plays an important role in stabilizing the knee joint under different flexion angles and, therefore, compensating for shifting knee flexion axes[10,14,16]. The PL bundle has been shown to have particular stabilizing effects on the anteroposterior and rotational forces in near-to-extension positions of less than 30°, whereas the AM bundle becomes tensioned and functional at higher flexion angles[8,10,16]. Nevertheless, in a recent study, Kondo *et al*[14] found that the influence and reciprocal relationship of an insulated AM or PL bundle tear might have been overestimated. Recently, the existing knowledge of ACL anatomy was enhanced by a landmark anatomical study. Śmigielski *et al*[17] analyzed the detailed anatomical ACL structure of 111 human cadaveric knees. They found that femoral insertion and midsubstance of the ACL were thinner than previously assumed, and they determined a width of 11-17 mm and a thickness of only approximately 3 mm (Figure 1). Additionally, the tibial insertion site was recently anatomically analyzed by Siebold *et al*[18] and described as a "C"-shaped structure.

In addition to collagen fibers, nerves and mechanoreceptors are integrated within the ACL and play an important role in the proprioception of the joint[19,20]. Nevertheless, there are more proprioceptive elements involved around the knee, such as other ligaments, muscles and the capsule.

KINEMATICS

Anterior tibial translation

In the intact knee, the ACL provides essential support for ATT and internal rotation. This functional role must be achieved at the base of the described anatomic insertion sites of the ACL, the complex oval-like shape of the condyles, and the tensile characteristics of the ligament[15]. In extension, the ATT is low, with a maximum 2 mm scope, and provides support while standing. In flexion angles and when applying an external anteroposterior load, the ATT may increase up to 3 mm when walking and up to 5.5 mm under the anterior tibial load[1].

When the ACL is ruptured or dissected, the ATT increases by up to 10 to 15 mm at 30° of knee flexion under 134 N of anterior load[10,14,21]. Robotic/universal force-moment sensor (UFS) testing systems have been able to quantify passive ATT under the anterior tibial load in cadaveric knees at different flexion angles without being influenced by active muscle forces. Without these muscle forces, the highest increase in ATT was found between 15° and 40° of flexion. Clinically, ATT is often tested at different flexion angles. Stress radiographs, KT-1000 or rolimeters can help quantify the clinically observed ATT. The ischiocrural muscle group induces flexion by connecting the tuber ischiadicum with the proximal crus (pes anserinus tibia and fibular head). These muscle groups show a greater than 70° posterior force vector at 90° of knee flexion, which actively stabilizes against ATT (Figure 2). Considering these ligamentous and muscular kinematics, the ATT may therefore be clinically evaluated most accurately at near to extension angles (15° to 30°).

Cutting-edge studies have demonstrated an important role of the two functional ACL bundles for ATT and pivot shift at different flexion angles. In cadaveric studies, a

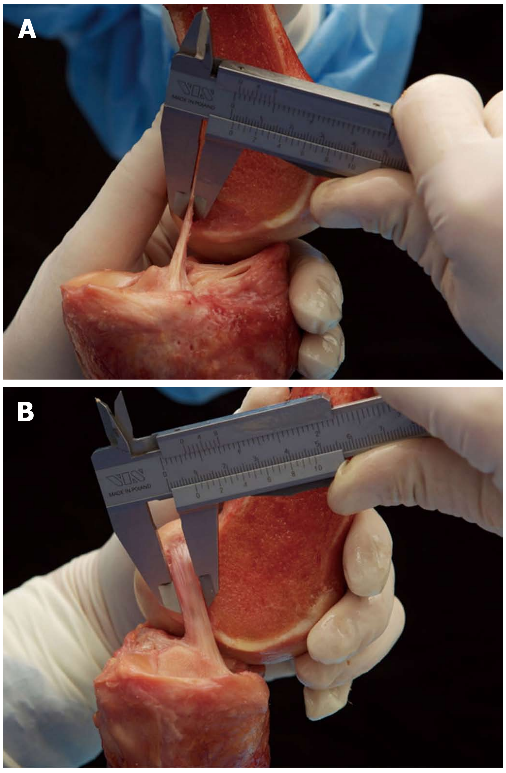

Figure 1 Śmigielski *et al*[17] measuring the thickness (A) and width (B) of the "ribbon-like" midsubstance of the anterior cruciate ligament.

stabilizing role for the PL bundle in controlling the ATT at near-to-extension angles was found[8,10,16]. The AM bundle seemed to have more influence in controlling higher flexion angles. Nevertheless, the suggested reciprocal relation of the two bundles is controversial and is still being discussed. A recent human cadaveric study by Kondo *et al*[14] showed different result s than prior studies: They reported that partial tears of the AM or the PL bundle showed a nonsignificant and less-than-expected increase of ATT. According to previous studies[8,10,16], the tension of the PL bundle, as indicated by the distances of the bundle's insertion sites, was increased at near-to-extension angles. Nevertheless, unlike others, Kondo *et al*[14] found that AM bundle tensioning did not increase with growing flexion angles but stayed rather constant between 0° and 120° of flexion (Figure 3). Therefore, they concluded that when detecting a clinically unstable ATT in an examination of the knee, more than a partial (one-bundle) rupture of the ACL has to be assumed.

Rotational instability and pivot shift testing

Considering the anatomy of the ACL, its main structure has a complex diagonal route through the knee (anteroposterior and horizontal mediolateral fibers), which is almost reciprocal to the posterior cruciate ligament fibers[22]. The role of the mediolateral ACL fibers might be versatile. In the intact knee, these fibers resist a complex internal tibial rotational force. Although a correlation between increased internal tibial rotation and deficient ACL seems obvious, the internal tibial rotation increases by less than 4°, from up to 30° of

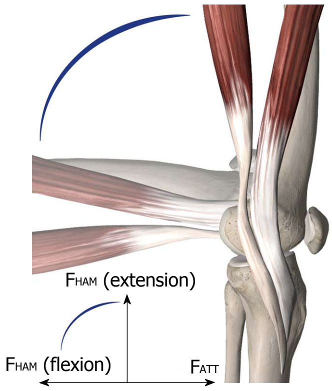

Figure 2 Semitendinosus and gracilis muscles with their insertions. At 90° of flexion, the forces of the hamstrings (F_{HAM}) are opposed to the anterior tibial translation (ATT) forces (F_{ATT}).

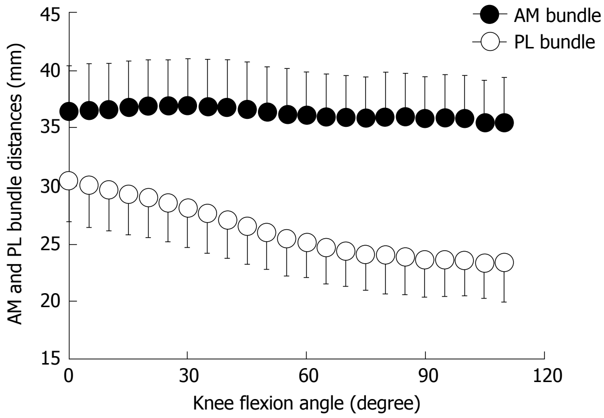

Figure 3 Distance between the femoral and tibial attachments of the anteromedial and posterolateral bundles of the anterior cruciate ligament during knee flexion (mean/SD) from Kondo *et al*[14]. AM: Anteromedial; PL: Posterolateral.

internal rotation in the intact knee[15], when the ACL is completely ruptured[14,22], as other collateral ligaments are also important stabilizers against internal rotation[23].

Although the resulting effect on isolated internal rotation stability seems small, the rotational axis of the knee alters from the center to a medial position near the pars intermedia of the internal meniscus when the ACL is ruptured[24]. As a consequence, the movement in the lateral compartment increases (Figure 4).

Kanamori *et al*[25] determined that both medial and lateral collateral ligaments compensate for *in situ* forces against internal rotation when the ACL is ruptured. Based on the effects of the medialized center of rotation with a subsequent increase of motion radius of the lateral compartment after an ACL rupture, the *in situ* forces of the posterolateral ligamentous structures increase by up to 413% at 15° of knee flexion[25]. The influence of an ACL rupture on near-to-extension pivoting kinematics can be clinically assessed by the pivot shift test.

The pivot shift test is an established and valid clinical test for examining the ACL's influence on complex rotational instability when ACL is ruptured[26]. It not only is a dynamic knee instability test with a high specificity for ACL ruptures but also is influenced by active

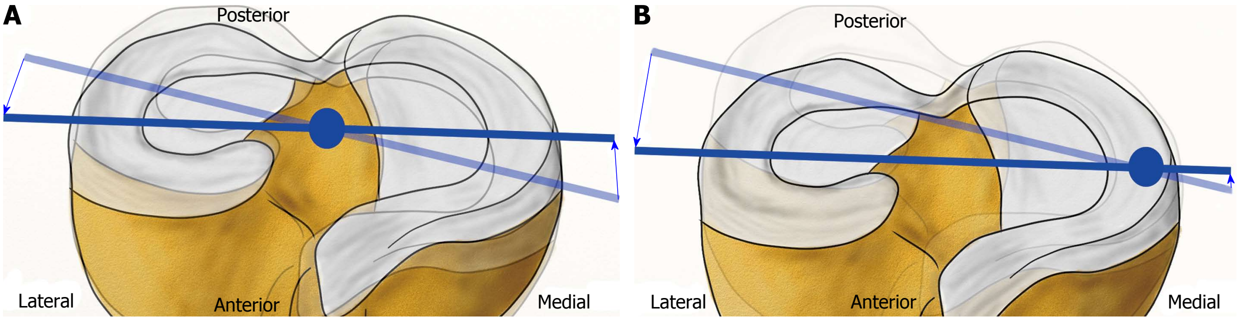

Figure 4 Shift of the center of the rotatory axis from the center/eminentia in an anterior cruciate ligament-intact knee (A) to a medial position (B). Modified from Amis *et al*[24].

muscle forces and by an inter-observer bias[27]. Near extension the combined internal rotatory and valgus loads induces an anterolateral tibial subluxation in the ACL-deficient knee. With ongoing flexion, the collateral ligament apparatus and the iliotibial tractus reach tension at approximately 30° and retract the subluxated tibia[26]. Biomechanically, the pivot shift examination can be simulated *in vitro* with a robotic/UFS system by applying combined internal rotatory (4-5 Nm) and valgus (10 Nm) loads while measuring the resulting anterolateral tibial translation[8,21,22,28,29]. Several *in vitro* studies have demonstrated a correlation between a positive pivot shift phenomenon and a deficiency of horizontal (*e.g.*, PL bundle) fibers, as in the case of a steep PL-to-High-AM reconstruction[8,10,16]. Clinically, the pivot shift phenomenon may be difficult to detect, especially in a situation of pain from an acute ACL tear and subsequent contraction of muscles, which can inhibit the subluxation phenomenon. Additionally, due to improving technologies, such as navigation and sensors, new techniques and tools have been developed to quantify clinical pivot shift kinematics[30-32]. Although the pivot shift seems more complicated to evaluate compared to the ATT, studies report its strong correlation to clinical outcomes[33]. In a clinical study of 63 patients with a follow-up at 5 to 9 years after ACL reconstruction surgery, Jonsson *et al*[34] found a positive correlation of the pivot shift phenomenon and osteoarthritic changes. Kocher *et al*[35] investigated the relationship between clinical assessment and different outcome parameter scores after ACL reconstruction surgery. While there was no correlation with investigated parameters regarding a positive ATT, a positive pivot shift was detected to be a significant predictor of satisfaction, giving way, difficulty in different types of activity, overall knee function, sports participation, and inferior Lysholm score.

Joint pressure

After an ACL rupture with a subsequent shift of the rotatory axis and increased instability, an altered intra-articular cartilage pressure seems obvious[24]. Several biomechanical *in vivo* and *in vitro* studies have found decreased total joint pressure after an ACL rupture by pressure-sensitive sensors or electromyography driven model[36-38]. As a possible consequence of decreased joint pressure, the knee's flexion movement after an ACL rupture is also reduced[37,39]. The complex kinematics of the knee joint and the altered strain of other ligamentous or cartilage structures suggest the importance of distinguishing the joint pressure in terms of its intra-articular sector, loading or passive condition and respective flexion angle[15]. In the ACL-deficient knee, there is a shift of the rotatory axis to the medial compartment with slightly increased freedom of motion[22,24]. Li *et al*[40] determined the tibiofemoral contact points during a one-legged lunge at different flexion angles in an *in vivo* study (Figure 5). They found out that there was a significant shift of the contact points on the tibial surface after an ACL rupture, most of them at flexion angles close to 15°. In the medial compartment, the contact points altered to a more posterior and more lateral position toward the intercondylar eminentia. In the lateral compartment, a lateralization of contact points was also observed but without alteration in the anteroposterior axis. While total patellofemoral joint pressure and the pressure of the medial patellofemoral compartment decrease after an ACL rupture, the lateral patellofemoral joint pressure increases at higher flexion angles above 60°[36]. In a human cadaveric study, Imhauser *et al*[41] measured increased tibiofemoral contact forces in the posterior medial and lateral compartments under axial load and simulated Lachman and pivot shift tests after an ACL rupture (Figure 5).

In situ forces and tensile characteristics

In situ forces of the ACL have been calculated by Morrison[42-44]. For normal walking, *in situ* forces of 169 N were observed. When descending stairs, increased *in situ* forces of 445 N were determined, which Morrison explained by the complementary effects of knee extensor muscles. Woo *et al*[45] performed tensile testing of young human cadaveric femur-ACL-tibia complexes and determined an ultimate load to failure of 2160 (± 157) N with a linear stiffness of 242 (± 28) N/mm.

INFLUENCE OF ACL RUPTURE ON OTHER STRUCTURES OF THE KNEE

A non-contact combined valgus- and internal-rotation trauma of the knee is described as one of the most

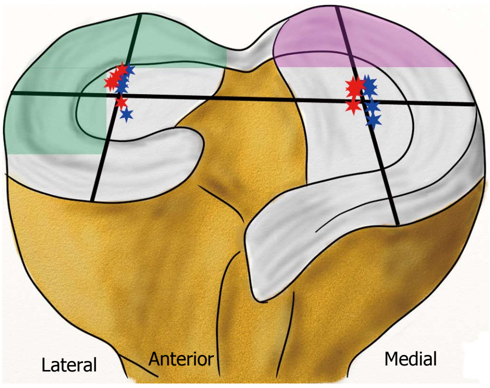

Figure 5 Lateral shift of femorotibial contact points at various flexion angles with intact anterior cruciate ligament (blue stars) and deficient anterior cruciate ligament (red stars) - modified from Li *et al*[40]. Increased contact stress after an anterior cruciate ligament rupture in the posterior lateral compartment during pivot shifting (green area) and in the posterior medial compartment during Lachman testing (violet area) - modified from Imhauser *et al*[41].

frequent mechanisms for an ACL rupture, as it may occur in pivoting sports such as in soccer or handball[2,4]. This complex rotational trauma mechanism indicates that other structures should be examined to determine whether they were injured when an ACL rupture is suspected. The incidences of other accompanying injuries with the trauma mechanism and with altered kinematics of ACL rupture are detailed below.

MCL

MCL rupture is a frequent possible result of the valgus-stress component of a typical ACL trauma. The co-incidence of MCL rupture was reported in every fifth case when the ACL was ruptured[4,46]. An overseen and maintained medial instability after ACL reconstruction may result in inferior kinematics and persistent giving way, despite sufficient anteroposterior and pivot-rotational stability. In a clinical study, Zaffagnini *et al*[47] found a persistent valgus instability after three years post ACL surgery and conservative treatment of a chronic MCL grade Ⅱ rupture, but there was no difference in antero-posterior stability and in clinical outcome scores after three years compared to a surgically treated MCL. In another prospective randomized clinical study, Halinen *et al*[48] also found equal stability and clinical outcome scores after operative or nonoperative treatment of concomitant MCL grade Ⅲ lesions and combined ACL reconstruction in acute cases. Nevertheless, due to persistent instability, a higher risk for secondary graft failure after ACL reconstruction and for osteoarthritis is still discussed. Medial muscles, especially vastus medialis muscle, are considered to provide active stabilizing effects on medial instability. Therefore, alternative tendon grafts, other than the medial-inserting m. semitendinosus tendon, can be considered for ACL reconstruction, but the exact influence of the hamstring muscles has not yet been investigated.

Medial meniscus

Medial meniscus concomitant injuries are reported in 18%-54% of cases[4,46,49,50] and have a comorbidity to acute and chronic ACL tears of up to 90%[51]. A possible cause for this correlation in acute valgus- and internal-rotational trauma could be the mechanism of sudden medial instability with subsequent anteroposterior and rotational shear forces when the ACL ruptures. This shear trauma might even be enhanced by an accompanying MCL rupture[4]. With persistent ACL instability, a shifted rotatory axis[24] and contact points[40] result in an altered flexion path of the medial femoral condyle and increase the risk for secondary injuries of the medial meniscus[51,52]. Shear forces deriving from anteroposterior instability of the tibia will either extend the anterior displacement of the medial meniscus by up to 15 mm or result in compression forces on the meniscus[10,14,21,24]. Decreased passive joint pressure within the medial compartment[37,38] and combined instability seem to result in increased impact forces[41] under stress, *e.g.*, walking. Allen *et al*[53] determined an increased peak yield of 50 N at 60° of flexion. The correlation of biomechanical influences between the ACL and the medial meniscus has been investigated in biomechanical human cadaveric studies. After dissection of the ACL and the medial meniscus, an increased ATT in contrast to a dissected ACL with an intact medial meniscus was found[29,54].

Lateral meniscus

Lateral meniscus injuries are reported with concomitant rates of 17%-51%[4,46,49,50], which is slightly less frequent than medial meniscus tears in cases of acute ACL rupture but also often caused by the typical valgus-internal-rotation trauma mechanism. The risk for a lateral meniscus injury seems to correlate with a coexisting lateral bone bruise, which is indicated on an MRI[46]. Additionally, like the medial meniscus, the lateral meniscus provides significant stability. A deficient lateral meniscal root evokes pivot-rotational instability of the knee in cadaveric studies[54,55].

Lateral collateral ligament

Lateral collateral ligament (LCL) concomitant injuries are rare and may be caused by anterolateral knee luxation injuries[46]. Nevertheless, the LCL is an important stabilizer for the joint. Zantop *et al*[56] have shown in a biomechanical study that a standalone ACL reconstruction cannot restore intact knee kinematics if the LCL is also deficient. Increased pivot-rotational anterolateral instability after an ACL rupture has promoted anatomical investigations of the anterolateral corner[57]. Parsons *et al*[58] found that the anterolateral ligament (ALL) provides stability against internal rotation at flexion angles greater than 35°. It has been proposed that a deficient ALL may correlate with a positive pivot shift sign. In addition, other structures of the anterolateral corner, such as the iliotibial tractus with its connecting Kaplan fibers, the lateral retinaculum and the lateral capsule, are suggested to influence pivot-rotational stability[57]. Additionally, it is currently being discussed whether the ALL becomes insufficient over time in cases of chronic

Table 1 Biomechanical properties of tendons, grafts and fixation techniques

Subject	Maximum load to failure (N)	Stiffness (N/mm)	Ref.
Intact ACL (with femur and tibia)	2160 (± 157)	242 (± 28)	[45]
Two gracilis strands	1550 (± 369)	370 (± 108)	[69]
Two semitendinosus strands	2640 (± 320)	534 (± 76)	[69]
Four combined hamstring strands	4090 (± 295)	276 (± 204)	[69]
7 mm BPTB	2238 (± 316)	327 (± 58)	[67]
10 mm BPTB	2977 (± 516)	424/455 (± 57/67)	[67]
15 mm BPTB	4389 (± 708)	556 (± 67)	[67]
10 mm QTB	2353 (± 495)	621 (± 122)	[70]
Interference screw (BPTB)	683-863	76-80	[71]
Interference screw (hamstrings)	534-925	189-315	[68,72]
Endobutton (hamstrings)	520-1364	35-195	[68,73]
Interference screw and endobutton (hamstrings)	1290-1449	307-341	[68]

ACL: Anterior cruciate ligament; QTB: Quadriceps-tendon-bone; BPTB: Bone-patellar-tendon-bone.

ACL insufficiency[59].

Secondary osteoarthritis

Secondary osteoarthritis is often observed after an ACL rupture: A meta-analysis by Ajuied *et al*[60] calculated a relative risk of 389 for radiographic osteoarthritic progression after an ACL rupture. There is good evidence for long-term degenerative progression and inferior clinical outcomes after concomitant meniscal and chondral injuries[60,61]. Additionally, persistent pivot-rotational instability after an ACL rupture was found to be a predictor for osteoarthritis and subjective satisfaction[33-35]. Nevertheless, although a positive effect of ACL reconstruction on osteoarthritic progression is proposed, to date there is no evidence for a preventive effect[60,61].

ACL RECONSTRUCTION

ACL reconstruction is currently a topic of intense research, with more than 1940 hits in the Medline database for the term "ACL reconstruction" published within the past 5 years. Nevertheless, the history of ACL reconstruction goes back to the end of the 19th century. In 1895, Robson[62] directly sewed the ACL in place *via* open medial arthrotomy. In 1903, Lange proposed an alloplastic ACL reconstruction with a silk graft[5]. Grekow described in 1914 the first autologous transplant with a free iliotibial tractus stripe[5]. From that moment, different autologous grafts have been used for transplantation. Brückner used a free patellar tendon graft for an arthroscopically assisted transplantation in 1966[63]. Because of the high harvesting morbidity of the graft, the primary suture regained favor in the 1970s[64,65]. Additionally, new synthetic materials (*e.g.*, Goretex, Carbonates) were used, but, due to complications, these alloplastic grafts, as well as the primary suture, were considered obsolete in the 1990s[66]. Since then, arthroscopically assisted ACL reconstruction with autologous or allogeneic tendon graft has evolved to worldwide acceptance.

Graft choice and graft fixation

Currently, hamstring-tendons (semitendinosus and gracilis), bone-patellar-tendon-bone (BPTB) complexes and quadriceps tendon-bone complexes are frequently used grafts. Tensile characteristics of these grafts are shown to be superior (maximum loads 2977 N[67], 4140 N and 2353 N) to the native femur-ACL-tibia complex (2160 N)[45] with similar stiffness (Table 1)[45,67-73]. Nevertheless, the weakest point of primary graft failure has turned out to be the graft fixation (Table 1). There are many biomechanical studies that evaluate the biomechanical properties of graft fixation. Due to the scarcity of young human donors, animal or old human specimens have often been used, leading to results that may vary from those of typical young ACL reconstruction patients. Still, the dimensions of biomechanical properties range between the calculated *in situ* forces of the ACL[42-44] and its ultimate failure load[45]. In addition to sufficient failure loads of fixation techniques, fixation of the graft close to the insertion site is suggested to decrease longitudinal ("bungee") and sagittal ("windshield wiper") graft movements[66,68]. Furthermore, Oh *et al*[68] have found significantly increased stiffness when an interference screw was added to an extracortical endobutton fixation (307 N/mm *vs* 195 N/mm).

Beyond biomechanics, clinical studies have shown good and comparable results with semitendinosus, quadriceps and bone-patellar-tendon-bone grafts for ACL reconstructions[74-76]. Thus, it is feasible to make an individual graft choice - for instance, to avoid BPTB grafts when anterior knee pain is at risk (floor tiler) or to avoid semitendinosus grafts when concomitant medial collateral ligament injury exists. Novel minimally invasive surgical harvesting techniques for quadriceps tendons promise less cosmetic burden and more clinical acceptance[77]. In a systematic review of overlapping meta-analyses, Mascarenhas *et al*[78] concluded that allografts were equal to autografts in terms of rerupture rates and clinical outcomes.

Tunnel positioning and effects on biomechanics

Until the beginning of the 21st century, ACL reconstruction with transtibial drilling of the femoral tunnel was the common surgical technique[66]. As femoral tunnel placement depended on the tibial tunnel placement, it was difficult to aim for the anatomic ACL footprint of the lateral femur condyles through a tibial tunnel. The over-the-top position, with tunnel placement near the deep cartilage margin and the intercondylar roof, was preferred to achieve a good near-to-anatomic reconstruction[66]. From an anatomical point of view, this position corresponds best to a near AM-bundle position. In 2002, Loh *et al*[79] were possibly the first to transform the known reciprocal relation of ACL bundles *in situ* forces into a cadaveric ACL reconstruction study. By drilling the femur in the 10 o'clock position, Loh intended

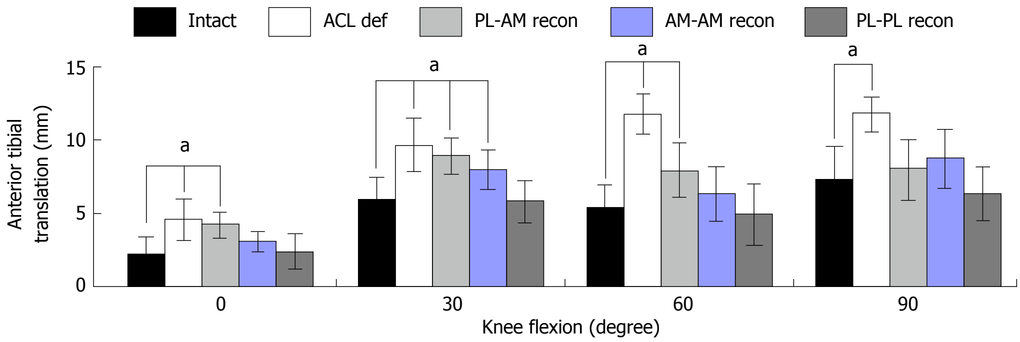

Figure 6 Anterior tibial translation under a simulated pivot shift test (combined 10 Nm valgus and 4 Nm internal rotational load, mean/SD, $^{a}P < 0.05$) as influenced by anterior cruciate ligament mismatch reconstruction of posterolateral and anteromedial bundles in a human cadaveric study by Herbort *et al*[8]. AM: Anteromedial; PL: Posterolateral; ACL: Anterior cruciate ligament.

to address PL-bundle fibers and evaluated the results against the conventional 11 o'clock over-the-top position. After evaluating resulting kinematics with a UFS/robotic testing system, the 10 o'clock reconstruction resulted in superior stability under combined rotatory loads. Consideration of anatomical ACL insertion sites continues to be a focus of biomechanical investigations. Mismatch reconstruction studies using robotic/UFS testing systems have demonstrated superior kinematics for combined rotatory loads and near-to-extension ATT when fibers of both the PL and AM bundles are reconstructed (Figure 6)[8,16,21,80].

Most authors have concluded that the more horizontal fibers of the reconstructed PL bundle in particular were responsible for stabilizing the joint at near-to-extension angles.

With the "dependent" transtibial drilling technique, accurately and reliably addressing the femoral ACL footprint was very difficult[81,82], although recently a novel modified transtibial technique was introduced that promises better aiming for the native footprint[83]. Nevertheless, the introduction of the anteromedial portal technique allowed "independent" drilling of femoral ACL tunnels and, thus, a method to reliably and visually address the native tibial and femoral ACL footprints[84,85]. Hence, novel anteromedial portal "anatomical" single- and double-bundle ACL reconstruction techniques have been clinically introduced and biomechanically evaluated[21,86-89].

Correlating to the results of the biomechanical mismatch studies[8,16], both anatomic double-bundle and anatomic single-bundle ACL reconstruction techniques resulted in superior kinematics compared to transtibial ("high-AM") femoral tunnel drilling for ACL reconstruction[21,89,90]. In a human cadaveric study, Bedi *et al*[91] determined that even an increased graft sized of a "high-AM" misplaced femoral ACL single bundle could not compensate for prime stability in contrast to a centrally placed smaller single bundle. However, in biomechanical studies, no superior kinematics could be found between anatomic double-bundle ACL reconstruction with drilling of an AM and a PL bundle tunnel in contrast to one centrally placed "anatomic" single-bundle ACL reconstruction[21,28,90]. Regardless, biomechanical advantages of "anatomic" double-bundle reconstruction may exist in larger knees: Siebold[92] calculated better coverage of femoral ACL insertion sites larger than 16 mm with the double-bundle technique and good coverage of the femoral ACL footprint for sites smaller than 13 mm with the single-bundle technique.

From a clinical perspective, Chhabra *et al*[93] and Griffith *et al*[94] reported less tunnel expansion, decreased instability and fewer incidences of revision surgery after ACL reconstruction using the anteromedial portal technique compared to the transtibial technique. There have been many prospective randomized clinical studies comparing anatomic single- and double-bundle ACL reconstruction[95,96]. Several of the clinical studies have shown minor but significant advantages for the anatomic double-bundle technique. In their meta-analysis, Desai *et al*[96] included 15 prospective clinical trials and found that 3 of those indicated significant superior anteroposterior stability of the anatomic double-bundle group in contrast to the anatomic single-bundle group. Furthermore, 2 of the included clinical studies resulted in superior pivot-rotational stability[96]. Regarding clinical outcome scores, van Eck *et al*[95] reported in their meta-analysis of 12 prospective clinical studies that no significantly different parameters of IKDC score, Lysholm score, range of motion and complication rate between anatomic double-bundle and anatomic single-bundle were detected. Despite these good biomechanical and clinical results, the anatomic double-bundle ACL reconstruction is controversial. In contrast to anatomic single-bundle reconstruction, its upfront costs are more expensive[97], and the surgical technique and tunnel revision surgery are considered to be more sophisticated[98].

New trends and concepts in ACL reconstruction surgery

Trying to simulate anatomic ACL insertion sites has resulted in good biomechanical and clinical parameters over the last decade. To mimic the effect of the anatomic double-bundle technique to effectively address both the PL and the AM bundle for femoral tunnel drilling, Herbort *et al*[99] introduced a rectangular tunnel technique, which is supposed to show better coverage of both bundle

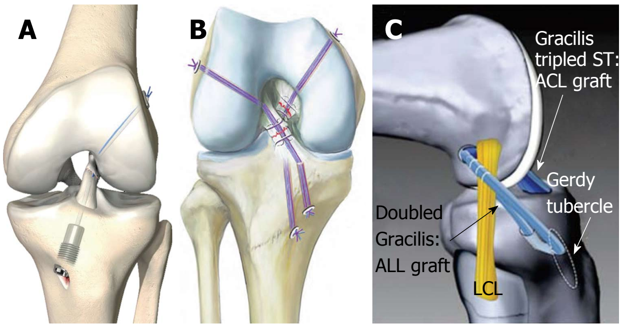

Figure 7 Novel anterior cruciate ligament repair techniques. A: Anterior cruciate ligament (ACL) suture and dynamic augmentation (Ligamys™, copyright Mathys Ltd., Bettlach, Switzerland); B: Ligament bracing (from Heitmann *et al*[104]); C: ACL reconstruction with anterolateral ligament (ALL) augmentation (from Sonnery-Cottet *et al*[59]). ST: Semitendinosus, LCL: Lateral collateral ligament.

insertions with one single, regular-sized transplant. Their biomechanical human cadaveric study resulted in superior ATT stability in contrast to a conventional round-tunnel, single-bundle reconstruction at 0° and 15° of flexion[99]. Sonnery-Cottet *et al*[59] and Kittl *et al*[57] reported a combined ACL and ALL reconstruction technique (with tenodesis) to improve the stability of the anterolateral corner in cases of acute or chronic ACL rupture with increased anterolateral rotational instability (Figure 7C) An initial case study of 92 patients resulted in significantly improved pivot-rotational stability after 2 years[59]. However, prospective randomized clinical studies to distinguish the pivot-rotational stabilizing effects between a conventional ACL reconstruction and a combined ACL/ALL reconstruction are still lacking. Primary suture with or without alloplastic augmentation of the ruptured ACL has resulted in inferior clinical outcomes in prospective and retrospective studies[66,100]. The majority of these alloplastic augmentations have been stiff constructs in a nonanatomical position (over-the-top position or extra-articular)[66,100]. However, with the aim to restore proprioceptive properties of the ligament and to avoid the harvesting morbidity of tendon grafts, Eggli *et al*[101], and Kohl *et al*[102] have introduced a new method of primary suturing of a traumatic ACL rupture with combined dynamic alloplastic intraligamentous stabilization (Figure 7A). To avoid mechanical fatigue of the augmentation and to adapt to the complex flexion axis of the knee[15], the augmentation cord is placed near-anatomical within or slightly behind the ACL and dynamically suspended by an intraosseous spring mechanism. Initial small-sample clinical studies after suturing with dynamic alloplastic intraligamentous stabilization have shown promising results for primary ACL ruptures and for combined suturing and augmentation of other structures for complex knee dislocation injuries[101,103].

Heitmann *et al*[104] described a similar technique with suturing and anatomically placed intraligamentous alloplastic augmentation of torn cruciate ligaments in cases of acute knee dislocation injury (Figure 7B). The authors exclusively recommend the technique for acute knee dislocations injuries of Schenck Ⅲ and Ⅳ types that do not involve a dynamic suspension of the augmentation. An initial clinical study of 20 patients showed satisfying results one year after surgery[104].

The perspective of suturing for preserving autologous graft material and the native ACL has often been considered to reduce morbidity in the past, but the results were not promising[66,100]. For complex ligamentous knee dislocation injuries, there seems to be a good potential for reduced harvesting morbidity and OR time. Additionally, it remains unclear whether a dynamic or a static augmentation suture in a combined cruciate ligament injury was best either for restoring stability or not inducing deficits of range-of-motion or misplacing the physiological axes of the knee. To date, there are no data from prospective randomized controlled studies.

CONCLUSION

The knee is a complex joint with shifting contact points, pressures and axes that are affected when a ligament is injured. The ACL, as one of the intra-articular ligaments, has a strong influence on the resulting kinematics. Often, other meniscal or ligamentous injuries accompany ACL rupture and further deteriorate resulting kinematics and clinical outcomes. Knowing the surgical options, anatomic relations and current evidence to restore ACL function and considering the influence of concomitant injuries on resulting kinematics to restore full function together can help to achieve an optimal outcome.

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P- Reviewer: Bicanic G, Fukuchi RK, Mugnai R, Seijas R
S- Editor: Gong ZM **L- Editor**: A **E- Editor**: Liu SQ

World Journal of Orthopedics

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Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
DOI: 10.5312/wjo.v7.i2.94

World J Orthop 2016 February 18; 7(2): 94-101
ISSN 2218-5836 (online)
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MINIREVIEWS

Direct anterior total hip arthroplasty: Comparative outcomes and contemporary results

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Author contributions: Connolly KP and Kamath AF contributed to this paper.

Conflict-of-interest statement: The authors have no conflicts of interest to disclose pertaining to the subject of this review manuscript.

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Received: May 29, 2015
Peer-review started: June 2, 2015
First decision: September 29, 2015
Revised: October 25, 2015
Accepted: December 3, 2015
Article in press: December 4, 2015
Published online: February 18, 2016

Abstract

Direct anterior total hip arthroplasty has become increasingly more popular among arthroplasty surgeons, in large part due to the use of an intramuscular interval and desire to reduce soft tissue damage. Several studies have now been published comparing the anterior intramuscular to other commonly used approaches, and many studies have published complication rates on large series of patients. Review of comparative studies indicates direct anterior hips tend towards shorter hospital stays and high rates of patients discharged to home. Although some studies show evidence of early benefit in functional outcomes, there is no strong evidence that the anterior approach provides any long term functional improvements compared to other approaches. Additionally, evidence to support reduced damage to soft tissue may not translate to certain clinical significance. Rates of intra-operative femur fracture, operative time and blood loss rates are notably higher for those developing familiarity with this approach. However, when surgeons have performed a modest number of procedures, the complication rates tend to markedly decrease in most studies to levels comparable to other approaches. Accuracy of component positioning also favors the anterior approach in some studies. This review summarizes the available literature comparing the direct anterior to other approaches for total hip arthroplasty and provides a comprehensive summary of common complications.

Key words: Complications; Direct anterior approach; Surgical hip approaches; Outcomes; Total hip arthroplasty

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Core tip: Direct anterior total hip arthroplasty may provide higher rates of patients discharged to home and shorter hospital stays when compared to other approaches. Long term functional outcomes do not appear to be improved by an intramuscular approach. Complication rates may be high during the initial learning period of performing this approach; however, these rates are generally shown to not exceed that of other approaches once a surgeon has completed a modest number of cases.

Connolly KP, Kamath AF. Direct anterior total hip arthroplasty: Comparative outcomes and contemporary results. *World J Orthop* 2016; 7(2): 94-101 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/94.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.94

INTRODUCTION

The continued desire to perform hip reconstruction through less invasive and tissue sparing methods has markedly increased the proliferation of direct anterior total hip arthroplasty (THA) over the past 15 years[1]. Although an abundance of recent material has been promoted, largely online, to tout the direct anterior approach (DAA) as superior to other commonly performed approaches, strong evidence to support these claims has been lacking[2]. Several studies seem to indicate that hospital length of stay and percentage of patients discharged home are improved *via* the DAA. These results may be balanced by increased operative time and blood loss, particularly early in the surgeon's performance of this technique. Studies evaluating damage to soft tissues between approaches seem to favor the DAA, yet differences in pain and other patient-reported variables do not consistently show a significant advantage. Functional outcomes tend to be improved in the early post-operative period using the DAA; however, these differences are largely equivalent in longer-term follow-up. Complication rates in this review were consistent with other approaches and appear to be markedly reduced as a surgeon gains familiarity with the procedure.

OUTCOMES AND COMPARATIVE STUDIES

Outcomes related to modern practice of anterior hip arthroplasty have been described in a number of studies, though the vast majority has been retrospective with small or moderate sample sizes. There have been an increasing number of recent prospective studies comparing DAA with other approaches, including less-invasive or minimal-incision posterior and lateral approaches. Results of the only meta-analysis comparing anterior and posterior approaches showed the anterior approach may provide potential benefits in patient reported pain and functional outcomes, post-operative length of stay, dislocations and post-operative narcotic requirements. It further suggested that the anterior approach trended toward higher percentages of patients discharged home and percentages of cups placed within the Lewinnek safe zone[3].

Several studies have looked at the inpatient and early post-operative outcomes comparing different THA approaches. A comparison of selected outcomes from studies included in this review is summarized in Table 1. Alecci *et al*[4] compared 419 patients receiving standard lateral and minimally invasive direct anterior approaches showing similar operative time and blood loss, with less pain, shorter time to and more patients discharged home with the DAA. A retrospective review of 372 less invasive direct lateral and 258 anterior supine intramuscular anterior approaches showed greater estimated blood loss (EBL), more patients discharged home, higher Harris Hip Scores (HHS), and higher Lower Extremity Activity scores at six weeks in the anterior group. Hospital length of stay and operative time were equal between the two groups[5]. A comparison by D'Arrigo *et al*[6] of three tissue sparing methods (direct anterior, direct lateral and anterolateral) with a standard lateral approach control group, found a decrease in blood loss compared to the control in all groups, better early functional scores in the direct anterior and anterolateral groups, and lower complication rate with an anterolateral approach. There was no difference in hospital stay. Of note, the study groups were comprised of only twenty patients each and were the first tissue sparing surgeries performed by the surgeon for each approach. A retrospective comparison of 100 minimal-incision DAA and 100 transgluteal lateral approaches showed decreased hospital length of stay, decreased pain on post-operative day zero and one, and decreased time to reach defined range of motion for the anterior approach. However, pain during physiotherapy was higher during some time periods for the DA hips[7]. A retrospective comparison of 41 anterior and 47 posterior approaches found shorter hospital stay and fewer days to mobilization with the anterior approach. Incision length was shorter in the anterior approach; however, lateral femoral cutaneous nerve injury and fracture were more common with the anterior approach and operative time was 20% longer. There was a 56% rate of any complications with the anterior compared to 45% with the posterior approach[8].

A study comparing DAA and mini-posterior approach performed by two experienced surgeons found no difference in return to activities of daily living (ADLs), length of stay, complication rate, pain medication requirements, physical therapy metrics or discharge disposition. The direct anterior approach had a longer operative time, higher visual analog scale pain score in the hospital, and more patients requiring gait aids at two weeks. Direct anterior hips had higher Harris hip scores at 8 wk; however, fewer patients had returned to work and driving. There were no differences in use of gait aids or narcotics, performance of ADLs, or 0.5 mile walking at 8 wk. The DAA group had lower minor wound complications. Component placement was adequate in both groups[9]. Spaans compared 46 DA and direct lateral (DL) hips, with operative time and EBL about double with the DA group. The DA hips in the study were the first performed by the surgeons. Hospital stays were equivalent[10]. A comparison of 54 patient randomized to mini-posterior approach THA (MPA-THA) or DA THA showed time to ambulation without assistive device favored DA-THA (22 d *vs* 28 d). Three weeks SF-12 mental scores and WOMAC function and total

Table 1 Summary of select outcomes reported in the literature in comparative studies of direct anterior and other total hip approaches

Author	Study variable						
	Length of stay	Discharge to home	Post-operative pain	Short-term functional outcome	Long-term functional outcome	Blood loss	Operative time
Alecci	↓	↑	↓			↔	↔
Barrett	↓		↓	↑	↔	↑	↑
Berend	↔	↑		↑	↔	↑	↔
D'Arrigo	↔			↑	↔	↓	↑
Goebel	↓		↓				
Lamontagne				↔	↔		
Martin	↓	↔		↑	↔	↔	↑
Mayr				↑	↔		
Poehling-monaghan	↔	↔	↑	↔	↔		↑
Rathod				↔	↔		
Rodriguez	↔		↔	↑	↔		
Spaans	↔			↔	↔	↑	↑
Taunton				↑	↔		
Zawadsky	↓	↑	↓	↑			

Arrows indicate relative magnitude of the variable (*i.e.*, ↑: Increased; ↓: Decreased; ↔: Similar) for direct anterior approach compared to alternative approach for applicable study.

scores favored MPA. There were no differences at any other time point for SF-12, WOMAC or HHS scores[11]. A study of 50 posterior, 50 DA and 50 DA approaches in a learning curve period showed decreased length of stay and more patients discharged to home in the DA groups. The DA groups also had significantly less use of assistive devices, pain scores and narcotic use at six weeks. Operative time for the learning curve group was significantly longer[12].

Another area of interest in assessing approaches to the hip joint is functional capacity of patient post-operatively. A prospective, randomized, single surgeon study compared 43 direct anterior approaches to 44 posterior approaches, with the primary endpoint of normal ability to climb stairs and walk unlimited distances. The study showed that DAA patients performed better in the immediate post-operative period with lower Visual Analog Scale pain scores on post-operative day one, more subjects climbing stairs and walking unlimited distances at six weeks and higher HOOS Symptoms scores at three months. However, there were no significant differences at later time points[13]. A comparison of 60 hips between anterior muscle-sparing, direct lateral approaches and a matched control group showed abnormal stair climbing kinematics were exhibited in both groups after surgery. There were fewer differences with smaller magnitudes when compared to the control population in the anterior group than the lateral group[14]. A gait analysis study by Mayr *et al*[15] compared sixteen direct anterior hips and seventeen anterolateral hips. At six and twelve weeks, the anterior hip group showed significant improvement in cadence, stride length and time and walking speed. The anterolateral group showed no statistically significant improvements in time-distance parameters at six or twelve weeks. Normal level of walking speed was not achieved in either group. Both groups showed improvements in range of motion; however, neither group achieved a physiologically normal range of flexion/extension in the study period. A comparison of gait parameters in 22 patients, 11 direct anterior and 11 posterior approaches, showed improvements in flexion/extension range of motion, peak flexion, and extension moments without differences between the groups. The DAA group showed statistically significant improvements in external and internal rotation compared to the posterior group, which may be related to release and repair of external rotators in posterior group. The posterior approach group had a significant improvement in gait velocity from pre-operatively to 6 mo, becoming similar to the pre-op value for DAA[16].

A comparison of 35 computer-navigated minimally-invasive anterior approach and 40 posterolateral approach hips found no differences in recovery of spatiotemporal parameters or angular movements of the pelvis and thorax between the groups. Both groups retained lower values for spatiotemporal parameters and frontal plane angular movements compared to healthy subjects at six months and one year[17].

A prospective non-randomized trial comparing 60 DAA and 60 posterior hips showed early functional differences favoring the DAA group, including improved timed up and go (TUG) parameters immediately post-operatively, faster time to walk 150 feet and stairs and transfers. Beyond two weeks, there were no differences in HHS, University of California at Los Angeles (UCLA), functional independence measure (M-FIM), and TUG scores, as well as need for gait aids, time to walk 0.5 miles or resumption of activities of daily living[18]. An analysis of 20 DAA and 20 direct lateral hips compared to 20 controls showed negligible difference between the two approach groups with both groups showing gait anomalies. Neither group achieved kinetics and kinematics similar to the control group[19]. A small study comparing DAA and anterolateral THAs with a control group showed no difference in return of hip strength and mobility between the two groups compared to control groups. Patients in the DAA hip group showed greater gait velocity and stride length, abductor strength and sagittal plane range of motion at six weeks compared to pre-operatively, but was not significantly different in improvement from the anterolateral group. Strength and mobility between DAA and anterolateral groups were similar at 16 wk post-surgery[20].

A limited number of studies have also evaluated the patients' perceived outcomes related to the surgical approach. A survey of 1273 patients in approximately equal distribution of lateral, anterior and posterolateral approach groups showed that adjusted HOOS scores for pain, other symptoms, activities of daily living, sport/recreation, and quality of life (QOL) were significantly worse for the lateral approach than for the anterior approach and the posterolateral approach. These results were largely related to more patient-reported limping with the lateral approach than with the anterior and posterolateral[21]. A prospective, randomized comparison of 100 patients enrolled in either a modified direct anterior or small-incision anterolateral approach of equivalent incision lengths showed better improvement in SF-36 scores for role limitation, bodily pain and general mental health for patients in the anterior group[22]. A comparison of 85 DAA hips and 86 transgluteal lateral hips found no difference in HHS, SF-36 mental and physical component scores and daily activity by daily activity questionnaire. There was a significant difference in the UCLA activity score, with the lateral group scoring higher[23]. A prospective randomized trial between 50 DAA and 50 DL hips showed improvements at follow-up up to one year that were statistically significantly better for DAA in physical functioning, role limitations, bodily pain, social functioning, general mental health, vitality energy or fatigue and post-op physical and mental health dimensions of the SF-36, WOMAC and QOL component of Linear Analogy Scale Assessment. There were no differences remaining at 2 years[24].

One of the main arguments for superiority of the DAA is the minimal soft tissue and muscle damage resulting from utilizing an intramuscular plane. Twenty-nine patients treated with minimally invasive THA through a DAA and twenty-eight patients treated with the same procedure through a posterior approach were prospectively analyzed. The levels of the markers of inflammation were slightly decreased in the direct-anterior-approach group as compared with those in the posterior-approach group. The rise in the CK level in the posterior-approach group was 5.5 times higher than that in the anterior-approach group in the post-anesthesia-care unit and nearly twice as high cumulatively[25]. A study comparing 25 DAA and transgluteal approaches found detachment of abductor insertion, partial tears and tendinosis of the glut medius and minimus, presence of peri-trochanteric bursal fluid and gluteus medius and minimus fatty atrophy were significantly less in DAA approach when compared using magnetic resonance imaging one year post-operatively[26]. A comparison of visually inspected muscle damage to cadaveric specimens undergoing anterior or posterior approaches showed less damage to the gluteus medius and minimus with the anterior approach. Thirty-one percent of the anterior hips showed evidence of tensor fascia lata (TFL) damage and 12% had damage to the direct head of the rectus femoris. The greatest difference was in damage to the gluteus minimus. All external rotators were released as part of the posterior approach, whereas 50% of anterior hip procedures required release for mobilization[27]. A study of 421 DAA hips estimated that increasing TFL damage was related to the male sex and increasing body mass index (BMI)[28]. The incidence of heterotopic ossification (HO), possibly related to retraction damage to the TFL or rectus femoris, has also been evaluated in anterior hips. An analysis of 236 hips in 214 patients at two hospitals undergoing DAA showed an overall incidence of HO of 41.5% between two hospitals. There was a significant reduction in patients on aspirin compared to Coumadin or Lovenox for deep venous thrombosis prophylaxis, and a higher rate in male patients. Hospital One had an incidence of 33% compared to 48.8% at Hospital Two. The rate of HO was similar to reported rates of 28%-61% with other approaches. It was hypothesized that use of the OSI Hana table and mechanical lift at Hospital One may have reduced soft tissue trauma and also contributed to lower HO rates[29].

In summary, several studies seem to indicate that hospital length of stay and percentage of patients discharged to home are improved *via* the DAA. These results may be balanced by increased operative time and blood loss, particularly early in the surgeon's performance of this technique. Some functional outcomes may be improved in the early post-operative period using the DAA; however, these results are largely negligible in long-term follow-up.

COMPLICATIONS

One of the common arguments against the DAA is the high rate of complications. Table 2 summarizes reported complications from multiple studies and available complications from comparative approaches. Several studies note markedly higher rates of complications in the "learning curve" period, or the initial series of surgeries performed by a surgeon adapting the approach. Moskal *et al*[30] proposed that the surgeons level of experience with DA approach directly correlated with complication rates, with a plateau between the first 40-100 cases. A study reporting outcomes of the first 43 cases performed by a single surgeon showed significant reductions in operative time and EBL between the first and last ten cases performed, with a decline in total complications[31]. Seng *et al*[32] tracked conversion of surgeries from lateral to DAA, and found that after 6 mo and 37 cases, more than half of joint replacements were being performed

Table 2 Summary of select complications reported in the literature in comparative studies of direct anterior and other total hip approaches *n* (%)

Author	Complications												
	Approach	No. patients	Dislocation	Femur fracture	Great trochanter fracture	Hematoma	Ankle injury	Nerve injury	Reoperation due to infection	Reoperation - other than infection	Bursitis	Superficial infection/ wound complication	Acetabulum (or pelvis) fracture
Alexandrov	A	43	1 (2.3)	1 (2.3)	5 (11.6)	1 (2.3)	0	2 (4.7)					
Amile	A	421	13 (3.1)					25 (5.9)	5 (1.2)	8 (1.9)			
	L	431	16 (3.7)					27 (6.3)	8 (1.9)	21 (4.9)			
	P	421	10 (2.4)					14 (3.3)	5 (1.2)	7 (1.7)			
Bal	A	100		1 (1.0)				4 (4.0)					
Barrett	A	43	0 (0.0)	0 (0.0)		1 (2.3)					0 (0.0)	1 (2.3)	
	P	44	1 (2.3)	1 (2.3)		0 (0.0)					1 (2.3)	0 (0.0)	
Berend	A	258		4 (1.6)				2 (0.8)		2 (0.8)			
	L	375				2 (0.5)		2 (0.5)	1 (0.3)			1 (0.3)	1 (0.3)
Bhandari	A	1277	8 (0.6)	22 (1.7)	13 (1.0)	5 (0.4)		13 (1.0)	3 (0.2)	32 (2.5)	1 (0.1)	22 (1.7)	8 (0.6)
Christensen	A	505							3 (0.6)	2 (0.4)		2 (0.4)	
	P	1288							1 (0.1)	1 (0.1)			
De Geest	A	300	2 (0.7)	12 (4.0)	3 (1.0)			16 (5.3)	6 (2.0)	14 (4.7)		6 (2.0)	
Hallert	A	200	4 (2.0)	3 (2.0)				3 (2.0)	1 (1.0)				
Hoell	A	113	0 (0.0)	1 (0.9)					1 (0.9)	3 (2.7)			
Keggi	A	687	17 (2.5)	15 (2.2)	5 (0.7)	13 (1.9)		5 (0.7)	1 (0.1)				
Jewett	A	800	7 (0.9)	24 (3.0)			0 (0.0)	1 (0.1)	7 (0.9)	19 (2.4)			1 (0.1)
Kennon	A	2222	28 (1.3)	63 (2.8)	24 (1.1)	31 (1.4)		9 (0.4)	7 (0.3)				3 (0.1)
Martin	A	41	1 (2.4)	1 (2.4)				7 (17.1)			3 (7.3)	3 (7.3)	
	P	47	3 (6.4)	0 (0.0)				0 (0.0)			7 (14.9)	4 (8.5)	
Matta	A	494	3 (0.6)	6 (1.2)	3 (0.6)	3 (0.6)	3 (0.6)	1 (0.2)	1 (0.2)	3 (0.6)			
Mirza	A	258	4 (1.5)	9 (3.5)					1 (0.4)				
Reichert	A	85	0 (0.0)					6 (7.1)		1 (1.2)	1 (1.2)		
	L	86	0 (0.0)	1 (1.2)					1 (1.2)	1 (1.2)			
Sariali	A	1764	27 (1.5)	28 (1.6)	1 (0.1)					3 (0.2)			
Spaans	A	46	1 (2.2)							3 (6.5)			1 (2.2)
	P	46	1 (2.2)							0 (0.0)			1 (2.2)
Wayne	A	100	2 (2.0)	8 (8.0)				6 (6.0)	0 (0.0)	5 (5.0)		0 (0.0)	3 (3.0)
	L	100	1 (1.0)	2 (2.0)				0 (0.0)	3 (3.0)	3 (3.0)		4 (4.0)	1 (1.0)
Yi	A	61	1 (1.6)	2 (3.3)	3 (4.9)	1 (1.6)		1 (1.6)	1 (1.6)	2 (3.3)			
Zawadsky	A	100	0 (0.0)						2 (2.0)	3 (3.0)			
	P	50	1 (2.0)						3 (6.0)	0 (0.0)			

A: Anterior; L: Lateral; P: Posterior.

with the anterior approach, indicating increased comfort with the procedure. This time mark also coincided with a plateau in operative time and EBL. They had two femoral perforations during this learning curve period and observed no dislocations. Surgeons who performed less than 100 cases had a twofold increase in complications in one review of 1277 DAA THAs[33]. Wayne *et al*[34] compared the first 100 patients in a DAA compared to the previous 100 patients receiving a direct lateral approach and showed increased blood loss (change in hemoglobin pre- *vs* post-operatively), longer operative time, increased rate of nerve damage, femur fracture, blood transfusion, acetabular malposition, with shorter hospital stays and fewer operative site infections.

Femur fractures have been particularly found to be of high incidence in initial adaptation of the approach. A study of 800 DA hips showed a significantly higher rate of femur fracture early in the series, with none in the second half. A second-generation fracture table with electronic hook elevation system, allowing for more gradual and gentle femoral elevation, was attributed to reduce the rate of fracture, along with better understanding of tension applied to the femur and necessary superior capsule and occasional piriformis tendon release during exposure. Femoral perforations also occurred early in the series in patients with severe flexion contracture which was mitigated through better understanding of the using a more horizontal insertion angle of starting broach to follow the angle of the femur in the contracted position[35]. Yi *et al*[36] reported an 8.2% rate of intraoperative femoral fracture during the first 61 cases of anterior supine intermuscular THA performed, all occurring during the first 32 of 61 cases. De Geest *et al*[37] compared early outcomes and complications of 300 hips and showed 5 proximal femur fractures with Medacta Quadra and anterior minimally invasive surgery stems but none in the group using Taperloc stems. They did not find a difference in infection rates between early and later cases, but had a high rate of post-operative overall complication rate (14%), and 6.7% of patients required a surgical re-intervention. The authors concluded that there may be a significant learning curve with a complication rate that may be too high for some surgeons to change their surgical technique.

Dislocation rates have been shown to be low with the DAA in several studies. It is postulated that inherent stability exists, as muscles are not detached posteriorly or anteriorly[38]. Siguier showed a dislocation rate of 0.96% (10 of 1037 patients) with MIS DAA THA[39]. An analysis of 22237 hips performed through posterior, anterolateral, direct lateral, and anterior approaches found that anterolateral and anterior hips had lower dislocation rates compared to posterior. Among 42438 hips analyzed for need for revision, there was no difference between approaches. The dislocation rate for DA hips was 0.8%[40]. A prospective study by Sariali *et al*[41] of 1764 DA hips found an overall dislocation rate of 1.5%. Significant risk factors for dislocation were male sex, higher BMI, osteonecrosis, head diameter (22 > 28 mm, 2% *vs* 0.5%), higher EBL and low post-operative range of motion.

Wound complications have also been a source of concern, particularly in obese patients with poorer proximal skin where the DAA incision may lie in the overhanging fat apron or over fold itself. Use of an abdominal binder for patients with pendulous abdomens to keep the pannus from resting on the incision until healed has been suggested, as well as maintaining a sterile bandage[30]. A comparison of 1288 posterior approach and 505 DAA hips showed a higher rate of re-operation for wound-related complications (0.2% to 1.4%, respectively)[42]. Some authors have endorsed use of tissue protectors intra-operatively to reduce skin damage; however, use of a ring retractor did not improve wound cosmesis in a small study on the subject[31,43,44].

CONCLUSION

All standard approaches to the hip have been shown to be safe and efficacious, with particular advantages and disadvantages to each approach. The DAA to the hip has gained significant popularity recently, and can be a valuable technique for hip replacement in most patients. Although it has been associated with a steep learning curve, overall complication rates in the available literature do not appear to exceed those of other approaches to the hip. The growing desire for less invasive arthroplasty with improvement in functional results makes this approach an attractive choice. The surgeon must carefully consider the possible benefits and disadvantages of the approach, especially in an early phase of adopting the procedure. Long-term studies of larger numbers of patients are still required to demonstrate a cost benefit or quality of care advantage to other hip approaches. As patient driven health care and hospital associated costs became a larger factor in the practice of arthroplasty, the trends in outcomes related to direct anterior total hip arthroplasty should be more closely examined.

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P- Reviewer: Aprato A, Buttaro MA, Cui QT **S- Editor**: Qiu S
L- Editor: A **E- Editor**: Liu SQ

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Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
DOI: 10.5312/wjo.v7.i2.102

World J Orthop 2016 February 18; 7(2): 102-108
ISSN 2218-5836 (online)
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MINIREVIEWS

Osteochondritis dissecans of the capitellum in adolescents

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Author contributions: van Bergen CJA drafted and finalized the manuscript; van den Ende KIM and ten Brinke B provided the figures; Eygendaal D supervised the writing process; all authors reviewed and commented on the text and approved the final version.

Conflict-of-interest statement: The authors have no conflict of interest.

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Received: May 28, 2015
Peer-review started: June 1, 2015
First decision: August 4, 2015
Revised: September 16, 2015
Accepted: December 1, 2015
Article in press: December 2, 2015
Published online: February 18, 2016

Abstract

Osteochondritis dissecans (OCD) is a disorder of articular cartilage and subchondral bone. In the elbow, an OCD is localized most commonly at the humeral capitellum. Teenagers engaged in sports that involve repetitive stress on the elbow are at risk. A high index of suspicion is warranted to prevent delay in the diagnosis. Plain radiographs may disclose the lesion but computed tomography and magnetic resonance imaging are more accurate in the detection of OCD. To determine the best treatment option it is important to differentiate between stable and unstable OCD lesions. Stable lesions can be initially treated nonoperatively with elbow rest or activity modification and physical therapy. Unstable lesions and stable lesions not responding to conservative therapy require a surgical approach. Arthroscopic debridement and microfracturing has become the standard initial procedure for treatment of capitellar OCD. Numerous other surgical options have been reported, including internal fixation of large fragments and osteochondral autograft transfer. The aim of this article is to provide a current concepts review of the etiology, clinical presentation, diagnosis, treatment, and outcomes of elbow OCD.

Key words: Osteochondritis dissecans; Cartilage; Elbow; Capitellum; Athletes; Overhead sports; Arthroscopy; Bone marrow stimulation; Adolescent; Osteoarthritis

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Core tip: The aim of this article is to provide a current concepts review of the etiology, clinical presentation, diagnosis, treatment, and outcomes of elbow osteochondritis dissecans. This well illustrated paper highlights the need for a high index of suspicion to prevent delay in the diagnosis. Various imaging methods are outlined. Current treatment options are discussed and future directions are provided.

van Bergen CJA, van den Ende KIM, ten Brinke B, Eygendaal D. Osteochondritis dissecans of the capitellum in adolescents. *World J Orthop* 2016; 7(2): 102-108 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/102.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.102

INTRODUCTION

Osteochondritis dissecans (OCD) is a process in which a segment of articular cartilage separates from the subchondral bone. In the human body, OCD lesions are most commonly found in the knee, followed by the ankle and the elbow[1]. OCD of the elbow typically affects the capitellum of the humerus. It can be a debilitating injury in a young patient population.

Epidemiology

Elbow OCD presents typically in adolescent athletes engaged in repetitive overhead or upper extremity weight-bearing activities (*e.g.*, baseball, tennis, volleyball, weight lifting and gymnastics). The prevalence of OCD of the humeral capitellum was 3.4% among more than 2000 adolescent baseball players[2]. Not all of these patients had symptoms[2]. Patients with an OCD usually are in their second decade of life, with an age ranging from 11 to 23 years. Boys are affected more commonly than girls. The capitellum of the dominant elbow is mostly affected. Bilateral involvement is seen in up to 20% of the patients[3].

Elbow OCD should be distinguished from Panner's disease or osteochondrosis of the capitellum. Panner's disease is encountered in younger children (aged 4-12 years), and characterized by ischemia and necrosis of the capitellar epiphysis, followed by regeneration and recalcification. It is a self-limiting, benign disorder that usually resolves with rest.

Etiology

The exact etiology of OCD is unknown. A genetic predisposition has been suggested in twin studies[4]. The main cause, however, is thought to be excessive repetitive valgus compression across the elbow joint with immature articular cartilage[5,6]. Repetitive stress to the lateral elbow compartment could lead to localized injury of subchondral bone of the poorly vascularized humeral capitellum (Figure 1), characterized by focal avascular necrosis and subchondral bone changes. Subsequently, this could result in loss of support for the overlying articular cartilage and eventually breakdown and formation of loose fragments once the mechanical support of the articular cartilage is compromised[5,6].

Pathology

OCD usually evolves through three stages[3,6]. In stage 1, hyperemic bone and edematous periarticular soft tissues are found. In stage 2, the epiphysis deforms, sometimes with fragmentation. In stage 3, necrotic bone is replaced by granulation tissue. The articular surface may separate and form a loose body as the bone heals.

Natural history

It seems logical to assume that patients with OCD are predisposed to early osteoarthritis of the elbow. However, the relation between cartilage defects in general and the development of osteoarthritis in the long term has not been elucidated to date. Most evidence is available for cartilage lesions in the knee and ankle[7,8]. Large chondral and osteochondral lesions of the knee are presumed to predispose to osteoarthritis, although the scientific evidence is limited[7]. In the ankle, however, a relation between OCD and osteoarthritis has not been shown[8]. Only 4% of ankle OCDs develop a narrowed joint space up to 20 years of follow-up[9].

With regard to the elbow, little is known about the risk of developing degenerative changes in the long term. Bauer *et al*[10] investigated elbow degeneration amongst 31 OCD patients at a mean follow-up of 23 years. One-third had radiographic degenerative changes and 42% of patients complained of pain and/or reduced range of motion at the time of follow-up. Younger patients had better odds of having a pain-free elbow without radiographic signs of degeneration in the long term. In addition, larger lesions may be more prone to degenerative changes over time. Takahara *et al*[11] noted a poorer long-term outcome of patients with large cartilage lesions compared to those with small lesions. There is no evidence that surgical debridement with or without microfracturing protects against degeneration.

CLINICAL PRESENTATION

Patient's delay and doctor's delay are very common in elbow OCD. Therefore, a high index of suspicion and directed imaging studies are necessary. In fact, any teenager presenting with lateral elbow pain should be suspected of having an OCD lesion. The typical patient is a young male sports person, initially presenting with pain, tenderness, and swelling over the lateral aspect of the elbow[12]. In a later stage, there may be loss of extension and intermittent catching and locking of the elbow, but physical examination findings are not very distinct in the early stage of OCD. Yet, it is important to detect OCD as early as possible to prevent expansion of the lesion and possible degeneration of the joint.

IMAGING

Plain anteroposterior and lateral radiographs are often used as an initial screening method (Figure 2). Radiographic signs of an OCD are flattening of the capitellum, a focal defect of the articular surface, and loose bodies. However, routine radiographs of the elbow are insensitive in identifying OCD of the capitellum[13]. In fact, approximately half of the radiographs of patients with a capitellar OCD appear normal[13]. An anteroposterior view with the elbow in 45° of flexion may better depict the lesion[14].

Because of the low sensitivity of plain radiography, additional imaging is indicated when an OCD is suspected. Ultrasound of the elbow has been described to detect capitellar OCD[15-17]. However, the capitellum is partially obscured by the radial head[17]. Computed tomography (CT) and magnetic resonance imaging (MRI) are most useful in diagnosing an OCD. MRI demonstrates

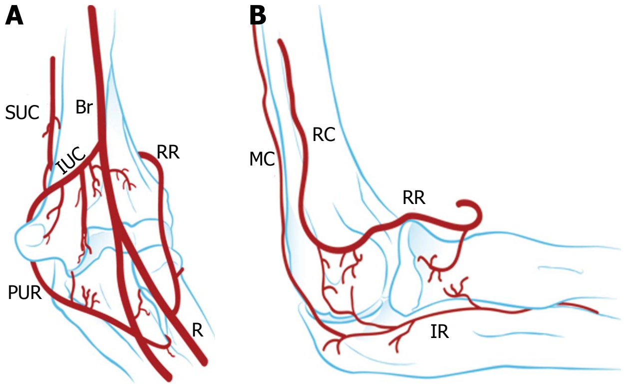

Figure 1 Vascularisation of the capitellum. A: Anterior view; B: Lateral view. Br: Brachial; IR: Interosseous recurrent; IUC: Inferior ulnar collateral; MC: Middle collateral; PUR: Posterior ulnar recurrent; R: Radial; RC: Radial collateral; RR: Radial recurrent; SUC: Superior ulnar collateral artery.

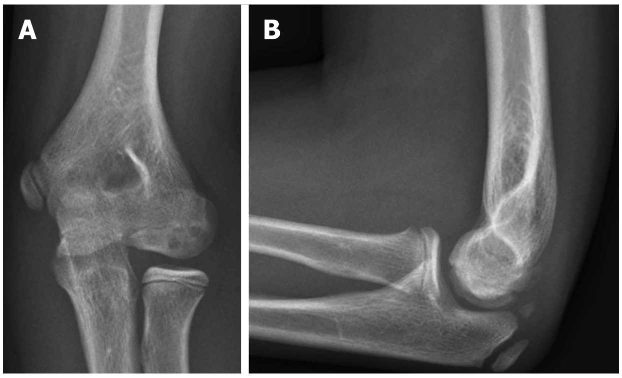

Figure 2 Plain radiography of the elbow showing an osteochondritis dissecans lesion of the capitellum. A: Anteroposterior; B: Lateral.

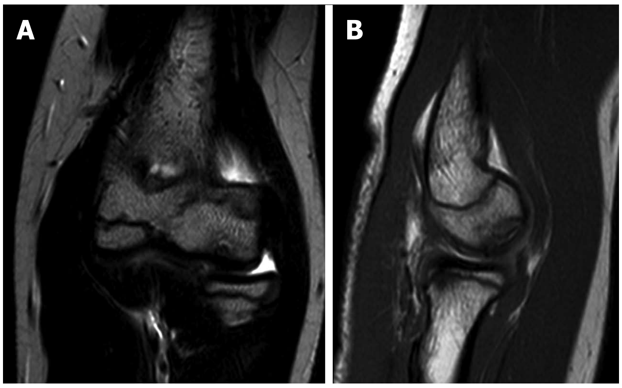

Figure 3 Magnetic resonance images of an elbow affected with osteochondritis dissecans of the capitellum. A: Coronal view; B: Sagittal view.

early OCD and is valuable in determining the stability and viability of the OCD fragment (Figure 3)[10,17,18]. Magnetic resonance arthrography utilizes intra-articular gadolinium contrast agent to detect OCD and loose bodies[18]. However, the addition of intra-articular contrast agent does not improve the sensitivity of MRI without contrast agent in detecting cartilage lesions in the elbow[19]. CT scans might be more sensitive and better depict loose bodies (Figure 4). We studied 25 patients with an OCD proven by arthroscopy who all had preoperative radiographs, MRI and CT. The OCD was visible on 25 CT scans (sensitivity, 100%), on 24 MRI scans (sensitivity, 96%), and on 19 radiographs (sensitivity, 76%). Arthroscopy identified loose bodies in 20 cases. These were visible in 18 CT scans (90%), 13 MRI scans (65%) and 11 radiographs (55%). Based on these preliminary data, one might carefully conclude that CT seems to be the optimal imaging technique to diagnose OCD and loose bodies.

Classification

Although the value of grading capitellar OCD seems limited, various classifications have been described. Most are based on radiography, MRI, or arthroscopy.

Minami *et al*[20] in 1979 described a classification based on anteroposterior radiography. Grade 1 describes a stable lesion with a translucent cystic shadow in the capitellum; grade 2, a clear zone between the OCD and adjacent subchondral bone; and grade 3, loose bodies.

Itsubo *et al*[21] recently introduced a T2-weighted MRI staging system that provides accurate and reliable estimation of stability of OCD. The following stages are distinguished: Stage 1, normally shaped capitellum with several spotted areas of high signal intensity that is lower than that of cartilage; stage 2, as with stage 1 but with several spotted areas of higher intensity than that of cartilage; stage 3, as with stage 2 but with both discontinuity and noncircularity of the chondral surface signal of the capitellum and no high signal interface apparent between the lesion and the floor; stage 4, lesion separated by a high intensity line in comparison with cartilage; and stage 5, capitellar lesion displaced from the floor or defect of the capitellar lesion noted. Stages 1 and 2 are considered stable. Stages 3, 4 and 5 are considered unstable[21].

The International Cartilage Repair Society has proposed an arthroscopic classification system for OCD lesions[22]. Grade 1 indicates a stable lesion with a continuous but softened area covered by intact cartilage; grade 2, a lesion with partial discontinuity that is stable when probed; grade 3, a lesion with a complete discontinuity that is not yet dislocated; and grade 4, an empty defect as well as a defect with a dislocated fragment or a loose fragment lying within the bed.

TREATMENT AND OUTCOMES

The treatment choice depends on several aspects, including the severity of symptoms and the size, location and stability of the lesion. It is important to differentiate between stable and unstable OCD lesions. In general, stable lesions may be reversible and can heal completely with nonoperative management, while unstable lesions need surgical treatment[23]. Stable lesions are characterized by an immature capitellum with an open growth plate, and flattening or radiolucency of the subchondral bone, in a patient with (almost) normal elbow motion[23,24]. Unstable lesions have at least one of

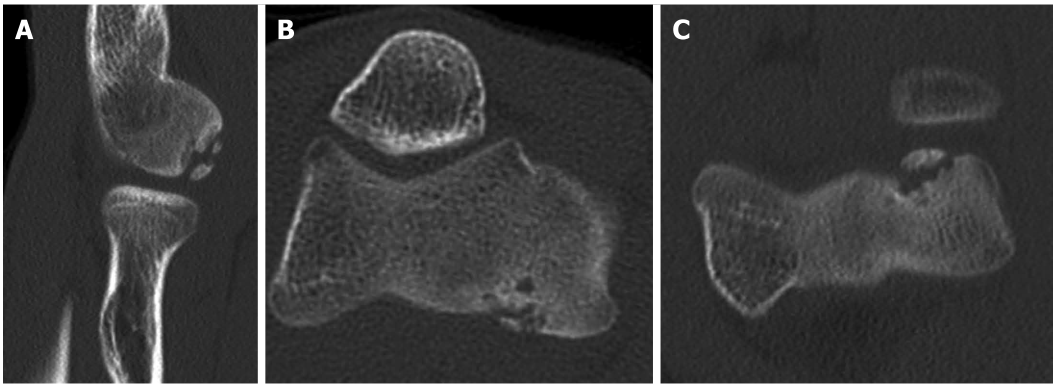

Figure 4 Computed tomography scans showing capitellar osteochondritis dissecans (A-C).

the following findings: A capitellum with a closed growth plate, fragmentation, or restriction of elbow motion 20 degrees or more[23,25]. On MRI, unstable lesions are characterized by a high signal intensity line through the articular cartilage, a high signal intensity interface, and an articular defect[21,26].

Nonoperative treatment

Nonoperative measures consist of rest or sports restriction (cessation of repetitive stress on the elbow), muscle strengthening exercises, non-steroidal anti-inflammatory drugs, and/or a short course of immobilization[23,24,27]. The minority of OCD lesions are classified as stable and the initial success rates of nonoperative treatment were poor[23,28]. Takahara *et al*[28] in 1999 reported a success rate of only 50% after an average follow-up of 12.6 years. Factors that are associated with the outcomes of nonoperative treatment were identified later. Bradley and Petrie reported that most patients fully recovered with complete return to sports with rest alone if they had a lesions with all of the following conditions: (1) open capitellar growth plate; (2) localized flattening or radiolucency of the subchondral bone; and (3) good elbow motion[27]. Likewise, Mihara *et al*[24] showed that spontaneous healing potential of OCD in patients with open capitellar growth plates appears high. Conversely, healing potential with nonoperative management is extremely low in advanced OCD lesions with closed growth plates and in those that are unstable, even if they are undisplaced[6,10,24,27,28].

Operative treatment

Although outcome studies on surgical treatment lack long-term follow-up and have limited methodologic quality, they generally show satisfactory results regarding pain, return to sports, and elbow function[29]. Surgical intervention is therefore indicated for lesions that do not respond to initial nonoperative treatment and for unstable lesions[29].

Primary surgical management most commonly consists of arthroscopic debridement of the lesion, bone marrow stimulation (by microfracturing the subchondral bone) and removal of loose fragments. Alternatively to arthroscopic surgery or for lesions after failed previous surgery, numerous open surgical approaches have been reported, including internal fixation of large fragments and osteochondral autograft transfer[14,30-33].

Arthroscopic treatment

Arthroscopic surgery has become the standard procedure for the treatment of capitellar OCD[34]. It offers the advantage of direct visualization of the pathology and the ability to treat the lesion through small stab incisions. This minimally invasive approach reduces the risk of operative morbidity and allows the patient to start rehabilitation directly after surgery[34].

Arthroscopic treatment consists of debridement of the lesion to achieve a stable rim, followed by bone marrow stimulation, and removal of any loose fragments and osteophytes[35,36]. The patient is placed in the lateral decubitus position on the operating table. A tourniquet is placed around the upper arm, which rests on a padded arm holder that is attached to the side of the table (Figure 5). The portal sites and the ulnar nerve are marked, and the elbow is disinfected and draped. The joint is injected with 20 mL of saline solution. The complete elbow joint is inspected from anterior and posterior with use of five to six portals. A distal ulnar portal allows for ergonomic exposure to the posterolateral capitellum providing easy access for drilling, burring and local debridement[34]. A bonecutter shaver or curette is brought into the posterolateral capitellar joint space through the standard soft-spot lateral portal. All unstable cartilage and necrotic bone are removed. Any cysts underlying the defect are opened and curetted. After debridement, several connections with the subchondral bone are created by drilling with a Kirschner wire or microfracturing with an awl (Figure 6). The objective is to partially destroy the calcified zone that is often present and to create openings into the subchondral bone. Intraosseous blood vessels are disrupted and the release of growth factors leads to the formation of a fibrin clot. The formation of local new blood vessels is stimulated, marrow cells are introduced in the defect, and fibrocartilaginous tissue is formed[37,38].

Arthroscopic treatment has shown encouraging results at intermediate follow-up[35,36,38,39]. Most studies report significant improvement in clinical outcome

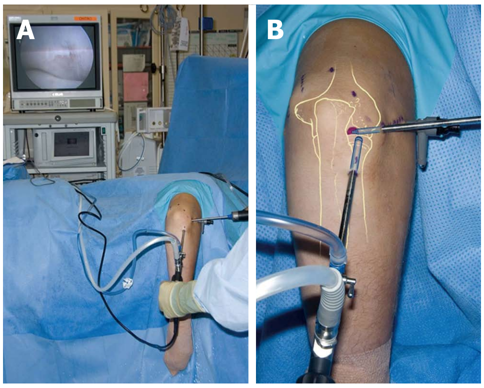

Figure 5 Patient positioning for arthroscopy of a right elbow (A and B). The patient is in the lateral decubitus position and the arm rests on a support.

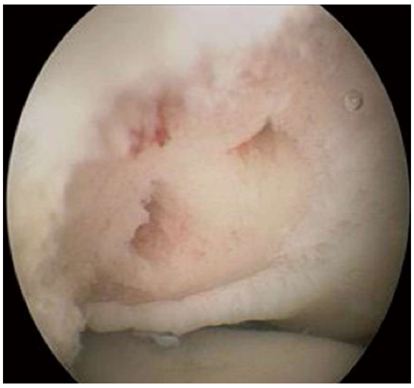

Figure 6 Arthroscopic picture showing an osteochondritis dissecans lesion after debridement and microfracturing.

scores up to 9 years of follow-up[35,36,38-40]. Approximately 80% to 90% of patients return to sports. Time to return to sports varies from 1 to 5 mo[41-43]. Complications of elbow arthroscopy are seen in 7% to 14% of cases[44,45]. Most complications are minor, *e.g.*, superficial wound problems and transient nerve palsies not affecting clinical outcome. Major complications occur in 0.5% to 5% of cases (*e.g.*, deep infection, permanent nerve injury, or complications requiring additional anesthesia)[44,45].

Open surgical treatment

Refixation of the lesion can be indicated for large and (sub)acute osteochondral fragments[31,32,46]. Different fixation techniques are available, including metal and bioresorbable screws[31], pull-out wiring[32,47], and cortico-cancellous bone pegs from the iliac crest or olecranon process[3]. Cancellous bone can be additionally grafted into the defect to enhance union of the fragment[31,32].

In follow-up studies, the clinical success rate of refixation is approximately 80%[46-48]. Reossification is observed in 44% to 100% at follow-up[31,32,47]. An intact lateral wall of the capitellum appears to be important for fixation to be successful[48]. Complications have been observed in terms of intra-articular protrusion and loosening of screws[27].

After successful application in the knee and ankle[49], autologous osteochondral transplantation (or mosaic-plasty) has been used in repairing OCD lesions of the humeral capitellum. With this technique, cylindrical osteochondral grafts are harvested from a non-weight-bearing area at the proximal aspect of the lateral femoral condyle and transplanted to the elbow to resurface the capitellar OCD.

Several authors have evaluated the technique[30,33,50-52]. In a series of 10 patients, eight were completely pain free after a mean follow-up of 30 mo[51]. In a recent investigation of 33 patients who were allowed to begin throwing after 3 mo and to return to sports after 6 mo, 31 patients returned to a competitive level at which they had previously played after a mean of 7 mo[50]. Although the clinical outcomes are encouraging, the grafting technique implies damaging a healthy knee joint, possibly leading to donor-site morbidity. In a study that addressed the effect of the harvesting on donor knee function in young athletes, a time lag was evident in recovery between postoperative symptoms and muscle power at 3 mo[53]. However, harvesting osteochondral grafts did not exert adverse effects at 2 years after the procedure[53].

Osteochondral autograft transfer has the advantage of replacing the affected articular surface with hyaline cartilage, but is an invasive procedure with possible donor-site morbidity. Therefore, we recommend reserv-ing this method for revision cases after failed primary arthroscopic treatment.

Other open procedures in the literature include rib osteochondral autograft and capitellar correction osteotomy[54-56]. Rib autografting provided satisfactory results after a follow-up of 1 to 6 years for advanced OCD with extensive lesions ⩾ 15 mm and those affecting the lateral wall[55,56]. Closed-wedge osteotomy of the capitellum has been described to widen the radiohumeral joint space, reduce compression, and stimulate revascu-larization and remodeling of the area of the lesion in the capitellum[54]. Although almost all patients returned to full athletic activity, postoperative osteoarthritic changes and enlargement of the radial head occurred in all patients. Because of the few scientific data, the place of these experimental treatment methods is unclear until more evidence is available.

Postoperative rehabilitation

A physical therapist supervises the rehabilitation after surgery. Rehabilitation is aimed at reducing pain and swelling and restoring range of motion. The recovery after arthroscopic treatment is usually faster than after open surgery[3]. Active-assisted motion exercises are started within a couple of days after surgery. After arthroscopy, the range of motion is unrestricted as pain tolerates. For patients who were treated by mosaicplasty, flexion is restricted for the first 6 wk. Resistive exercises are begun at 8 wk after arthroscopic treatment and at 12 wk after open treatment. If the patient has no pain and normal range of motion, an interval throwing program is initiated before the patient returns to sports[3].

FUTURE DIRECTIONS

Investigations in the near future primarily should be focused on improvement of awareness and early recognition of OCD, since early intervention may prevent expansion of the lesion and future degeneration. Future studies should also aim for improvement of current treatment and development of new treatment modalities. Although outcomes of arthroscopic treatment are encouraging, larger, randomized, prospective trials are required[29]. Likewise, promising outcomes have been described following autologous osteochondral transplantation[50-52], but future studies should be performed with a longer follow-up time to evaluate intra-articular changes on the long term.

CONCLUSION

OCD of the elbow typically affects the humeral capitellum of adolescent throwing athletes and leads to pain on the lateral aspect of the joint. CT or MRI are indicated to confirm the diagnosis and to address stability of the lesion. Nonoperative treatment can be initiated for stable lesions. Arthroscopic surgery has become the standard primary surgical procedure for treatment of capitellar OCD. This minimally invasive approach shows good results, low risk of operative morbidity, and early recuperation postoperatively. Open surgery is indicated for more advanced cases or for those that failed previous operative treatment.

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World J Orthop 2016 February 18; 7(2): 109-116
ISSN 2218-5836 (online)
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MINIREVIEWS

Tumors of the spine

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Author contributions: Ciftdemir M wrote the manuscript, helped in literature review and making the tables, and checked the references; Kaya M, Selcuk E and Yalniz E performed the literature review and drafted the article; all authors approved the final version of the manuscript.

Conflict-of-interest statement: The authors declare that they have no conflict of interest related to the work.

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Received: May 12, 2015
Peer-review started: May 18, 2015
First decision: August 19, 2015
Revised: September 20, 2015
Accepted: November 13, 2015
Article in press: November 17, 2015
Published online: February 18, 2016

Abstract

Spine tumors comprise a small percentage of reasons for back pain and other symptoms originating in the spine. The majority of the tumors involving the spinal column are metastases of visceral organ cancers which are mostly seen in older patients. Primary musculoskeletal system sarcomas involving the spinal column are rare. Benign tumors and tumor-like lesions of the musculoskeletal system are mostly seen in young patients and often cause instability and canal compromise. Optimal diagnosis and treatment of spine tumors require a multidisciplinary approach and thorough knowledge of both spine surgery and musculoskeletal tumor surgery. Either primary or metastatic tumors involving the spine are demanding problems in terms of diagnosis and treatment. Spinal instability and neurological compromise are the main and critical problems in patients with tumors of the spinal column. In the past, only a few treatment options aiming short-term control were available for treatment of primary and metastatic spine tumors. Spine surgeons adapted their approach for spine tumors according to orthopaedic oncologic principles in the last 20 years. Advances in imaging, surgical techniques and implant technology resulted in better diagnosis and surgical treatment options, especially for primary tumors. Also, modern chemotherapy drugs and regimens with new radiotherapy and radiosurgery options caused moderate to long-term local and systemic control for even primary sarcomas involving the spinal column.

Key words: Spinal column; Sarcoma; Metastasis; Spinal neoplasms; Palliative surgery

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Core tip: Primary tumors involving the spine are rare, while spinal column metastases are present in up to 70% of cancer patients. Both primary and metastatic tumors of the spine are often asymptomatic or have non-specific symptoms because in spine tumors, delayed diagnosis is not very unusual. Goal of treatment in spinal column metastases is to optimize the patient's quality of life by providing effective pain relief and preserving or restoring neurological functions. Treatment strategy for primary tumors should be planned after both oncological and surgical staging. Because of that, biopsy is a very important step in primary tumors. Surgery in metastatic

tumors are mostly palliative, aiming short-term control. Primary benign and malignant lesions mainly cause canal compromise and are treated surgically according to oncological staging and Weinstein-Boriani-Biagini classification.

Ciftdemir M, Kaya M, Selcuk E, Yalniz E. Tumors of the spine. *World J Orthop* 2016; 7(2): 109-116 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/109.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.109

INTRODUCTION

Spine tumors are examined under two subtitles called primary tumors which originate from the spine itself and its adjacent structures and secondary (metastatic) tumors of distant organs which spread hematogenously and lymphatically and are located in the spine and its surrounding tissues. As the spine is well vascularized and has close relationship with regional lymphatic and venous drainage systems (especially Batson's venous plexus), it is generally susceptible to metastasis. Metastatic tumors are most common (97%) tumors of the spine[1]. It is known that the adenocarcinomas which mostly originate from the lung, breast, prostate, kidney, gastrointestinal tract and thyroid tend to metastasize especially to the spine[2]. It was found that the percentage of cancer patients who have had bone metastasis before death is between 50% and 70%, and especially in case of breast cancer this percentage rose up to 85%. Up to 10% of patients who have symptomatic spine metastases can be treated by surgery[3]. The most common (70%) sites for spine metastasis are thoracic and thoracolumbar spine, and lumbar spine and sacrum have more than 20% of metastatic lesions. Cervical spine is a less frequent metastasis site[1].

As primary tumors of the spine are rare and most of these lesions are asymptomatic, their real incidence is unknown. It is estimated that the incidence of hemangiomas and enostoses, which were accepted as the most common primary tumors of the spine, is between 11% and 14%. This ratio has been found to be dependent on lesions which have been detected incidentally in performing diagnostic procedures for another reasons. Proper diagnosis of these asymptomatic lesions which are seen in the spine very common and do not require treatment will prevent the performance of unnecessary diagnostic procedures[3]. Except some primary tumors (osteoblastoma, chordoma) which tend to effect especially the spine, tumors originate from the skeleton system itself are not seen in the spine frequently. Differential diagnosis of primary tumors of the spine from especially spinal infections is extremely important. Primary malignant tumors of the spine is the rarest tumor type in the spine. In all bone and soft tissue sarcomas, only 10% of them are related with the spine[4].

Clinical features

Patients with spine tumors have medical histories and physical examination findings which are not directly associated with current disease. However, these findings need to be perfectly understood and evaluated in order to give some clues about the disease to the physician. In patients with spine tumors, the most common and leading symptom is pain[4]. As in almost all skeletal system tumors, the patients with spine tumors believe that their pain is relevant to a real or suspected traumatic event in the recent past. This condition sometimes indicates a pathological fracture which occurs by collapsing of the vertebral body due to a current destruction as a result of a minor trauma. The pain that slowly starts, gradually increases, is usually persistent at night and eventually disturbs the patient even at rest is considered the most typical sign for spine tumors. An acute pain that starts without any trauma in a patient without any previous symptom should also be considered a pathological fracture. Pain in spinal tumors can occur as a result of many reasons. Generally a tumor that grows inside the vertebral body with expansion causes bone remodalization and thinning of the cortex at first, then causes pathologic fracture and invasion of paravertebral structures. At the beginning of disease the main source of pain is stretched periosteum as a result of cortical expansion. After the development of the fracture, pain due to neural compression, neurological deficits and instability comes foreground[3]. Waist and back pain is commonly seen in the population. However, most patients with spine tumors have local tenderness which is a sign that was not observed in other non-traumatic spine problems. Benign tumors in children can sometimes appear as secondary scoliosis or torticollis due to pain. In the case of pathological fracture, kyphotic posture may be seen.

In patients with spine tumors, radicular signs are also frequent. Radicular signs could also be as a result of invasion or compression of the nerve root by the tumor itself, and sometimes pathologic fractures could make root irritation. In patients who developed a neurological deficit, it is important to evaluate the processes associated with the development of this deficit[4]. There is a major difference in terms of prognosis and behavior of the tumor between a patient with a sudden onset of paraparesia and paraplegia who previously had pain and a patient who developed a neurological deficit in months.

Another important point about evaluating patients with spine tumors is the patient's age. Metastatic tumors, which are the most common tumors of the spine, and hematological malignancies are usually seen after 50 years of age.

In cases under the age of 18, usually benign primary bone tumors such as hemangiomas, eosinophilic granuloma, osteoid osteoma, osteoblastoma, aneurysmal bone cyst and giant cell tumor should be considered in the foreground[3,5]. The most common malignant

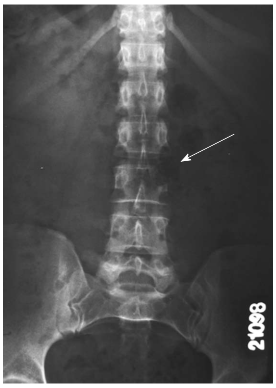

Figure 1 The (absent) pedicle sign known as the winking owl sign (arrow). A reliable sign of osteolytic spinal metastases on antero-posterior radiographs is loss of the normal pedicle contour.

tumors in young patients are osteosarcoma and Ewing's sarcoma[3].

When evaluating patients with spine tumors, the current and potential cancer and carcinogen contact history must be investigated. There are reports about cases who had spine metastases years after successful cancer treatment[3]. It must be kept in mind that benign musculoskeletal lesions in any part of the body may cause spine metastasis after malignant or sarcomatous transformation[6]. Especially history of mammographic examination in female patients over 40 years of age, and the smoking history in male patients must be questioned[4].

Diagnostic procedures

Plain radiographs must always take the first line in imaging for spinal diseases. In patients with suspected spine tumors, other parts of the spine and pelvis must be screened in addition to the plain radiographs of the suspected region. Plain radiographs can help to identify nearly 80% of the benign tumors that have a more specific appearance and some of malignant tumors and metastatic lesions[1]. Plain radiographic findings are present in 40% of patients with spine metastasis. At least 50% loss of the trabecular bone is required for a destructive spine lesion to be visualised on plain radiographs[4]. In many hematological malignancies, plain radiographic findings may not be seen until the advanced stages of disease. Plain radiographic characteristics of metastatic lesions can be osteoblastic, osteolytic or mixed. Spine metastases of prostate and breast carcinomas are generally osteoblastic or mixed-type lesions, but lung and thyroid carcinomas as well as renal cell carcinoma are usually in the form of lytic metastatic lesions[3].

Radiopaque lesions which extend outside of the rectangle that draws the boundaries of the vertebral body generally indicate primary malignant lesions of the spine like osteosarcoma or chondrosarcoma. Radiographic sign known as "winking owl sign" can be defined as a faint shadow obscuring the visibility of one pedicle on anteroposterior radiograph, indicates extending of the tumor mass from vertebral body to paraspinal area (Figure 1). Winking owl sign is generally accepted as the earliest direct radiographic sign of a metastatic lesion. Another plain radiographic finding for spine tumors is presence of one or more lytic lesions. Lytic lesions indicate bone destruction. However, destruction pattern gives information about nature of the tumor in the spine as well as in all bone tumors. Geographical destruction suggests that tumor is slowly progressive, moth-eaten lesions suggest that tumor grows faster, and permeative destruction suggests that tumor is very rapidly progressive[5]. Another plain radiographic finding is collapse of the vertebral body that can be called compression fracture. It is not easy to distinguish pathological compression fractures from benign osteoporotic ones. Bone scintigraphy is the most helpful diagnostic procedure in cases whose plain radiographs are negative or suspicious[4]. Bone scintigraphy is a diagnostic procedure performed by radioisotopes. Even though bone scintigraphy has a low specifity except in some tumors such as osteoid osteoma, it is a useful tool for diagnosis because of its high sensitivity and the ability to scan the entire body that is not found in other diagnostic tools. It is also useful in terms of recognizing the primary disease in metastatic tumors which have unknown primary origins and guiding biopsy.

Computed tomography (CT) is the most advantageous method in examination of mineralized tissues. Even complex anatomical structures like the spine could be evaluated by CT, which is superior to plain radiographs with regards to its ability of 3 plane examinaton. However, poor affinity and efficacy of CT in soft tissue lesions are disadvantages of this method .

Magnetic resonance imaging (MRI) is superior to all diagnostic procedures in spine tumors, especially in the evaluation of bone marrow and spinal canal, relationship of the tumor with neurovascular structures and tumor vascularity. In patients with spinal canal involvement, MRI is a useful technique for scanning the adjacent levels with wide, cross-sectional sagittal images. In 10% of spine metastases with spinal canal involvement, neurological compromise in adjacent or distant levels has been shown[3]. An important point about the MRI is its ability to differentiate osteoporotic compression fractures and pathological spinal fractures. Although there is no consensus so far, pathological fractures show low signal intensity on T1-weighted sequences and high signal intensity on T2-weighted sequences, but osteoporotic compressions show low signal intensity in both sequences. However, this finding is not valid for acute osteoporotic fractures. Osteoporotic compression fractures in the acute state (3-6 wk after the fracture) will be able to show low signal intensity on T1-weighted sequences and high signal intensity on T2-weighted sequences due to oedema and congestion within the trabecular bone. In such cases, the bone marrow signal pattern should be evaluated. Gadolinium contrast enhanced MRI can also distinguish intra and extra-dural tumors and also intra and extra-medullary tumors[7].

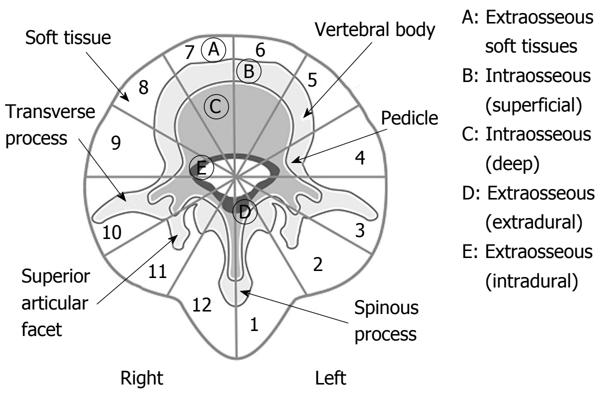

Figure 2 The Weinstein-Boriani-Biagini surgical staging system[13]. In this classification, the spine is radially divided into 12 equal radial segments (clock-face) in axial plane and examined in 5 layers from superficial to deep plane. Adapted with permission from Spine 1997; 22(9):1036-1044.

In spine tumors, especially those with unknown primary origin, biopsy is the latest and the most crucial step of the diagnostic process. Before planning the biopsy, all diagnostic tools should be used in a rational manner and precise localization of the lesion should be determined[8]. Biopsy in spine tumors can be performed as fine needle aspiration, tru-cut biopsy, incisional or excisional biopsy. Fine needle biopsy and tru-cut biopsy are percutaneously applied procedures. It should be kept in mind that biopsy tract is contaminated by tumor cells, and biopsies must be performed far from the neurovascular structures by small incisions which could then be removed with tumor mass in definitive surgical procedure.

Staging

In orthopedic oncologic surgery, where multidisciplinary approach is necessary, use of classifications that guide the treatment steps is inevitable[9]. The effective use of these classifications requires knowledge about the surgical margins in orthopedic oncologic surgery. Surgical treatment of bone tumors should be performed by targeting one of the four surgical margins[10]. In intra-lesional surgery, the tumor is removed in small pieces by destroying the anatomical structure and integrity of tumor. This type of surgery is usually performed in benign tumors, because it is not possible to obtain a clean surgical margin by this method. In marginal resection, the tumor is removed *en bloc* but, even in a small area of its surface, it is covered by the capsule or pseudo-capsule. In wide resection, the tumor is removed *en bloc* entirely enwrapped by a continious layer of normal tissue. Finally, in the radical resection, the tumor is removed *en bloc* with the entire anatomical compartments of origin bounded by its natural barriers such as the disc, fascia, cortex and end plate[11].

Enneking classification has been used for the classification of benign and malignant tumors of the musculoskeletal system for over 25 years[12]. In Enneking classification, benign tumors are indicated with arabic numbers (1, 2, 3) according to the nature of tumor and its histopathological grade. Benign tumors are classified as inactive (latent), active and aggressive. Malignant tumors are indicated with Roman numbers (Ⅰ, Ⅱ, Ⅲ) according to histopathological grade, localization and the relationship of tumor with natural barriers and whether the tumor metastasizes or not[12]. However, Enneking classification in treatment of spine tumors has been found to be insufficient for surgical planning over time. Because of that, in 1997, Boriani *et al*[13] have published a study about the new terminology and surgical staging for primary tumors of the spine. The authors stated a new classification system known as Weinstein-Boriani-Biagini classification, which is still actively in use today. In this classification, the spine is radially divided into 12 equal radial segments (clock-face) in axial plane and examined in 5 layers from superficial to deep plane (Figure 2).

In 2005, Tokuhashi *et al*[14] have published a study about preoperative prognostic classification for patients with spine metastases. The classification system was based on general condition of the patient, extraspinal bone metastases, number of metastatic foci in the spine, major visceral metastases, primary cancer focus (origin) and the patient's neurological status. The authors have stated that the patients with a Tokuhashi score between 12 and 15 points have a life expectancy more than 1 year and this patient group should be treated by tumor excision. The patients with a Tokuhashi score between 9 and 11 points have a life expectancy more than 6 mo, and patients in this group with single level spine metastasis but without major internal organ (visceral) metastases should be treated by tumor excision, while the rest should be treated by palliative surgery. The patients with a Tokuhashi score less than 8 points have a life expectancy less than 6 mo, and these patients should be treated by palliative surgery or conservative treatment[14].

Tomita *et al*[15] have published a classification regarding surgical strategy in spinal metastases in 2001. According to this classification, patient evaluation was based on 3 prognostic factors: Histopathologic grade of primary tumor, visceral metastasis to vital organs (the lungs, liver, kidneys and brain) and bone metastases including spine metastases (Table 1). Spine metastases were also evaluated in 7 types (Figure 3). As long-term regional control could be provided, the patients whose score is 2-3 points from Tomita classification are suggested to be treated by total *en bloc* spondylectomy which means marginal or wide resection; as medium-term regional control could be provided, the patients whose score is 4-5 points are suggested to be treated by marginal resection or intralesional treatment (total *en bloc* spondylectomy or curettage); as they are appropriate for short-term palliation, the patients whose score is 6-7 points are suggested to be treated by palliative surgery like spinal canal decompression and stabilization; the patients whose score is 8 and above points are suggested to be treated by conservative support treatment instead of surgical treatment with the

Table 1 Surgical strategy for spinal metastases

Point	Scoring system			Prognostic score	Treatment goal	Surgical strategy
	Prognostic factors					
	Primary tumor	Visceral metastases	Bone metastases[1]			
1	Slow growth (breast, thyroid, *etc.*)		Solitary or isolated	2	Long-term local control	Wide or marginal excision
				3		
2	Moderate growth (kidney, uterus, *etc.*)	Treatable	Multiple	4	Middle-term local control	Marginal or intralesonal excision
				5		
4	Rapid growth (lung, stomach, *etc.*)	Untreatable		6	Short-term palliation	Palliative surgery
				7		
				8	Terminal care	Supportive care
				9		
				10		

No visceral metastases = 0 points; [1]Bone metastases: Including spinal metastases.

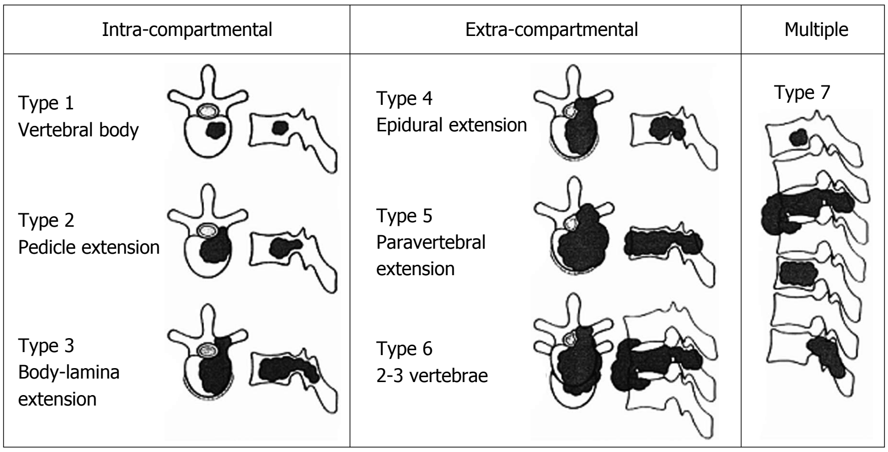

Figure 3 Schematic diagram of surgical classification of spinal tumors according to Tomita *et al*[15]. Adapted with permission from Spine 2001; 26(3): 298-306.

idea that they are at the terminal stage.

Surgical treatment

In spine tumors, main goal of surgical treatment is local control for local disease and at least one year survival for spine metastases. Surgery is the best treatment option for the pain and neurological symptoms caused by spinal instability. Spinal instability, vertebral collapse with or without any neurological deficit, radiotherapy resistant tumors, intolerable pain unresponsive to conventional therapy and neurological deficit before, during or after the radiotherapy are the indications for surgery[7]. General principals for spine tumor surgery are decompression of tumor compression to the spinal cord, establishing a tumor-free solid spine and performing the surgery with minimal morbidity.

Surgical modalities in metastatic spine tumors are palliative interventions including posterior decompression of spinal canal with posterior instrumentation, restoring the bone loss of the vertebral body with cement augmentation techniques (vertebroplasty/kyphoplasty), and total spondylectomy with anterior and posterior stabilization[15]. In primary tumors of the spine, total/partial laminectomy, total/partial vertebral body resection, piece-meal resection and curettage, in addition to the surgical procedures described above, can be used.

Total spondylectomy or vertebrectomy, which is the wide resection procedure for spine tumors, can be performed in 1 or 2 stage operation. In 2 stage total spondylectomy, initially posterior instrumentation is applied and total laminectomy *via* bilateral pedicle section is done. After that, the patient is turned in supine position and vertebral body removal is performed *via* an anterior approach. In total spondylectomy, segmentary nerve roots and vessels are ligated and sectioned as well as caudal and cranial discs. After vertebral body removal, anterior defect must be reconstructed[13]. One stage total *en bloc* spondylectomy was introduced by Tomita *et al*[16]. In this procedure, removal of vertebral body is performed through a posterior approach after blunt dissection of vertebral body from surrounding structures and large vessels that lie at the anterior of the spinal column[16] (Table 2).

Radical resection is not easy in spine tumors. According to surgical oncologic principles, total removal of involved level vertebral body as well as that level of dural sac, spinal cord and spinal nerves have to be sectioned[13]. Even though this procedure is extremely morbid, it is rarely used as a salvage procedure[7].

Primary benign spinal tumors

Osteoid osteoma, osteoblastoma, osteochondroma,

Table 2 Tokuhashi classification[14]

Characteristic	Score
General condition (performance status)	
Poor (10%-40%)	0
Moderate (50%-70%)	1
Good (80%-100%)	2
No. of extraspinal bone metastasis foci	
≥ 3	0
1-2	1
0	2
No. of extraspinal metastasis foci in the vertebral body	
≥ 3	0
1-2	1
0	2
Metastases to the major internal organs	
Unremovable	0
Removable	1
No metastases	2
Primary site of the cancer	
Lung, osteosarcoma, stomach, bladder, esophagus, pancreas	0
Liver, gallbladder, unidentified	1
Others	2
Kidney, uterus	3
Rectum	4
Thyroid, breast, prostate, carcinoid tumor	5
Palsy	
Complete (Frankel A, B)	0
Incomplete (Frankel C, D)	1
None (Frankel E)	2

Criteria of predicted prognosis: Total score (TS) 0-8: < 6 mo; TS 9-11: ≥ 6 mo; TS 12-15: ≥ 1 year.

giant cell tumor of the bone, aneurysmal bone cyst, eosinophilic granuloma and neurofibroma are the most common primary benign spine tumors. Primary benign tumors of the spine are more common than primary malignant ones. Benign aggresive tumors, such as giant cell tumor of the bone, osteoblastoma and aneurysmal bone cyst, tend to relapse. Because of that, surgical treatment of these tumors must include local adjuvant agents with marginal resection[17].

Osteochondromas as they are mostly seen in the other benign tumors of the spine, originate from posterior elements and become symptomatic by spinal canal compromise or nerve root compression. One should not forget that, if the cartilage cap of the osteochondroma is not completely removed, the tumor can recur[18].

Osteoid osteoma is a frequent primary benign spinal tumor. Osteoid osteoma is commonly seen in adolescents and young adults with painful secondary scoliosis and pain that worsens at night and is relieved by non-steroidal anti inflammatory agents, especially acetyl-salicylate. Treatment of osteoid osteoma is based on removal or ablation of entire nidus. Symptoms dramatically disappear after treatment[19].

The most common site for osteoblastoma in the entire skeleton is the spinal column. Although histopatologically similar to osteoid osteoma, osteoblastoma has different clinical and radiological characteristics. Osteoblastomas mostly originate from posterior elements, as other benign tumors. In contrast to osteoid osteoma, osteoblastoma can grow into the spinal canal and may cause dural sac compression. Treatment of osteoblastomas consists of intralesional excision or marginal resection according to histopatological grade. Postoperative radiotherapy may be feasible in terms of local control in some cases[20].

Hemangioma is the most frequent benign tumor involving the spinal column. Typically hemangiomas involve vertebral body and they are usually asymptomatic lesions. According to autopsy findings, hemangiomas are seen in 10% of the general population[3]. Even though hemangiomas are asymptomatic, they may cause pathological fractures. Also, hemangiomas can cause symptoms in the 3rd trimester of pregnancy.

Aneurysmal bone cysts (ABC) are commonly seen in the posterior elements of the spinal column in patients under the age of 20. ABC have a tendency to involve more than one segment. ABC are continuously growing and expanding active or aggresive (stage 2-3) lesions. Treatment of ABC consists of embolization or wide resection after embolization. ABC have an overall recurrence rate of 25%[21].

Giant cell bone tumor (GCT) is commonly seen in the sacrum more than other parts of the spinal column. It is difficult to obtain clean surgical margins in the surgical treatment of GCTs because of their localization within the vertebral body. Surgical margins should aim wide resection, because piece-meal removal is associated with a recurrence rate of 50% in surgical treatment of GCT. Postoperative radiotherapy for local control is controversial because of high risk of sarcomatous transformation. This transformation is generally to secondary osteosarcoma. Even though GCT is a benign tumor, it is capable of lung metastasis.

Eosinophilic granuloma is a benign tumor which is more often seen in children and adolescents. Eosinophilic granuloma generally causes uniform, rapid flattening of the vertebral body. Radiological apperance of this type of vertebral body involvement is called vertebra plana[3]. Always it heals spontaneously. Classical treatment is observation and bracing in some cases to prevent development of kyphosis.

Primary musculoskeletal system sarcomas in spine

Three types of major primary musculoskeletal system sarcomas that are mostly seen in the spinal column are osteosarcoma, Ewing's sarcoma and chondrosarcoma. These tumors can be seen in any part of the entire spinal column. Osteosarcoma and Ewing' sarcoma are more often seen in children and adolescents but chondrosarcomas are more often seen in adults and older individuals[22].

Ewing's sarcoma is more frequent in patients between the age of 5 and 20. Because of the inflammatory characteristics of Ewing's sarcoma, this tumor may be misdiagnosed as infection and diagnosis can be delayed[1]. Swelling, local tenderness, fever and increase in sedimentation rate are the significant characteristics of patients with Ewing's sarcoma. Spinal column involvement is seen in only 5% of patients with Ewing's sarcoma. In patients with axial skeleton involvement, Ewing's sarcoma is most commonly seen in the pelvis. In contrast to long bones in which periosteal reaction and permeative destruction are predominant, lytic lesions associated with soft tissue masses in the vertebral body is the main radiological finding of spine involvement of Ewing's sarcoma. Preservation of contiguous discs help to distinguish Ewing's sarcoma from spondylodiscitis. In pediatric spinal infections, disease generally starts from disc space and extends to vertebral end plates, but in Ewing's sarcoma involvement starts from the core trabecular bone of the vertebral body, and endplate involvement may be seen in late phase of the tumor invasion[7]. Because of high cellularity of the tumor tissue, Ewing's sarcomas located in extremities and the spine respond well to chemotherapy. Wide resection with clear surgical margins is possible after neo-adjuvant chemotherapy in Ewing's sarcoma. Postoperative radiotherapy should be given in cases with contaminated surgical margins[5].

Even though osteosarcoma is the most commonly seen primary malignant tumor of bone, spinal involvement is rare. Approximately 2% of all osteosarcomas originate from the spine. Classic osteosarcoma is most commonly seen in the second decade of life. Occasionally, osteosarcoma may have its second peak incidence in the 6th decade of life as secondary osteosarcomas which arise from sarcomatous transformation of presarcomatous lesions such as Paget's disease of bone and fibrous dysplasia[3]. Paget's osteosarcomas more commonly occur in the spine and pelvis. Treatment of osteosarcomas involving the spinal column is similar to that for extermity osteosarcomas. Treatment of osteosarcoma has evolved in the last 40 years. Before 1970s, 5-year-survival rate was 10% for osteosarcomas, with 70%-80% of the patients surviving with no evidence of disease today. Current treatment of osteosarcoma consists of 2 episodes of neoadjuvant chemotherapy followed by wide or radical resection and at least 4 more chemotherapy episodes. Tumor response to chemotherapy is important for prognosis[3,5].

Chondrosarcomas are more common than the other primary sarcomas in the spine. As a result of highly avascular characteristics of cartilage tissue, chondrosarcoma is unresponsive to chemotherapy and radiotherapy so that main determinative for prognosis is surgical treatment with wide or radical surgical margins[3]. In surgical treatment main target should address radical resection.

Chordoma does not originate from the musculoskeletal system, and this tumor arises from remnants of the notochordal cells. Even though it is not a primary skeletal tumor, chordoma involves the spinal column and affects mainly the sacrum and lower lumbar vertebrae with its destructive behaviour. Chordoma is one of the most common tumors of the sacrum. While 60% of chordomas arise in the sacrum, 25% are seen at the skull base and the remaining 15% seen in the rest of the axial skeleton[23]. Chordomas are generally seen in the midline and caudal half of the sacrum (S3 and more caudal levels). Constipation, coccygodynia, hemorrhoids and urinary incontinence are the most common symptoms. Half of the sacral chordomas are palpable in digital rectal examination. As an original soft tissue tumor, chordoma is best evaluated using MRI. Surgical margins have great importance in prognosis of chordoma, therefore especially in the treatment of sacral chordoma wide resection should be aimed.

CONCLUSION

Spinal column represents the major portion of the axial skeleton that supports vital organs. Metastatic tumors are the most frequent tumors that involve the spine. In terms of frequency, benign bone tumors follow the metastatic tumors and primary bone sarcomas are the least frequent tumors that involve the spine. Sometimes it is difficult to distinguish primary tumors from metastatic tumors in the spine. Metastatic tumors with unknown origin are also common in the spine. Knowledge about the primary lesion has critical importance in treatment protocol for metastatic tumors of the spine. Therefore, in primary unknown metastases, biopsy is an important step which affects the treatment modalities. It should be kept in mind that metastatic lesions that involve the spinal are a part of systemic malignancies. Surgical staging is important for determining treatment protocol. Treatment of metastatic tumors should aim pain relief with preservation of mechanical and neurological functions of the spine. In primary tumors treatment strategy should address removal of local disease while preserving the mechanical and neurological functions of the spine. As in all oncological surgery procedures, all diagnostic and interventional procedures in primary or metastatic tumors of the spine, as well as the general management of the patient should be performed in a multidisciplinary approach.

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P- Reviewer: Anand A, Robertson GA **S- Editor**: Qiu S
L- Editor: Wang TQ **E- Editor**: Liu SQ

World Journal of Orthopedics

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Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
DOI: 10.5312/wjo.v7.i2.117

World J Orthop 2016 February 18; 7(2): 117-122
ISSN 2218-5836 (online)
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ORIGINAL ARTICLE

Basic Study

Effect of elbow position on radiographic measurements of radio-capitellar alignment

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Author contributions: Sandman E, Canet F and Rouleau DM performed the majority of experiments and analysed the data; Sandman E and Canet F performed the radiographic investigations; Petit Y, Athwal GS and Rouleau DM participated equally in the design of the research; all the authors contributed to the drafting of the paper.

Supported by Fondation de Recherche et d'Éducation en Orthopédie de Montréal.

Institutional review board statement: Comité d'éthique de la recherche de l'HSCM, CÉR 2010-04-32. Each individual was asked to give informed consent.

Informed consent statement: Each individual was asked to give informed consent.

Conflict-of-interest statement: The authors declare no conflicts of interest regarding this manuscript.

Data sharing statement: No data were created so no data are available.

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Received: May 15, 2015
Peer-review started: May 15, 2015
First decision: September 29, 2015
Revised: November 18, 2015
Accepted: December 3, 2015
Article in press: December 4, 2015
Published online: February 18, 2016

Abstract

AIM: To evaluate the effect of different elbow and forearm positions on radiocapitellar alignment.

METHODS: Fifty-one healthy volunteers were recruited and bilateral elbow radiographs were taken to form a radiologic database. Lateral elbow radiographs were taken with the elbow in five different positions: Maximal extension and forearm in neutral, maximal flexion and forearm in neutral, elbow at 90° and forearm in neutral, elbow at 90° and forearm in supination and elbow at 90° and forearm in pronation. A goniometer was used to verify the accuracy of the elbow's position for the radiographs at a 90° angle. The radiocapitellar ratio (RCR) measurements were then taken on the collected radiographs using the SliceOmatic software. An orthopedic resident performed the radiographic measurements on the 102 elbows, for a total of 510 lateral elbow radiographic measures. ANOVA paired *t*-tests and Pearson coefficients were used to assess the differences and correlations between the RCR in each position.

RESULTS: Mean RCR values were -2% ± 7% (maximal extension), -5% ± 9% (maximal flexion), and for elbow at 90° and forearm in neutral -2% ± 5%, supination 1% ± 6% and pronation 1% ± 5%. ANOVA analyses demonstrated significant differences between the RCR in different elbow and forearm positions. Paired *t*-tests confirmed significant differences between the RCR at maximal flexion and flexion at 90°, and maximal extension and flexion. The Pearson coefficient showed significant correlations between the RCR with the elbow at 90° - maximal flexion; the forearm in neutral-supination; the forearm in neutral-pronation.

CONCLUSION: Overall, 95% of the RCR values are included in the normal range (obtained at 90° of flexion) and a value outside this range, in any position, should raise suspicion for instability.

Key words: Elbow subluxation; Radiocapitellar ratio; Elbow; Elbow dislocation

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Core tip: Assessing radial head alignment after injury and obtaining perfect lateral radiographs with the elbow at 90° and the forearm in neutral may be difficult. Therefore we designed this study to assess whether the radiocapitellar ratios (RCR) calculated from true lateral radiographs at different positions of elbow flexion and forearm pronosupination differ from those taken in 90° flexion and neutral position. The paper shows that the RCR measurement continues to be an overall valid and reliable method throughout different elbow and forearm positions. However, values in the negative range, > 5% regardless of forearm rotation, should raise suspicion for elbow instability.

Sandman E, Canet F, Petit Y, Laflamme GY, Athwal GS, Rouleau DM. Effect of elbow position on radiographic measurements of radio-capitellar alignment. *World J Orthop* 2016; 7(2): 117-122 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/117.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.117

INTRODUCTION

The elbow is a complex joint that is comprised of three articulations: The ulno-humeral, the radiocapitellar and the proximal radio-ulnar joints. The joint capsule and the ligamentous structures surrounding the elbow's congruent osseous articulations provide static stability while its adjacent muscles and tendons offer dynamic stability by aligning and compressing the joint surfaces together[1]. The components of elbow stability can be divided into primary and secondary stabilizers. The elbow's primary stabilizers consist of the anterior bundle of the medial collateral ligament, the lateral ulnar collateral ligament, and the ulnohumeral joint[2]. The secondary stabilizers involve the radial head, the joint capsule and the adjacent muscles surrounding the articulation. All of these structures function together to permit functional elbow flexion-extension and forearm pronation-supination ranges of motion (ROM). However, elbow stability and alignment can easily be disrupted after a trauma. In fact, the elbow is second only to the shoulder for the incidence of non-prosthetic joint dislocation[3].

The literature highlights the importance of evaluating a joint's integrity throughout its full arc of movement, as the stability of an articulation is a dynamic process. Assessing an articulation with a single radiologic view may lead to suboptimal diagnostics and treatments. Therefore, the evaluation of the radiocapitellar joint, which is known to contribute to elbow stability, would be an added resource. In their study of 80 healthy elbows, Rouleau *et al*[4] described a quantitative method to assess radiocapitellar joint translations, the radiocapitellar ratio (RCR), defined as the displacement of the radial head (minimal distance between the right bisector of the radial head and the center of the capitellum) divided by the diameter of the capitellum[4]. The mean normal RCR was 4% ± 4% (95%CI: -5% to 13%). It has been reported to have good inter- and intra-observer reliability when measured on a lateral radiograph with the elbow positioned at 90° of flexion with neutral forearm rotation. In a trauma setting, it may be difficult to obtain standardized lateral radiographs with the elbow flexed at 90° and the forearm in neutral rotation due to factors such as pain, swelling, or fractures[1], which may cause radiographs to be taken with the elbow and the forearm in different positions. The purpose of this study was to assess whether RCRs calculated from true lateral radiographs, at different positions of elbow flexion and forearm pronosupination, differ from those taken in 90° flexion and neutral position.

MATERIALS AND METHODS

Radiographs

Fifty-one healthy volunteers were recruited and bilateral elbow radiographs were taken to form a radiologic database. In this study, the volunteers included 31 females and 20 males, with an average age of 32 years old (SD = 9.0). The number of radiographs observed followed the guidelines of Harrison *et al*[5]. The inclusion criteria were: patients aged between 18-50 years old, and the absence of a preexisting elbow pathology in both upper extremities. The exclusion criteria consisted of: Elbows with preexisting abnormalities, such as arthrosis, fractures, surgical implants, *etc.*, and pregnant women or those at risk of being pregnant. Each individual was asked to give informed consent and protected with lead aprons. They were asked to actively move their elbow into the various positions, so that no passive maximal pressure was applied. Ninety degree elbow flexion was assured by measuring with a goniometer at the time of imaging and was reviewed during measurements on the computer software. Lateral elbow radiographs were taken with the elbow in five different positions: Maximal extension and forearm in neutral, maximal flexion and forearm in neutral, elbow at 90° and forearm in neutral, elbow at 90° and forearm in supination and elbow at

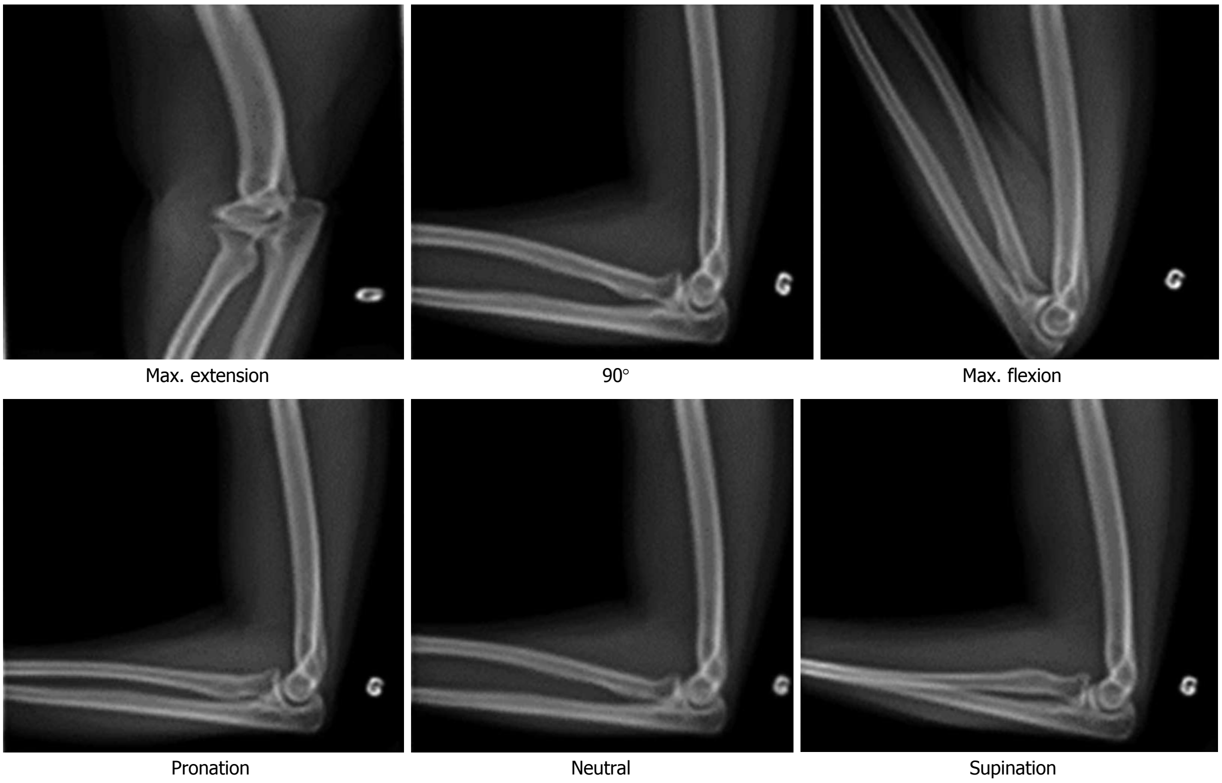

Figure 1 Different elbow and forearm positions evaluated.

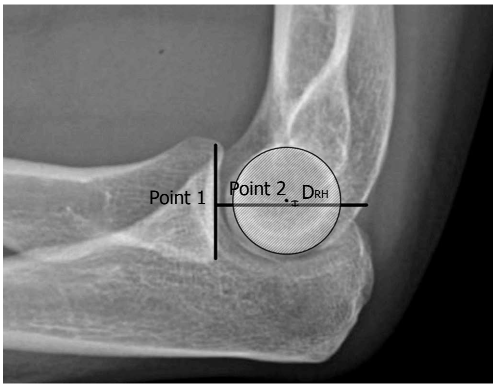

Figure 2 Method for radiocapitellar ratio measurement. (1): A line, perpendicular to the joint, was drawn at the center of the articular surface of the radial head (point 1); (2): The diameter of the capitellum (Ø capitellum) was measured; (3): The center of the capitellum was identified as the bisector of the capitellum's diameter (point 2); (4): The minimal distance between the center points of the radial head and the capitellum was measured (D_{RH}); (5): The RCR was calculated: RCR (%) = $D_{RH}/Ø_{capitellum}$. RCR: Radiocapitellar ratio.

90° and forearm in pronation (Figure 1). As described by London *et al*[6] a true lateral elbow radiograph was achieved when the trochlear sulcus, the capitellum and the medial trochlea were concentrically superimposed. The Institutional Review Board of the ethical committee approved this study.

Measurement method

The RCR method was used to measure the translation of the radial head on the capitellum, described in 5 steps[4], with SliceOmatic (Tomovision Inc, Magog, Quebec, Canada) software: (1) A line, perpendicular to the joint, was drawn at the center of the articular surface of the radial head (Figure 2, point 1); (2) The diameter of the capitellum (Ø capitellum) was measured; (3) The center of the capitellum was identified as the bisector of the capitellum's diameter (Figure 2); (4) The minimal distance between the center points of the radial head and the capitellum was measured (Figure 2); and (5) The Radial-Capitellum-Ratio was calculated: RCR (%) = $D_{RH}/Ø_{capitellum}$.

A positive RCR value indicates anterior radial head translation, while a negative RCR result signifies posterior radial head translation. An orthopedic resident (ES) performed the radiographic measurements on the 102 elbows, for a total of 510 lateral elbow radiographic measures. The intra-observer (0.72) and inter-observer reliability (0.52) of this method were previously reported using intraclass correlation tests[4]. The results obtained were compared to the normal RCR range, measured in the previous study by Rouleau *et al*[4] and described as a RCR value between -5% to 13%. In their study, the measurements were taken twice by two different observers and the mean normal RCR was 4% ± 4%, with the normal RCR range within a 95%CI.

Statistical analysis

ANOVA and paired *t* tests were used to assess the differences in RCR measurement results between the five different elbow and forearm positions, with a level of significance established at $P < 0.05$. Pearson coefficients were calculated to assess the correlation between the

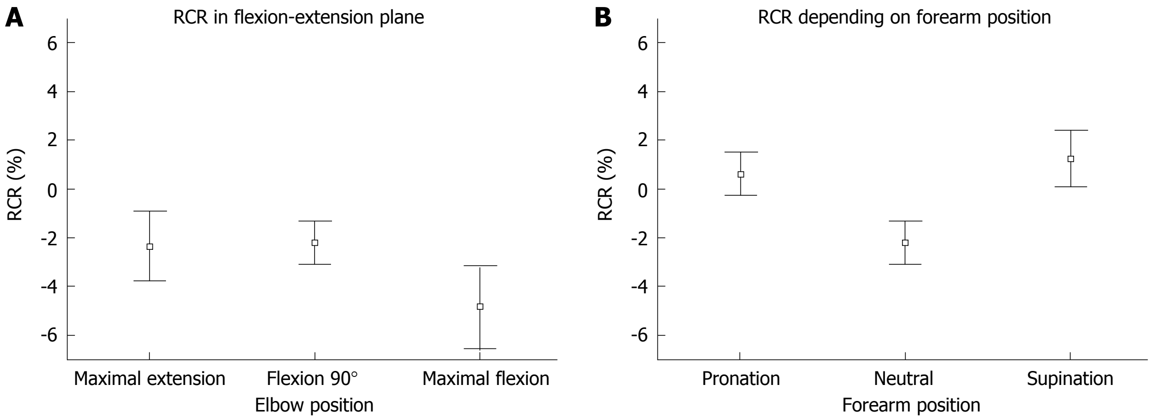

Figure 3 Mean radiocapitellar ratio and 95%CI for each elbow position (A) and prosupination movement (B). RCR: Radiocapitellar ratio.

Table 1 Paired *t*-tests for the different elbow and forearm positions

Paired *t*-test for elbow and forearm positions	*P*
Maximal elbow extension and maximal elbow flexion	0.034
Maximal elbow flexion and elbow flexion at 90°	0.003
Maximal elbow extension and elbow flexion at 90°	0.86
Forearm in neutral and forearm in pronation	0.001
Forearm in neutral and forearm in supination	0.001
Forearm in pronation and forearm in supination	0.28

RCR measurements in each different elbow and forearm position. Correlation coefficients (r) were considered small if $r = \pm 0.00$ to 0.09; medium if $r = \pm 0.10$ to 0.30; and strong if $r = \pm 0.50$ and 1.00[7]. According to the results of the mean and standard deviation, analyses of the power for the Pearson coefficients correlations were also calculated. Statistical review of the study was performed by a biomedical statistician.

RESULTS

The mean maximal flexion achieved by the 51 subjects was of 151° ± 5° and the mean maximal extension was of 12° ± 7°. The mean RCRs for each position were: elbow in maximal extension: -2% ± 7% (95%CI: -4% to -1%), elbow in maximal flexion: -5% ± 9% (95%CI: -6% to -3%), elbow at 90° and forearm in neutral: -2% ± 5% (95%CI: -3% to -1%), elbow at 90° and forearm in supination: 1% ± 6% 95%CI: 0% to 2%), and elbow at 90° and forearm in pronation: 1% ± 5% (95%CI: 0% to 2%) (Figure 3). According to the ANOVA results, a significant difference exists between the RCRs in different elbow positions ($P = 0.01$) and in different forearm positions ($P < 0.001$). Moreover, 95% of our cohort obtained RCR values between the normal ranges initially evaluated, with posterior translation of the radial head of 5% to anterior translation of 13%.

Paired *t* tests were used to accommodate the fact that these are non-independent events, and confirmed a significant difference between maximal elbow flexion and 90° of elbow flexion ($P = 0.003$), as well as for maximal elbow extension and maximal elbow flexion ($P = 0.034$) (Table 1). Additionally, the paired *t* test showed significant differences between the positions of the forearm in neutral and pronation ($P \leqslant 0.001$), as well as between the forearm in neutral and supination ($P < 0.001$). However, there was no significant difference between the positions of elbow flexion at 90° and maximal extension ($P = 0.86$), nor between the positions of the forearm in pronation and in supination ($P = 0.28$).

According to the Pearson coefficients, significant correlations exist between elbow flexion at 90° and in maximal flexion ($r = 0.19$, $P = 0.049$), the forearm in neutral and in supination ($r = 0.34$, $P < 0.001$), as well as the forearm in neutral and in pronation ($r = 0.42$, $P < 0.001$).

There was no significant correlation observed between the forearm positions in pronation and supination ($r = 0.37$, $P = 0.55$), the elbow positioned at 90° and in maximal extension ($r = 0.086$, $P = 0.39$) or between maximal elbow flexion and maximal elbow extension ($r = 0.085$, $P = 0.39$).

Post hoc power analyses of the Pearson coefficient correlations were done for the different elbow and forearm positions (Table 2). Significant power was only obtained when comparing maximal elbow flexion and maximal elbow extension ($\Pi = 0.84$). The power calculated for elbow flexion at 90° with the forearm in neutral and maximal elbow extension was $\Pi = 0.63$, and $\Pi = 0.05$ for elbow flexion at 90° with the forearm in neutral and maximal elbow flexion. When analyzing the power for the different forearm positions, significant results were obtained when comparing pronation and neutral, as well as between supination and neutral forearm positions, both with a power $\Pi = 0.99$. The power found for the correlation between supination and pronation forearm positions was 0.18.

DISCUSSION

Following upper extremity trauma, a complete evaluation of the elbow's primary and secondary stabilizers is necessary to avoid occult injuries and inappropriate treatments. The stability of an articulation can be

Table 2 Pearson coefficient correlation power analyses for the different elbow positions and forearm positions

	r	*P*	Power (Π)
Pearson coefficient correlation for the elbow			
Maximal extension and Maximal flexion	-0.0854	0.394	0.84
Maximal flexion and flexion at 90°	0.1948	0.050	0.05
Maximal extension and flexion at 90°	-0.0860	0.390	0.63
Pearson coefficient correlation for the forearm			
Neutral and pronation	0.42	0.001	0.99
Neutral and supination	0.34	0.001	0.99
Pronation and supination	0.37	0.55	0.18

determined clinically or with radiographic imaging. In the trauma setting, an elbow's clinical stability and complete ROM evaluation may be difficult due to associated injuries and pain. Perfect lateral radiologic views at 90° of flexion may also be difficult to obtain due to multiple factors. Cheung *et al*[8] described the importance of obtaining proper alignment on a lateral radiograph with the forearm in neutral, with views of both the elbow and the wrist. Moreover, it has been suggested in the literature that stability of the radial head, especially after reduction, should be evaluated throughout its full ROM under radiological imaging which is what would make the RCR value of interest.

When analyzing the results obtained with the paired *t*-tests, significant differences were found for the RCR measurements between maximal elbow flexion and elbow flexion at 90°; between maximal elbow flexion and maximal elbow extension; between neutral and pronation forearm positions; as well as between neutral and supination forearm positions. Thus, elbow and forearm positioning seem to substantially influence radiocapitellar alignment, because our results tend to demonstrate significant differences for most of the positions evaluated. Although these differences are statistically significant, further research is needed to evaluate if they are clinically important, as a RCR of 5% represents a small translation of the radial head (1.25 mm for a capitellum of 25 mm of diameter).

The RCR measurement method has previously been shown to be valid and reliable when evaluating translations of the radiocapitellar articulation, with the elbow at 90° and the forearm in neutral[4]. This study evaluated the RCR method in five different elbow and forearm positions. The different elbow positions seem to have a greater effect on the RCR measurement results, when compared to the different forearm ranges of motion. Nonetheless, 95% of our cohort obtained RCR values between the normal ranges initially evaluated from -5% to 13%[4]. To illustrate, this range corresponds, in a capitellum with a diameter of 25 mm, to a radiocapitellar translation of 1.25 mm posterior to 3.25 mm anterior, for a total average of 5 mm displacement. Thus, the RCR measurement continues to be an overall valid and reliable method throughout different elbow and forearm positions.

The main limitations of this study are that the radiographs were all taken with the radiological beam perpendicular to the elbow joint, to obtain a perfect lateral view. Further studies should be done to evaluate the effect of the radiological beam angle on the measurement of radial head displacement, since radiographs taken with mild misalignment or with the elbow slightly oblique might influence the measurements. Finally, an injured elbow may not be able to achieve the different elbow positions tested in the study, due to pain, swelling or altered mechanics. However, the positions were chosen to cover the entire range of motion of the elbow, as well as to maximize the differences on the RCR measurements.

To conclude, even if positioning is not ideal, if a true lateral radiograph of the elbow is taken, the RCR should fall within the normal range of -5% to 13% when the radiocapitellar joint is intact. The RCR measurement method is dependent on elbow (flexion-extension) and forearm (pronation-supination) positions. In both maximal elbow positions in flexion and extension, the measurements of the RCR have a higher standard deviation. In order to decrease its variability, we recommend, as a convention, measuring the RCR on lateral radiographs with the elbow at 90° and the forearm in any position (pronation, neutral or supination). In normal elbows, at 90° of flexion, the RCR measurement with the forearm in pronation and supination show a significant difference from the forearm in neutral, and move the RCR in a positive direction. Therefore values in the negative range, > 5% regardless of forearm rotation, should raise suspicion for instability. A clinical study on the prognosis value of RCR in the presence of acute elbow dislocation would further support its clinical utility[9].

COMMENTS

Background

The elbow is a complex joint that is comprised of three articulations and all of these structures function together to permit functional elbow flexion-extension and forearm pronation-supination ranges of motion (ROM). The literature highlights the importance of evaluating a joint's integrity throughout its full arc of movement, since the stability of an articulation is a dynamic process. However, elbow stability and alignment can easily be disrupted after a trauma and few reliable measurement methods are available. The radiocapitellar ratio (RCR) was described as a quantitative method to assess radiocapitellar joint translation on standardized lateral radiographs with the elbow flexed at 90° and the forearm in neutral rotation. However, it may be difficult in a trauma setting to obtain perfect lateral radiographs. Thus, it was of interest to assess whether the RCRs calculated from true lateral radiographs, at different positions of elbow flexion and forearm pronation-supination, differ from those taken in 90° flexion and neutral position.

Research frontiers

The authors aimed to evaluate the effect of different elbow and forearm positions on radiocapitellar alignment, using the RCR on fifty-one healthy volunteers. Bilateral elbow radiographs were taken with the elbow in five different positions to form a radiologic database to investigate if elbow position influenced the RCR.

Innovations and breakthroughs

This study demonstrate that even if positioning is not ideal, if a true lateral radiograph of the elbow is taken, the RCR should fall within the normal range of -5% to 13% when the radiocapitellar joint is intact. However, values in the negative range, > 5% regardless of forearm rotation, should raise suspicion for elbow instability or subluxation.

Applications
The authors believe that further studies should be done to evaluate the effect of the radiological beam angle on the measurement of radial head displacement, since radiographs taken with mild misalignment or with the elbow slightly oblique might influence the measurements.

Terminology
A quantitative method to assess radiocapitellar joint translations, the RCR, is defined as the displacement of the radial head (minimal distance between the right bisector of the radial head and the center of the capitellum) divided by the diameter of the capitellum. The mean normal RCR is 4% ± 4% (95%CI: -5% to 13%). It has been reported to have good inter- and intra-observer reliability when measured on a lateral radiograph with the elbow positioned at 90 degrees of flexion with neutral forearm rotation.

Peer-review
The authors concur with the literature with regard to the importance of obtaining proper alignment on a lateral radiograph with the forearm in neutral, with views of both the elbow and the wrist. Moreover, stability of the radial head, especially after reduction, should be evaluated throughout its full ROM under radiological imaging which is what would make the RCR value of interest. Therefore, this review article may have potential to increase knowledge to optimize diagnosis and treatment of elbow injuries.

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DOI: 10.5312/wjo.v7.i2.123

World J Orthop 2016 February 18; 7(2): 123-127
ISSN 2218-5836 (online)
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ORIGINAL ARTICLE

Prospective Study

Reverse-total shoulder arthroplasty cost-effectiveness: A quality-adjusted life years comparison with total hip arthroplasty

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Author contributions: Bachman D drafted the manuscript and performed data analysis; Nyland J participated in study design and edited the manuscript; Krupp R provided oversight to manuscript development, recruited patients, and collected data; all authors read and approved the final manuscript.

Institutional review board statement: This study was approved by the University of Louisville and Norton Healthcare Medical Institutional Review Boards (NHORA 12-No155).

Clinical trial registration statement: Data used in this study was obtained from clinical trial PS-901.

Informed consent statement: All study participants provided written consent prior to study enrollment.

Conflict-of-interest statement: Dr. Ryan Krupp has served as a past consultant for DJO Surgical previously receiving an honorarium for teaching and also for research support. Drs. Bachman and Nyland have no conflicts of interest to disclose.

Data sharing statement: There is no additional data available.

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Received: July 3, 2015
Peer-review started: July 9, 2015
First decision: September 30, 2015
Revised: October 10, 2015
Accepted: December 7, 2015
Article in press: December 8, 2015
Published online: February 18, 2016

Abstract

AIM: To compare reverse-total shoulder arthroplasty (RSA) cost-effectiveness with total hip arthroplasty cost-effectiveness.

METHODS: This study used a stochastic model and decision-making algorithm to compare the cost-effectiveness of RSA and total hip arthroplasty. Fifteen patients underwent pre-operative, and 3, 6, and 12 mo post-operative clinical examinations and Short Form-36 Health Survey completion. Short form-36 Health Survey subscale scores were converted to EuroQual Group Five Dimension Health Outcome scores and compared with historical data from age-matched patients who had undergone total hip arthroplasty. Quality-adjusted life year (QALY) improvements based on life expectancies were calculated.

RESULTS: The cost/QALY was $3900 for total hip arthroplasty and $11100 for RSA. After adjusting the model to only include shoulder-specific physical function subscale items, the RSA QALY improved to 2.8

years, and its cost/QALY decreased to $8100.

CONCLUSION: Based on industry accepted standards, cost/QALY estimates supported both RSA and total hip arthroplasty cost-effectiveness. Although total hip arthroplasty remains the quality of life improvement "gold standard" among arthroplasty procedures, cost/QALY estimates identified in this study support the growing use of RSA to improve patient quality of life.

Key words: Quality of life; Arthroplasty; Shoulder; Cost-analysis

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Core tip: Based on industry accepted standards, cost/quality-adjusted life year (QALY) estimates supported both reverse-total shoulder arthroplasty (RSA) and total hip arthroplasty cost-effectiveness. The cost/QALY estimates identified in this study support the growing use of RSA to improve patient quality of life.

Bachman D, Nyland J, Krupp R. Reverse-total shoulder arthroplasty cost-effectiveness: A quality-adjusted life years comparison with total hip arthroplasty. *World J Orthop* 2016; 7(2): 123-127 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/123.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.123

INTRODUCTION

The biomechanical advantage provided by improved deltoid muscle function following reverse-total shoulder arthroplasty (RSA) has led to its increased use for treating patients with massive rotator cuff tear arthropathy, severe shoulder fracture or gleno-humeral joint degeneration. Associated with this increased use is the need to better identify RSA cost-effectiveness with consideration for revision challenges[1], and its true utility in the context of diminishing healthcare financial resources[2]. History has demonstrated that total hip and knee arthroplasty use has progressively increased among patients with widely-ranging ages and diagnoses[3,4]. If patient outcomes prove comparable to these other arthroplasty procedures a similar evolution may develop for RSA.

The cost-effectiveness of RSA in terms of quality-adjusted life years (QALY) within the context of healthcare industry standards is currently unknown[5]. The purpose of this study was to compare RSA cost-effectiveness with total hip arthroplasty cost-effectiveness, widely considered to be the "gold standard" among arthroplasty procedures[6]. The study hypothesis was that both procedures would prove cost effective based on industry accepted standards of a $30000-50000 dollars United States/QALY[1-4]. Information such as this would provide vital insight into the true efficacy of RSA.

MATERIALS AND METHODS

Following University of Louisville and Norton Healthcare Medical Institutional Review Board approvals, 15 consecutive patients preparing to undergo RSA underwent pre-operative clinical examination by the same fellowship-trained shoulder surgeon. All patients had severe rotator cuff arthropathy. Given the lack of functional rotator cuff tissue an RSA was selected rather than a standard total shoulder arthroplasty. By reversing humeral head and glenoid component locations, RSA increased deltoid muscle mechanical efficiency during shoulder elevation and improved joint stability. All patients received a Donjoy Orthopaedic Reverse Shoulder Prosthesis (DJO, Vista, CA, United States). Patients also completed the short form-36 Health Survey subscales [physical function (PF), role physical (RP), role emotional (RE), bodily pain (BP), general health (GH), vitality (VT), mental health (MH), and social function (SF)]. Clinical examination and short form-36 surveys were repeated at 3-mo, 6-mo, and at 1-year post-surgery. By the end of the first post-operative year all patients were satisfied with the RSA procedure and had met their pain reduction and functional restoration expectations. These data were compared with the findings of Mangione *et al*[7] who studied 224 patients of similar age following total hip arthroplasty over the same follow-up time intervals, also collecting 0-100 point scale short form-36 survey data. Short form-36 subscale data from both studies was converted to EuroQual Group Five Dimension Health Outcome Scores using previously reported methods[8] and the following formula ($\alpha \times$ PF + $\beta \times$ RP + $\gamma \times$ RE + $\delta \times$ BP + $\varepsilon \times$ GH + $\zeta \times$ VT + $\eta \times$ MH + $\theta \times$ SF). In this formula the Greek letters signify constants from an accepted conversion algorithm[8]. Short form-36 physical function subscale score values for each follow-up time period were converted to QALY values[8]. Baseline values were then subtracted from follow-up QALY scores to identify condition improvements over time (1, 6 and 12 mo). This accounted for the entire first post-surgical year. For study purposes a 12 mo follow-up period was considered representative of peak quality of life improvement following arthroplasty[9,10].

A stochastic model and decision making algorithm[11,12] (Figure 1) incorporated revision rates[13,14] and a standard annual general health reduction to incrementally estimate QALY changes from baseline for each arthroplasty procedure simulating aging over the course of life expectancy[12]. The expected revision rate for each procedure (revisions/patient years followed) was applied to the stochastic model (Ω1, Ω2). Patient revisions/patient years was determined by taking the estimated number of procedural revisions divided by the number of patient follow-up years for total hip[13] and RSA[14]. For the duration of stochastic model application, for a projected revision, then the remainder of projected quality of life was considered to be only 50% improved from baseline state. If the patient required revision surgery 50% of their QALY potential was decreased

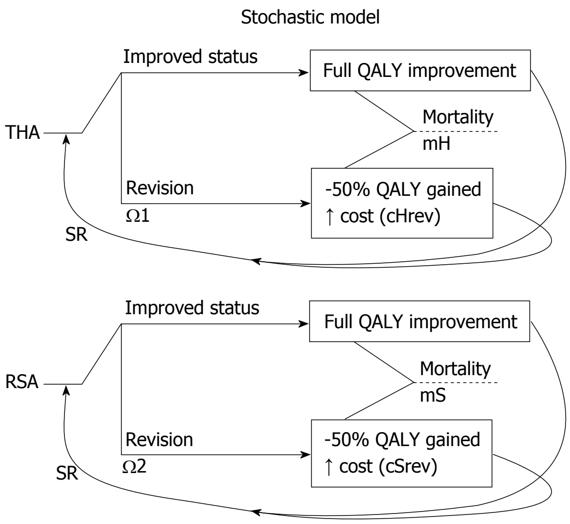

Figure 1 Stochastic model and decision-making algorithm. RSA: Reverse-total shoulder arthroplasty; QALY: Quality-adjusted life year; THA: Total hip arthroplasty; SR: Standard reduction in quality of life.

from that point forward[15]. A 3% annual general health decline representative of aging was also added to the model[16]. Annual quality of life improvement represented the previous year's quality of life improvement over baseline minus revision rate and standard general health reduction (3%). Collective quality of life improvement over baseline values were summed for the years of projected life for each arthroplasty group. This represented the QALY associated with each arthroplasty procedure.

Stochastic model variable definitions are provided in Table 1. Pre- (Hpreop, Rpreop) and post-operative (Ipostop) costs for each arthroplasty method including implant costs and hospital associated direct costs were determined using previously reported data[9] and data obtained from the hospital where the surgical procedure was performed. The same preoperative assessments were assumed for both arthroplasty surgical groups[9]. The average cost of a revision (Hrev or Rrev) was calculated by summing the non-implant related surgical and hospital costs (Hsurg or Rsurg), and the cost of the revised implant components (Hrevimplant or Rrevimplant), based on historical data[13,14] and post-operative cost estimates[15]. Revision costs calculated by the model represented the proportion of patients expected to undergo a revision multiplied by the average cost of a revision (either Hrev or Rrev). Revision expenses were then added to the primary cost. Cost per QALY were then calculated for each procedure.

Further evaluation was performed to determine the influence of short form-36 Health Survey subscale scores on the QALY of patients following total hip arthroplasty and RSA. Similar to the report of March *et al*[17], pain, physical function, and role-physical subscale scores displayed the greatest influence on QALY score improvement following either surgical procedure. The strongest single influence on QALY score improvement for both total hip arthroplasty and RSA was the physical function subscale. Focused attention to this subscale revealed that of 10 total items, nine related more specifically to ambulation while only three related more specifically to shoulder function. These included item 3a moderate activities such as moving a table, pushing a vacuum cleaner, bowling, or playing golf; item 3c lifting or carrying groceries; and item 3j bathing or dressing yourself[18]. The stochastic model was used to calculate QALY using both aggregate physical function subscale scores and scores based solely on the three more shoulder-specific physical function subscale question items.

RESULTS

Estimated QALY values were 2.0 years for RSA and 3.5 years for total hip arthroplasty. When the stochastic model and decision-making algorithm was applied without standard reductions for revision rates QALY values improved to 2.8 years for RSA and to 4.7 years for total hip arthroplasty. Total direct and indirect hospital cost estimates were $17000 for RSA and $11700 for total hip arthroplasty. Costs increased to $22200 and $13800, respectively, when adjusted for revision. Using these calculations the cost/QALY was $11100 for RSA and $3900 for total hip arthroplasty. Primary and revision implant costs represented 58% of RSA and 43% of total hip arthroplasty costs.

Short form-36 Health Survey physical function subscale scores initially revealed a considerable QALY value disparity between RSA and total hip arthroplasty patient groups. However, when including only shoulder-specific short form-36 physical function questions RSA QALY scores improved from 2.0 to 2.8 (t-test, P = 0.01) and RSA cost/QALY decreased to $8100.

DISCUSSION

The most important study finding is that the cost/QALY score for RSA is considerably less than the industry accepted standard of $30000-50000 cost/QALY[1-4]. Since only 3 of 10 (30%) short form-36 physical function subscale questions are specific to upper extremity function; this subscale is naturally skewed toward a hip and locomotion focus. When considering solely more shoulder-specific physical function subscale items the RSA QALY score improved significantly and shoulder region-specific estimate validity also improved.

Using a similar stochastic model and decision-making algorithm, Coe *et al*[5] reported than an implant cost less than $7000 United States dollars would make the RSA slightly more efficacious than shoulder hemiarthroplasty. In our study, total hip arthroplasty was approximately 2-3 times more cost effective than RSA. This finding however, does not preclude RSA cost effectiveness based on current industry accepted standards[1-4]. In a prospective study of 55 patients who were 70.8 (range = 46-88 years) years of age at time of RSA, Virani *et al*[2] reported that at a mean 48 mo

Table 1 Markov stochastic model

Component	Abbreviation	Value
Age of THA patients, yr ± SD[7]	AgeH	67.9 ± 9.0
Gender of THA patients, % men, % women[7]	%H-M, %H-W	46%, 54%
Age of RSA patient, yr ± SD	AgeS	69.3 ± 7.7
Gender of reverse shoulder patients, % men, % women	%RSM, %RSW	60%, 40%
Standard reduction in quality of life[9]	SR	-3%
1Pre-operative THA cost, $[7]	Hpreop	400
Pre-operative RSA cost, $[2]	Rpreop	600
1Cost of THA implant, $	Himplant	4300
1THA surgical and hospital costs, $	Hsurg	5600
1Total direct cost of THA, $	dcTHA	Himplant + Hsurg = 9900
1Cost of post-operative implant care, $[7]	Ipostop	1400
1Cost of primary THA, $	cTHA	dcTHA + Hpreop + Ipostop = 11700
Cost of THA revision implant, $[13]	Hrevimplant	%cup × cCup + %liner × cLiner + %stem × cStem = 1700
Average cost of THA revision, $[13]	Hrev	Hsurg + Hrevimplant = 7300
1Cost of RSA implant, $	Rimplant	8900
1RSA surgical, hospital costs, $	Rsurg	6100
1Total direct primary RSA cost, $	dcRSA	Rimplant + Rsurg = 15000
1Primary RSA cost, $	cRSA	dcRSA + Rpreop + Ipostop = 17000
1RSA revision implant cost, $	Revimplant	%glenoid × cGS + %Stem × cStem + %poly × cPoly %Hemi × cHemi = 4000
1Average revision RSA cost, $	Rrev	Rsurg + Revimplant
The length of first, second, third cycles hip, yr	hCL1, hCL2, hCL3	0.083, 0.416, 0.5
The length of first, second, third cycles shoulder, yr	sCL1, sCL2, sCL3	0.25, 0.25, 0.5
Length of cycle thereafter both, yr	CL	1
Age-specific mortality rate male, female[12]	mAgeM, AgeF	2007 United States life tables
Mortality rate, shoulder	mS	mAgeM × %SM + mAgeF × %SF
Mortality rate, hip	mH	mAgeM × %HM + mAgeF × %HF
THA revision cases[13]	hRev	44
Published cases[13]	hPC	211
THA follow-up years[13]	hFY	13.9 × hPC = 2932
Probability of THA revision/shoulder, yr	Ω1	hRev/hFY = 0.015
RSA revisions[14]	sRev	79
Published cases[14]	sPC	782
RSA follow-up years[14]	sFY	3.5 × sPC = 2737
RSA revision probability per shoulder, yr	Ω2	sRev/sFY = 0.029
Utility, quality of llfe improvement, EQ-5D	pQoL, oQoL	α × PF + β × RP + γ × RE + δ × BP + ε × GH + ζ × VT + η × MH + θ × SF
Utility hip, shoulder	qHwell, qSwell	oQOL - pQOL
The utility associated with a THA revision, QALY	qHrev	0.5 × qHwell
The utility associated with a RSA revision, QALY	qSrev	0.5 × qSwell

1Norton Healthcare cost data Louisville, KY, United States. RSA: Reverse-total shoulder arthroplasty; QALY: Quality-adjusted life year; THA: Total hip arthroplasty; PF: Physical function; RP: Role physical; RE: Role emotional; BP: Bodily pain; GH: General health; VT: Vitality; MH: Mental health; SF: Social function; oQOL: Post-operative quality of life; pQOL: Pre-operative quality of life.

follow-up patients had an 82% shoulder pain reduction and a 70% shoulder function improvement. This study estimated a mean 4-year total cost of $24661, with hospitalization accounting for 92% of the total cost[2]. These findings suggest the need for an earlier transition to a less expensive outpatient care environment as an important step in managing post-RSA costs.

Study limitations

The small sample size of this study necessitated several stochastic modeling assumptions. With the development of more shoulder-specific quality of life measurement tools and additional long-term RSA revision rate data, cost effectiveness estimates will become more accurate[5]. Regardless, identical analytical procedures were performed for both arthroplasty patient groups generating valid, cost/QALY estimates. Since patient outcomes, hospitalization timetables, and implant costs may be influenced by multiple factors including regional differences, patient age and comorbidities, rehabilitation strategies and activity expectations, clinicians are advised to use care when extrapolating these data to individual practice sites.

Conclusion

Based on industry accepted standards, cost/QALY estimates supported both RSA and total hip arthroplasty cost-effectiveness. Although total hip arthroplasty remains the quality of life improvement "gold standard" among arthroplasty procedures, cost/QALY estimates identified in this study support the growing use of RSA to improve patient quality of life.

COMMENTS

Background

Comparing the reverse-total shoulder arthroplasty (RSA) with the "gold standard" arthroplasty procedure was a daunting task.

Research frontiers

The results of this study confirm the efficacy of RSA for positively impacting patient quality of life.

Innovations and breakthroughs

Since hospitalization accounted for a high percentage of the total cost, future studies should investigate the efficacy of making an earlier transition to a less expensive outpatient care environment.

Peer-review

This is a nice paper.

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P- Reviewer: Fenichel I, Hasegawa M **S- Editor**: Ji FF
L- Editor: A **E- Editor**: Liu SQ

World Journal of Orthopedics

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Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
DOI: 10.5312/wjo.v7.i2.128

World J Orthop 2016 February 18; 7(2): 128-135
ISSN 2218-5836 (online)
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SYSTEMATIC REVIEWS

Corrective osteotomies of the radius: Grafting or not?

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Author contributions: Mugnai R, Catani F and Adani R designed the research; Lancellotti E and Di Giovine E performed the research; Mugnai R, Tarallo L and Zambianchi F wrote the paper.

Conflict-of-interest statement: The authors declare that they have no conflicts of interest concerning this article.

Data sharing statement: No additional data are available.

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Received: July 4, 2015
Peer-review started: July 12, 2015
First decision: September 30, 2015
Revised: November 14, 2015
Accepted: December 7, 2015
Article in press: December 8, 2015
Published online: February 18, 2016

Abstract

AIM: To review the current literature regarding corrective osteotomies to provide the best evidence of the rule of bone grafting.

METHODS: Our MEDLINE literature search included 280 studies using the following key words "Malunited distal radius fracture" and 150 studies using key words "Corrective osteotomy of the distal radius". Inclusion criteria were: Malunited distal radial, extra articular fracture, volar locking plate, use of iliac bone graft (cancellous or corticocancellous), non-use of bone graft. Twelve studies met the inclusion criteria.

RESULTS: Seven of the 12 studies considered, described the use of a graft; the remaining five studies didn't use any graft. Type of malunion was dorsal in most of the studies. The healing time was comparable using the graft or not (mean 12.5 wk), ranging from 7.5 to 16 wk. The mean disabilities of the arm, shoulder and hand score improvement was 23 points both in the studies that used the graft and in those not using the graft.

CONCLUSION: This review demonstrated that corrective osteotomy of extra-articular malunited fractures of the distal radius treated by volar locking plate does not necessarily require bone graft.

Key words: Radial fracture; Osteotomy; Graft; Volar plate; Malunion

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Core tip: The aim of this study was to review the current literature regarding corrective osteotomies in malunion of the distal radius to provide the best evidence of the rule of bone graft. The results of this review demonstrated that corrective osteotomy of extra-articular malunited fractures of the distal radius treated by volar locking plate does not necessarily require bone graft. Rate of union and functional outcomes were comparable.

Mugnai R, Tarallo L, Lancellotti E, Zambianchi F, Di Giovine E, Catani F, Adani R. Corrective osteotomies of the radius: Grafting or not? *World J Orthop* 2016; 7(2): 128-135 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/128.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.128

INTRODUCTION

Distal radius fractures represent the 10%-12% of all fractures[1-3]. One of the most common complication following distal radial fractures is malunion, especially when treated with close reduction and cast immobilization[4]. Patients with symptomatic malunions of the distal radius usually present with wrist pain; restricted wrist range of motion (ROM), especially supination; reduced grip strength; unsightly appearance; late neuropathy especially of the median nerve, with compression at the carpal tunnel[5-7]. Corrective osteotomy aims to restore anatomic configuration and improve function in unsatisfied patients.

Over the last few years, various corrective osteotomy techniques have been characterized[1,6,8]. Although opening wedge osteotomy through a dorsal approach, using bone graft and non-locking plates has been in the past years the most widely recommended technique for treating distal radius malunion, this procedure requires an extensive dorsal approach and often determines extensor tendons irritation. Recently, with the introduction of fixed-angle plates, interest in performing these osteotomies through a volar approach has increased[9,10]. According to the opening wedge treatment of a fracture united in a position of abnormality or deformity, a 3-D structural defect is produced by the surgeon in the distal radial metaphysis. The defect will then be filled with 3 different approaches: bone grafting, using a structural o non-structural autogenous corticocancellous bone graft; synthetic material [Norian, bone morphogenic proteins (BMP), osteogenic protein-1 (OP-1)]; no bone graft[11,12].

Bone graft

Corticocancellous bone can be derived from the iliac crest, distal femur, proximal tibia, fibula, distal radius and olecranon. Generally, the most used kind of bone graft is the autograft. Defects of a length smaller than 5 to 6 cm are well managed by nonvascularized iliac crest bone grafts, if in presence of well-perfused soft tissues and in absence of any active infection. Therefore they usually represent the first choice treatment of the defect created by the osteotomy. Bone graft helps to maintain the surgical corrections but with possible donor site morbidity: Persistent and chronic pain, serious discharge, nerve injury with meralgia, paresthesia, infection, fractures, pelvic instability, hematoma, cosmetic defects, hernia, ureteral injuries, arterial injuries[12]. Moreover, sometimes it is not always feasible to shape a structural bone graft based on the dimensions of the defect precisely[13]. Studies have demonstrated that osteotomies filled with cancellous or corticocancellous grafts give comparable results[14]. Anyway, cancellous is recognised to have three advantages over corticocancellous graft: first, it has no need for a specific anatomic configuration, since it can be totally compressed to stuff the defect, it gives the possibility to bypass the long procedure to prepare a structural graft, and lastly, it is not that difficult to applicate plate and screws (no displacement during the fixation) (Figures 1 and 2).

Synthetic graft

Autologous bone grafts can be replaced by bone substitute to elude donor site morbidity. Hydroxyapatite (HA) and calcium-sulphate (CS) are mineral-based substitutes for osteoconductive bone grafts. Osteotomies of malunited distal radial fractures[15] and surgery of distal radial fractures[16] has seen the use of HA as a substitute. Even tough the time lapse of resorbing graft is of years, it should have the strength necessary to absorb stress until the bone has formed. Although CS has been shown to be highly biocompatible, the resorption rate it is too rapid to be used in fracture treatment. Indeed the CS resorption is faster than the new bone formation; potentially causing hardware failure that can be avoided by maintaining a cortical contact across the osteotomy site[16,17].

Osteoconductive bone graft substitutes

Extensive research has been conducted on osteoconductive alternatives, associated with growth factors and proteins such as BMPs. Mesenchymal stem cells have been seen to differentiate into chondrocytes and osteoblasts driven by the primitive induction of the BMPs, which are members of the transforming growth factor-β. Preclinical effectiveness investigation on BMPs took to subsequent clinical introduction of the most powerful BMPs, BMP-2 and BMP-7[18,19]. OP-1, which also goes under the name of recombinant BMP-7, has been known for its osteoinductive properties. Animal and clinical trials showed therapeutic potential in more than a study. Demonstration of the efficacy of this grafts has been documented in spinal fusion, fibular defects, tibial non-union, and most recently also in pelvic girdle non-union[19,20]. According to Ekrol *et al*[20], OP-1 substitute has been shown not to elicit the same stability and stress absorption as bone graft across the osteotomy site; furthermore using the combination of a plate with OP-1 resulted in healing of the osteotomy but with a slower rate than autogenous bone graft.

No bone graft

Bone graft seems to be not always necessary when the distal malunion is extra articular and it's treated with a locking plate: The absence of bone graft seems not to adversely affect time to union and functional outcome.

In this case correction should be achieved in the coronal and sagittal planes by having the distal radius

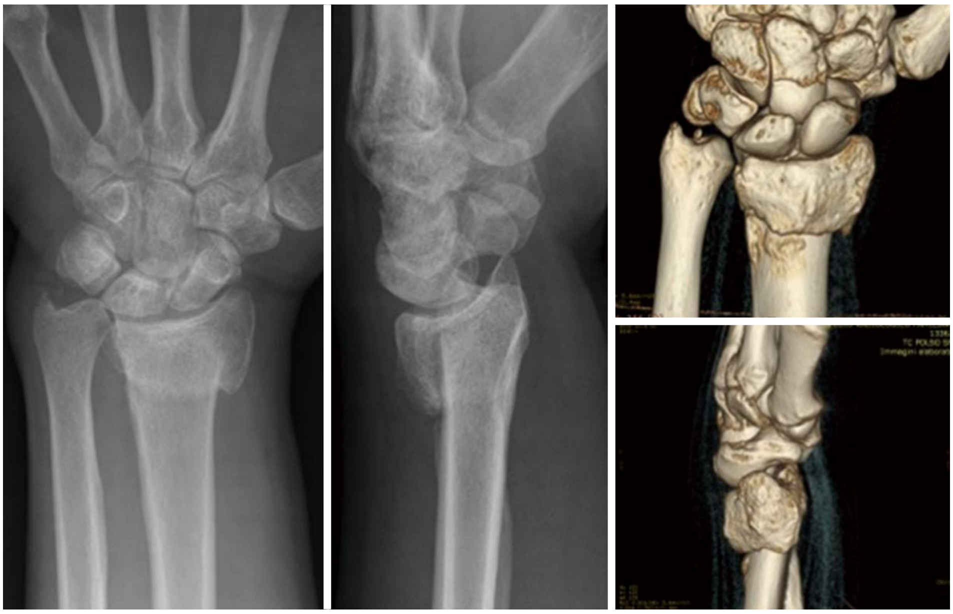

Figure 1 Preoperative X-rays and 3D-computed tomography evaluation showing an extra-articular dorsal malunion in a 36 years old man.

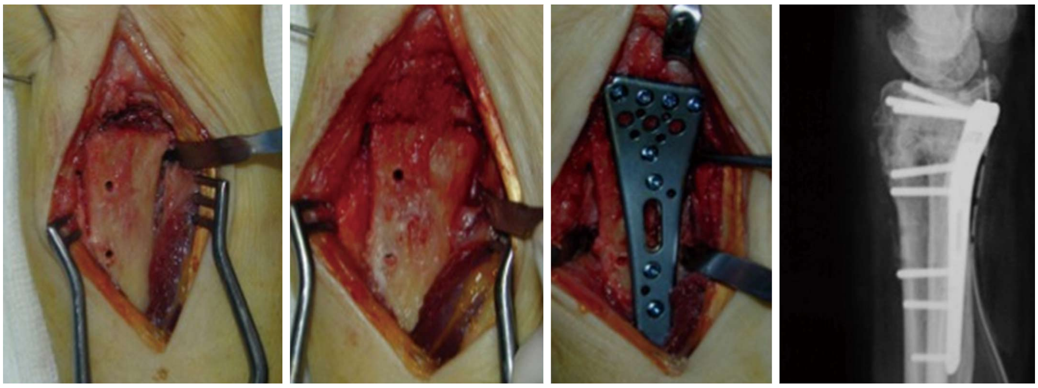

Figure 2 Intraoperative view and post-operative X-rays of the surgical procedure using a volar locking plate and cancellous bone graft.

Figure 3 Preoperative X-rays showing an extra-articular dorsal malunion in a 51 years old man.

conform to the tilt of the plate. It can be useful to maintain a volar cortical contact following corrective osteotomy, to ensure the physiological transmission of the force vector through the synthesis, from the distal to the proximal segment of the radius[21] (Figures 3-5).

MATERIALS AND METHODS

Our MEDLINE literature search included 280 studies using the following key words "Malunited distal radius fracture" and 150 studies using key words "Corrective osteotomy of the distal radius". Inclusion criteria were: Malunited distal radial, extra articular fracture, volar locking plate, use of iliac bone graft (cancellous or corticocancellous), non use of bone graft. Twelve studies met the inclusion criteria. Although important, time of healing and clinical outcome, were not reported in all the studies included in the review.

RESULTS

For each study the number of evaluated patients, surgical technique (graft or not), number of patients enrolled, type of malunion, time of healing and functional recovery regarded as disabilities of the arm, shoulder and hand (DASH) score, pain improvement [visual analogue scale (VAS) and any eventual post-

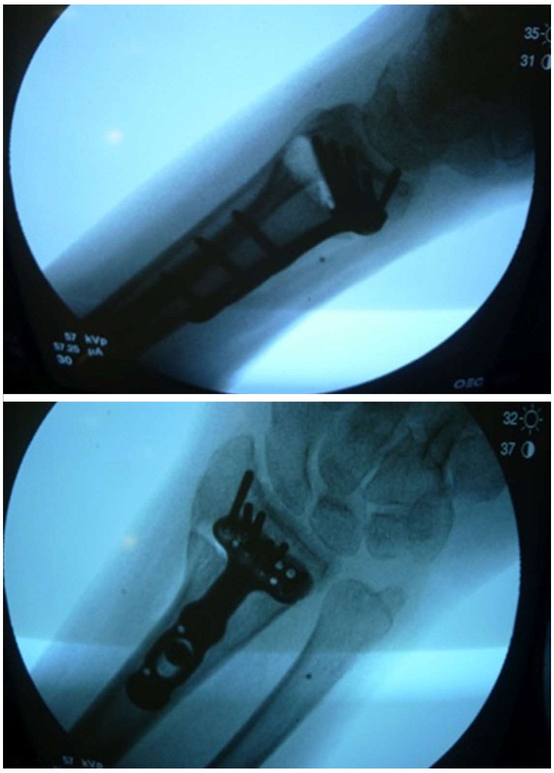

Figure 4 Intraoperative X-rays showing corrective osteotomy of extra-articular dorsally displaced malunion of the distal radius treated by volar locking plate without bone graft, and maintaining volar cortical contact.

Figure 5 X-rays performed 3 mo post-operatively showing the healing process in progress.

surgical complication (Table 1) were reported. In 7 out of the 12 studies included the graft was used: Iliac crest corticocancellous bone graft in 4 studies and iliac crest cancellous bone graft in 3. Moreover Malone *et al*[22] used crushed cancellous allograft in 1 case and Wada *et al*[23] tricalcium phosphate. In the remaining five studies grafting was not described. Despite this, the number of patients of all studies treated with graft was inferior to the number of those treated without graft (97 *vs* 104). Type of malunion was dorsal in most of the studies. The healing time was comparable using the graft or not (mean 12.5 wk), ranging from 7.5[24] to 16[25,26] wk. The mean DASH score improvement was 23 points both in the studies describing the use of the graft (range, 11-46)[22-24,27-29], and in those not using the graft (range, 13-28)[25,30-32]. Finally, few studies reported postoperative complications[11,22,23,26,29,32]. Among the majority of the studies neither complications nor significative correction loss were indicated after surgery, even in elderly people. The results of the main evaluated literature are summarized in Table 1.

DISCUSSION

The majority of the examined literature used the bone graft to fix the remaining defect with corticocancellous or cancellous autogenous bone from the iliac crest. Gradl *et al*[27] employed iliac crest corticocancellous bone graft in all case of malunion. He included in his study 18 patients treated using a palmar approach in 14 cases and a combined approach (palmar + dorsal) in 4 cases. There were 7 palmar and 11 dorsal malunions, and remaining defects were fixed with corticocancellous autogenous bone graft from the iliac crest in 14 patients, and cancellous bone graft from the radius in one patient. At a mean 7 years of follow-up wrist ROM improved significantly in all cases and the DASH score decreased significantly from 59 to 23 points.

Treatment with transverse opening wedge osteotomy with oblique iliac bone graft of volarly malunited distal radius fractures led to a significative improvement in DASH score as reported by Sato *et al*[24] in 2009. All patients were analyzed at a mean 25 mo of follow-up. Mean preoperative VAS scale was 45, improving significantly to 3 postoperatively. Range of wrist motion improved in all 28 patients, with supination range improving from 16° preoperatively to 80° postoperatively. Mean DASH score improvement from 55 to 9 postoperatively. X-rays evaluation showed an improvement of the volar tilt from 32° preoperatively to 10° postoperatively, and radial inclination increased from 17° to 21°. Preoperative ulnar variance of 5.9 mm was corrected to -0.1 mm postoperatively. Fifty-two days was the average time for bony union at osteotomy site (young patients, 51 d; older patients, 54 d).

Many authors described complications following the surgical treatment of dorsal malunion: Extensor tenosynovitis and, sometimes, tendon ruptures connected with the use of dorsal plates[20,33,34]. Keller *et al*[35] evaluated a series of 49 cases that underwent dorsal plating of the distal radius, reporting, at 32 mo follow-up, an average DASH score of 14.4 with good motion and grip strength. To be noted that 37 of the 49 patients required plate removal and of the 12 patients who did not undergo plate removal, one patient suffered a rupture of the extensor indicis proprius. It's common opinion among the authors that extensor tendon complications are the result of the profile of the dorsal plate[21,27], but more recent studies claim that this complication can occur even with low-profile plates. Moreover screw placement is important: Gradl *et al*[27] reported in one case the development of symptomatic tendinitis of the extensor pollicis longus tendon due to dorsal protrusion

Table 1 Results of the main evaluated literature

Ref.	No. of patients	Graft	Type of malunion	Time to healing	Clinical outcome (DASH)	Pain (VAS)	Complications
Gradl *et al*[27]	14	ICCCBG in all cases	Dorsal in 7 cases; volar in 4 cases	Not reported	36	4.2 ± 2.9	None
Malone *et al*[22]	3	ICCCBG in 2 cases; CCA in 1 case	Dorsal in all cases	9 wk	12	3.3	1 post-traumatic fracture
Peterson *et al*[28]	8	ICCCBG in all cases	Dorsal in 6 cases; volar in 2 cases	Not reported	10.8	Not reported	None
Rothenfluh *et al*[29]	14	ICCBG in all cases	Dorsal in all cases	12 wk	17.3	3.59	Secondary dislocation of the distal fragment was observed 21 d after surgery in 1 case
Wada *et al*[23]	16	ICCBG or tricalcium phosphate bone substitute	Dorsal and volar	13 wk	14	Significant improvement	2 delayed unions
Sato *et al*[24]	28	ICCCBG in all cases	Volar in all cases	7.5 wk	46	4.2	None
Miyake *et al*[26]	10	ICCBG in all cases	Dorsal in all cases	16 wk	Not reported	Significant improvement	Early postoperative screw loosening in 2 cases
Farshad *et al*[11]	28	None	Not specified	Not reported	Not reported	Not reported	Plate bending in 6 cases
Mahmoud *et al*[32]	22	None	Dorsal in all cases	10.4 wk	21.6 ± 13.5	3.4 ± 1.5	Intraoperative split in the shaft of the radius in 1 case CRPS in 1 case Residual pain in 2 cases
Opel *et al*[30]	20	None	Not specified	12 wk	13.4	Not reported	None
Ozer *et al*[31]	14	None	Dorsal in all cases	11 wk	28	Not reported	None
Tarallo *et al*[25]	20	None	Dorsal in all cases	16 wk	28.5	0.8	None

VAS: Vidual analogue scale; DASH: Disabilities of the arm, shoulder and hand; ICCCBG: Iliac crest cortico cancellous bone graft; CCA: Crushed cancellous allograft; ICCBG: Iliac crest cancellous bone graft; CRPS: Complex regional pain syndrome.

of screw tips after corrective osteotomy with a palmar locking plate and autogenous bone grafting. Malone *et al*[22] emphasized the role of the volar plate including structural bone grafting: Four corrective osteotomies has been performed using the volar approach for dorsally angulated malunion of distal radius fracture with a volar plate; two patients received autologous iliac crest bone graft, 1 patient received crushed cancellous allograft, and 1 patient had a distal ulna resection for ulnar impaction symptoms and the distal ulna was used as a source for the bone graft. The authors came to the concept that the stiff characteristics of fixed angle volar plates could provide an alternative to the traditional techniques of distal radius osteotomy including structural bone grafting and dorsal plate fixation or external fixation. Comparable results in terms of anatomic restoration of the distal radius, ROM improvement in the radiocarpal joint, and restoration of the anatomic relationships of the distal radioulnar join were obtained by Rothenfluh *et al*[29], Wada *et al*[23], and Peterson *et al*[28]. All these authors used bone graft from the iliac crest with a comparable DASH scores and no complications. Only Rothenfluh *et al*[29] reported in one case a secondary dislocation of the distal fragment observed 21 d after volar osteotomy. In his study Rothenfluh *et al*[29] compared the results of dorsal approach plus structural trapezoidal bone graft stabilized using a thin round-hole mini-fragment plate, with palmar approach plus nonstructural cancellous bone chips and a palmar fixed-angle plate, suggesting comparable results to those achieved with dorsal osteotomy and the interposition of cortico-cancellous bone graft. However, the palmar approach determined a more favorable effect on wrist flexion, entailing lower complication rates, mainly represented by extensor tendonitis and hardware removal.

Several articles treated corrective osteotomy without bone graft and the first reports concerning this topic dates back to 1930s[36]. In recent literature, Mahmoud *et al*[32] described the results of 22 corrective osteotomies of extra-articular dorsally-angulated malunited fractures of the distal radius fixed by a volar locked plate without the use of bone graft. Radiological healing was achieved in all patients at a mean of 10.4 wk (8 to 14). At a mean of 18 (12 to 25) mo of follow-up the DASH score improved from 34.5 points to 12.9; improvements in the VAS score and grip strength were respectively 3.4 points and 17.4 kg; radiological correction of the deformity and ROM improvement were achieved in all cases. Complications occurred in six cases (27%): an intraoperative longitudinal split occurred in the shaft of the radius in one patient, requiring an interfragmentary compression screw; one patient suffered a transient median nerve neuritis; another patient suffered from CRPS, which was healed by physiotherapy; a prominent screw determined tendon impingement and required removal; residual pain on the ulnar side of the wrist due to ulnar impaction was encountered in two patients, requiring ulnar shortening. Tarallo *et al*[25] treated 20 patients for symptomatic dorsally malunited extra-articular fractures of the distal radius with osteotomy and a volar locking plate without additional bone graft. The authors reported, at a mean 50 mo of follow-up, a significant improvement in pain level, ROM, grip strength, and DASH score.

An important factor to consider is that bone healing is determined by several factors, including cell differentiation, compromise of vascularity, and mechanical stability[37]. Sheer *et al*[37], in a recent study, concluded that although there are few data on metaphyseal bone healing, there are some indications that it adheres to the same biomechanical principles as diaphyseal bone healing, with some differences concerning bone formation, which may follow different paths. The cortical contact between the osteotomy fragments represents an important factor, too. Ozer *et al*[31], investigated this aspect underlining the importance to maintain a volar cortical contact following the placement of the volar locking plate in order to obtain a better outcome, especially in extra-articular malunited fractures of the distal radius. They state that in such cases, it would not be necessarily required the use of bone graft.

The use of autogenous bone grafts has been reported to have high complication rates, with associated morbidity of up to 73%, and an additional operative time averaging 20 min[31]. The most important complication reported by several authors is donor site morbidity, especially at the iliac crest. Minor complications, occurring in 7.1%-39% of patients, include persistent pain at the harvest site, sensory nerve injury, hematoma or seroma, and superficial infection[38,39]. Concerning the use of a synthetic material, such products come with an inherent advantage of no donor site morbidity; however their use also come with a high cost of production and sometimes a potentially low, but real, risk of disease transmission. Abramo *et al*[18] evaluated 25 consecutive patients with a dorsal malunion after a distal radius fracture treated with corrective osteotomy using a dorsal approach. A TriMed buttress pin and a radial pin plate were used, and calcium phosphate mixture (Norian SRS) as bone substitute. At a 1-year follow-up grip strength increased from 62% of the contralateral hand to 82%, with a DASH score improvement of 12 points. Minor complications involving transient tingling and numbness from the radial nerve branches were reported initially in 6 cases, but disappeared by the last follow-up. One major complication occurred: The bone substitute fragmented before osseous union and the plate and screws broke 2 mo postoperatively. The patient was reoperated using conventional bone grafting and fixation with a dorsal AO plate.

Jepegnanam *et al*[40] reported on early mechanical failure of injectable calcium sulfate, leading to implant failure in 2 elderly patients who had corrective osteotomies for malunited distal radius fractures. Faster resorption might have specific advantages under certain conditions but might also be disadvantageous if it is required to contribute to mechanical support for many weeks or months. The authors hypothesized that the failures occurred because new bone formation did not occur rapidly enough to replace resorption of the grafted material.

Jepegnanam *et al*[40], suggest that graft substitutes with a faster resorption rate should be used with caution in patients with expected slow bone healing. The major stability of bone graft compared with synthetic material is also emphasized by Ekrol *et al*[20]. They compared the OP-1 and autogenous graft for metaphyseal defects after osteotomy of the distal radius, concluding that OP-1 does not confer the same stability as bone graft, reducing the capacity for healing and resulting in osteolysis.

Conclusion

The results of this review demonstrate that corrective osteotomy of extra-articular malunited distal radius fractures treated by volar locking plate does not necessarily require the use of bone graft. Rate of union and functional outcomes are comparable to the use of bone graft. We suggest maintaining a volar cortical contact following corrective osteotomy, to ensure the physiological transmission of the force vector through the synthesis, from the distal segment of the radio to the proximal one.

Bone grafts however, remain a valuable support in this type of surgery, especially to fill gaps when a large defect is created. Synthetic materials come with an inherent advantage of no donor site morbidity but it seems that they do not confer the same stability as bone graft. Their use is limited by faster resorption rate than bone graft, so they should be used with caution in patients with expected slow bone healing rate.

COMMENTS

Background

Different techniques for corrective osteotomy have been described in recent years; although opening wedge osteotomy through a dorsal approach, using bone graft and non-locking plates has been in the past years the most widely recommended technique for treating distal radius malunion, this procedure requires an extensive dorsal approach and often determines extensor tendons irritation. Recently, with the introduction of fixed-angle plates, interest in performing these osteotomies through a volar approach has increased.

Research frontiers

According to the opening wedge treatment of a malunited fracture, the surgeon creates a 3-dimensional structural defect in the distal radial metaphysis, which will be filled with 3 different approaches: Bone grafting, using a structural o non-structural autogenous corticocancellous bone graft; synthetic material (Norian, bone morphogenic proteins, osteogenic protein-1); no bone graft.

Innovations and breakthroughs

Current publication is the first systematic review, which summarize published data concerning the use of bone graft in corrective osteotomy of extra-articular malunited fractures of the distal radius treated by volar locking plate. The results of this review demonstrate that corrective osteotomy of extra-articular malunited fractures of the distal radius treated by volar locking plate does not necessarily require the use of bone graft. Rate of union and functional outcomes are comparable to the use of bone graft. However bone graft still represents a valuable solution in this type of surgery, especially to fill the gap when a large osteotomy is performed.

Applications

Given similar rates of union, functional outcomes and complications occurrence, the authors suggest that when a volar cortical contact is maintained following corrective osteotomy the use of bone graft is not necessarily required.

Terminology

Cancellous bone is the meshwork of spongy tissue (trabeculae) of mature adult bone. The most common harvesting site for autogenous cancellous bone graft is the iliac crest, tibial crest, humeral greater tubercle and greater trochanter of femur. Cancellous bone autograft offers the considerable amounts of viable cells that boost the osteogenesis, matrix protein that promotes the osteoinduction and bone matrix that encourage the osteoinduction. Cancellous bone grafts lack biomechanical strength and do not supply structural support. Corticocancellous grafts yield significant mechanical strength and can be used to either replace bone losses or to augment the mechanical stability of the fixation. The most common sites for harvesting corticocancellous bone autograft are ribs, the anterosuperior iliac crest and the posterior iliac crest.

Peer-review

This is a good study.

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World J Orthop 2016 February 18; 7(2): 136-148
ISSN 2218-5836 (online)
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SYSTEMATIC REVIEWS

Photogrammetry as a tool for the postural evaluation of the spine: A systematic review

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Author contributions: Furlanetto TS and Sedrez JA gathered, analyzed and interpreted the data and drafted the manuscript; Candotti CT and Loss JF Study conceived and designed the study and performed the critical review.

Conflict-of-interest statement: All the authors declare that they have no competing interests.

Data sharing statement: The dataset is available from the corresponding author at jefferson.loss@ufrgs.br.

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Received: May 4, 2015
Peer-review started: May 5, 2015
First decision: June 20, 2015
Revised: July 24, 2015
Accepted: December 3, 2015
Article in press: December 4, 2015
Published online: February 18, 2016

Abstract

AIM: To evaluate the use of photogrammetry and identify the mathematical procedures applied when evaluating spinal posture.

METHODS: A systematic search using keywords was conducted in the PubMed, EMBASE, Scopus, Science and Medicine® databases. The following inclusion criteria adopted were: (1) the use of photogrammetry as a method to evaluate spinal posture; (2) evaluations of spinal curvature in the sagittal and/or frontal plane; (3) studies published within the last three decades; and (4) written entirely in English. The exclusion criteria were: (1) studies which objective involved the verification of some aspect of validation of instruments; (2) studies published as abstracts and those published in scientific events; and (3) studies using evaluation of the anteriorization of the head to determine the angular positioning of the cervical spine. The articles in this review were included and evaluated for their methodological quality, based on the Downs and Black scale, by two independent reviewers.

RESULTS: Initially, 1758 articles were found, 76 of which were included upon reading the full texts and 29 were included in accordance with the predetermined criteria. In addition, after analyzing the references in those articles, a further six articles were selected, so that 35 articles were included in this review. This systematic review revealed that the photogrammetry has been using in observational studies. Furthermore, it was also found that, although the data collection methodologies are similar across the studies, in relation to aspects of data analysis, the methodologies are very different, especially regarding the mathematical routines employed to support different postural evaluation software.

CONCLUSION: With photogrammetry, the aim of the assessment, whether it is for clinical, research or collective health purposes, must be considered when choosing which protocol to use to evaluate spinal posture.

Key words: Lordosis; Kyphosis; Spine; Photogrammetry; Scoliosis; Posture

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Core tip: With photogrammetry, various spinal posture assessment protocols can be adopted. However, the literature lacks evidence to support the use of photogrammetry in accompanying postural treatment, whether for clinical or research purposes. When using photogrammetry in scientific research, a protocol or software that provides detailed postural analysis should be the first choice. In the clinical environment, the choice of protocol will depend on the objectives established for the patient by the physiotherapist. When dealing with a collective health situation, such as groups of schoolchildren, it is necessary to prioritize simpler protocols.

Furlanetto TS, Sedrez JA, Candotti CT, Loss JF. Photogrammetry as a tool for the postural evaluation of the spine: A systematic review. *World J Orthop* 2016; 7(2): 136-148 Available from: URL: http://www.wjgnet.com/2218-5836/full/v7/i2/136.htm DOI: http://dx.doi.org/10.5312/wjo.v7.i2.136

INTRODUCTION

Photogrammetry is a widely used non-invasive technique for postural evaluation. It is a viable option for healthcare professionals and researchers in the field of posture[1], possibly because it allows a succinct and accurate quantitative evaluation by recording subtle changes in posture in general[2,3]. From the point of view of spinal evaluation, it is capable of providing information in the frontal and sagittal planes[4,5]. Furthermore, the use of photogrammetry undoubtedly contributes to reducing exposure to radiation and thus enables the monitoring of postural treatment. However, the application of this technique in postural evaluation is directly dependent on both the collection procedures and the mathematical methods used to provide measurements and postural diagnoses, and which should provide all the necessary aspects of validation[6,7].

Specifically regarding the application of photogrammetry in spinal evaluation, many studies have performed procedures to validate the technique[4,6,8-11]. Furthermore, in clinical practice, photogrammetry can be useful for evaluating and monitoring changes in spinal treatments by comparing quantitative data on posture[6,12]. Moreover, in scientific studies, its use may be helpful in both transverse and longitudinal observations and in intervention studies.

Although, according to the literature, the use of photogrammetry in spinal evaluation is widespread, its real applicability may be questioned, as it remains unclear how this technique is being used to monitor postural treatment or to map attitudes among populations in observational studies. Furthermore, many studies that have adopted the use of photogrammetry do not explain the methods used to generate the results obtained, thus constituting veritable "black boxes", which makes it difficult for users both in clinical practice and in scientific research to apply this evaluation method. Hence, the objective of this systematic review was to evaluate the use of photogrammetry and to identify the mathematical procedures involved when it is applied to assess spinal posture.

MATERIALS AND METHODS

This study was a systematic review, in which the eligibility criteria were observational studies and randomized and nonrandomized clinical trials that have used photogrammetry as a tool to evaluate the spine in an attempt to understand its importance in the assessment of posture. The systematic review follows methods recommended by the Cochrane Collaboration[13].

A systematic literature search was performed in the PubMed, Embase, Scopus, Science and MEDICINE® databases in the months of December 2013 and January 2014. The keywords used were found in the Health Sciences Descriptors (DeCS, Descritores em Ciências da Saúde), Medical Subject Headings or Emtree: ("Photogrammetry" OR "Digital Analysis" OR "Digital Photographs" OR "Digital photography") AND ("Spinal postural evaluation" OR "Spine" OR "Vertebral Column" OR "Column, Vertebral" OR "Columns, Vertebral" OR "Vertebral Columns" OR "Spinal Column" OR "Column, Spinal" OR "Columns, Spinal" OR "Spinal Columns" OR "Vertebra" OR "Vertebrae" OR "Lordosis" OR "Kyphosis" OR "Kyphoses" OR "Scoliosis" OR "Scolioses" OR "Posture" OR "Postures" OR "Spine Curvatures" OR "lumbar curvatures" OR "thoracic curvatures" OR "thoracic curve" OR "lordosis curve" OR "thoracic kyphosis" OR "lumbar lordosis"). The search was limited to articles written entirely in English, because it is the international language.

To constitute this systematic review, the articles identified by the initial search strategy had to meet the following inclusion criteria: (1) use photogrammetry as a method of postural evaluation; (2) evaluate the curvatures of the spine in the sagittal or frontal plane; (3) been published within the last three decades; and (4) been written entirely in English. The exclusion criteria were: (1) studies in which the objective involved verifying some aspect of instrument validation; (2) studies published as abstracts and published in scientific events; and (3) studies that used the evaluation of anteriorization of the head to determine the angular positioning of the cervical spine. These variables are believed to analyze different aspects of body posture and cannot be analyzed together.

All the search procedures, selection, quality assessment, data extraction and the reading of the articles were performed independently and individually by two reviewers. In case of any difference of opinion between the reviewers, a third reviewer was asked to appraise the article.

Initially, the studies were selected by reading the

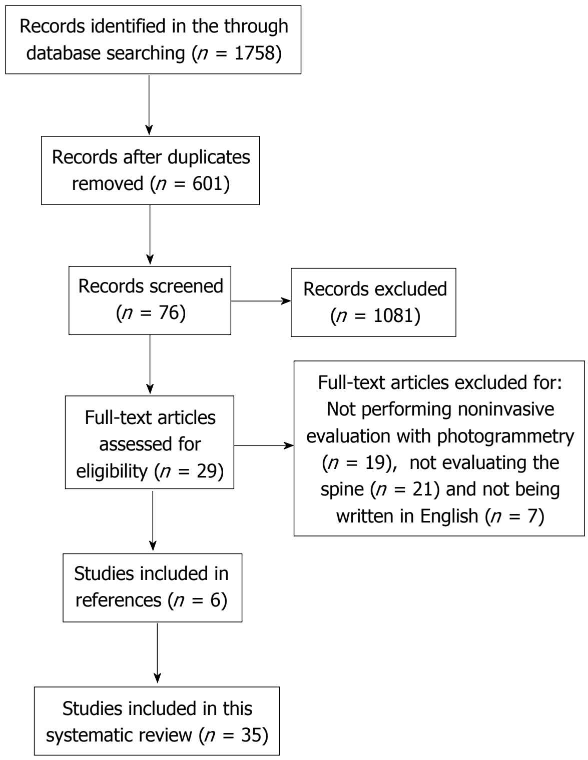

Figure 1 Flowchart of article selection.

titles and abstracts, and those considered to have the potential to be included in the search were read and analyzed in full. In those cases where the title and the abstract were inconclusive, the full article was obtained and read in order not to risk of leaving out important studies in this review. Complementing this process, the references of each included article were also checked in order to identify items not found in the electronic search.

The studies that met the inclusion criteria were evaluated for their methodological quality using the Downs and Black scale, which consists of a checklist of 26 criteria that are answered "yes", "no" or "impossible to determine"[14]. This scale was chosen because it is used to evaluate both observational studies and randomized clinical trials (RCTs), while some criteria are designed to assess RCTs exclusively, which were unnecessary in this systematic review. According to the guidelines for the use of the scale[14], the assessment criteria can be chosen based on the study objective, thus in the present study those criteria referring solely to the assessment of RCTs were excluded, and only 12 criteria from the Downs and Black scale were used when assessing methodological aspects.

The Downs and Black scale does not define a minimum score when determining the quality of studies[14]. Therefore, studies were not excluded based on their quality rating and only the total number of criteria rated as "yes" for each article was used. The higher the score for the criteria of article, the better methodological quality[14].

RESULTS

Initially, 1758 articles were found from the keywords used. Of these, 601 were excluded because they were duplicates and 1081 did not meet the inclusion criteria. Thus, 76 studies were initially included in this systematic review. After reading the articles in full, 29 studies were found to meet all the inclusion criteria. Subsequently, their reference lists were analyzed and, based on this analysis, a further that 6 articles were found to meet the inclusion criteria, thus 35 articles were selected for inclusion in this systematic review (Figure 1).

Table 1 presents the assessment of the methodological quality based on Downs and Black scale of the studies selected for review. All 35 items had checklist scores higher or equal to 6. In addition, 9 studies had scores between 7 and 8; 19 studies had scores between 9 and 10; and 6 studies had scores between 11 and 12 (Table 1).

The 35 studies included in this review that use photogrammetry as a tool to evaluate the spine in the sagittal and frontal planes are presented and described (Table 2). The aspects related to the objective, the type of study, the methodology and the results of the studies are also shown.

Of the studies in which photogrammetry is used as a postural assessment tool, only one involves a randomized clinical trial, while the others are observational studies. Regarding study populations, most studies involved adults, followed by children and adolescents, while a few studies involved populations with specific diseases that may affect some aspect of posture was evaluated (Table 2).

The vast majority of studies included in this systematic review are concerned with evaluating the sagittal curvature of the spine, while scoliosis is evaluated in only eight studies. To achieve their objectives, several mathematical routines are used in the postural evaluation software programs to measure the alterations in the spine. Most, whether for the frontal or sagittal plane, used angular and/or linear values to measure the magnitude of the spinal alterations (Table 2).

DISCUSSION

This systematic review aimed to verify the applicability of photogrammetry and to identify the mathematical procedures involved in the use of this technique to evaluate the posture of the spine. Among the 35 articles included in this study, there is considerable similarity regarding the applicability of photogrammetry within scientific circles. However, there are important differences in the mathematical procedures used to evaluate the spine. Next, the articles included in this review were analyzed by groups, regarding the methodology used to collect and analyze data with photogrammetry: (1) type of study; (2) evaluated population; (3) region of the spine and type of alteration evaluated; and (4) types of

Table 1 Results of the quality assessment of studies by downs and black scale

Ref.	Criteria checklist downs and black												Total
	1	2	3	6	7	9	10	11	12	16	18	20	(No. of √)
Almeida *et al*[15]	√	X	√	X	√	√	√	?	?	√	√	√	8
Cheng *et al*[16]	√	√	√	√	√	√	√	?	?	√	√	√	10
Fortin *et al*[17]	√	√	√	√	√	√	√	?	?	√	√	√	10
Annetts *et al*[18]	√	√	√	√	√	√	√	X	X	√	√	√	10
Weber *et al*[19]	√	√	√	√	X	?	√	X	X	√	√	√	8
Edmondston *et al*[20]	√	√	√	√	√	√	√	X	X	√	√	√	10
Milanesi *et al*[21]	√	√	√	√	√	√	√	?	?	√	√	√	10
de Oliveira Pezzan *et al*[22]	√	√	√	√	√	√	√	?	?	√	√	√	10
Yang *et al*[23]	√	√	√	√	?	√	√	?	?	√	√	√	9
Silveira *et al*[24]	√	√	√	√	√	√	√	?	?	√	√	√	10
Iunes *et al*[25]	√	√	√	√	X	√	√	?	?	√	√	√	9
Belli *et al*[26]	√	√	√	√	√	√	X	√	√	√	√	√	11
Chase *et al*[27]	√	√	√	√	√	?	√	√	√	√	√	?	10
Iunes *et al*[12]	√	√	√	√	√	√	√	X	X	√	√	√	10
Iunes *et al*[28]	√	√	√	√	√	√	√	?	?	√	√	√	10
Penha *et al*[29]	√	√	√	√	√	√	√	√	√	√	√	√	12
Rodrigues *et al*[30]	√	√	√	√	√	√	√	X	X	√	√	√	10
Straker *et al*[31]	√	√	√	√	√	√	√	√	√	√	√	√	12
Iunes *et al*l[32]	√	√	√	√	X	√	√	X	X	√	√	√	9
Smith *et al*[3]	√	√	X	√	√	√	√	?	?	√	√	√	9
Yi *et al*[33]	√	√	√	√	√	√	√	?	?	√	√	√	10
Min *et al*[34]	X	√	√	√	√	√	?	?	?	√	?	√	7
Straker *et al*[35]	√	√	√	√	√	√	√	√	√	√	√	?	11
Szopa *et al*[36]	√	√	√	√	√	X	√	?	?	√	?	√	8
Amsters *et al*[37]	√	√	√	√	√	√	X	?	?	√	?	X	7
O'Sullivan *et al*[38]	√	√	√	√	√	√	√	?	?	√	√	√	10
Milosavljevic *et al*[39]	√	√	√	√	√	√	√	√	√	√	√	√	12
Munhoz *et al*[40]	√	√	√	√	√	√	√	√	√	√	√	√	12
Lima *et al*[41]	√	√	√	√	X	?	√	?	?	√	√	?	7
Raine *et al*[42]	√	√	√	X	√	X	√	X	X	√	√	√	8
Christie *et al*[43]	√	√	√	√	√	√	√	?	?	√	√	√	10
Watson *et al*[44]	√	?	√	X	√	√	X	?	?	√	√	√	7
Raine *et al*[45]	√	√	√	√	√	√	√	X	X	√	√	√	10
Mitchell *et al*[46]	X	√	√	√	√	√	?	?	?	√	?	X	6
Dieck *et al*[47]	√	√	√	√	X	?	√	?	?	√	√	√	8

Downs and black criteria: (1) Is the hypothesis/objective clearly described? (2) Are the main results to be measured clearly described in the Introduction or Materials and Methods? (3) Were the characteristics of the patients included clearly described? (6) Are the main findings of the study clearly described? (7) Does the study estimate the random variability in the data of the main results? (9) Were the characteristics of the lost patients described in the study? (10) Were the true probability values reported for the main results? (11) Are the subjects asked to participate in the study representative of the entire population where they were recruited? (12) Are the subjects recruited to participate in the study representative of the entire population where they were recruited? (16) If any of the results of the study were based on "data dredging", was it clear? (18) Were statistical tests used to assess the main results appropriate? (20) Were the main results evaluated accurate (valid and reliable)? Responses to the criteria: √: Yes; X: No; ?: Unable to determine.

mathematical procedures.

Comparing the studies in which photogrammetry is used as a postural evaluation tool, only one study is a randomized clinical trial[25], all the others being observational studies. The reason for not using this tool in "trial" studies of type "trials" is unclear, since photogrammetry is recognized as a valid and reproducible instrument for monitoring treatment progression, both in clinical practice and research[5,6,25,48]. Among the possible explanations for these findings are the lack of free access software for evaluating the spine and/or recent use of digital photographs and analysis software for the use in large intervention studies[1].

Furthermore, the difficulty involved in treating conditions related to spinal posture may also go some way to explain these results, since this body segment is highly influenced by mechanical, social, political and psychological factors[49].

As nearly all the studies presented in this systematic review were cross-sectional, their objectives varied according to the population assessed, making it possible to evaluate some specific characteristics of spinal posture in the groups involved. Moreover, photogrammetry is particularly useful for that purpose because it is capable of recording subtle transformations and so is able to quantify the morphological variables related to posture[2,3]. Some specific populations were evaluated using photogrammetry, such as adults[12,19,20,42,45,47], children and teenagers[3,29,31,35], pregnant women[46] and athletes[44]. In some studies, where the samples consisted of adults, some utensils (*e.g.*, chairs and high-heeled shoes) are used in order to verify any change in the posture of the spine during their use[18,22,32].

Similarly, some studies include patients with various diseases, where the authors believe they have a relationship with spinal posture. There are articles in which

Table 2 Synthesis of the 35 studies included in this systematic review

Ref.	Objective	Type of study	Methodology	Results
Almeida *et al*[15]	To assess the correlation between pulmonary function and posture; to investigate the correlation between body composition and body posture	Observational	*n* = 34 adult patients with asthma. Measurements: Bioelectrical impedance, spirometry, whole-body plethysmography, measurement of diffusing capacity for carbon monoxide and assessment of respiratory muscle strength. The lumbar lordosis was assessed by the pelvic anteversion (PAS)	The patients exhibit lumbar hyperlordosis. These postural abnormalities correlate with patients' pulmonary function and body composition
Cheng *et al*[16]	To investigate the influence of lower body stabilization and pencil design on body biomechanics (postural alterations) in children with CP	Observational	*n* = 14 children with CP. In the posterior view was measured the trunk lateral inclination angle and posterior superior iliac spine-C7/L4 angle; and in the lateral view was measured the trunk forward inclination angle (AutoCAD software)	A chair which provides proper positioning was effective in improving trunk posture in children with CP during handwriting activity. A pencil with assigned grip height or with a biaxial design, when compared with a regular one, could improve trunk alignment
Fortin *et al*[17]	To explore differences in standing and sitting postures and to compare differences between thoracic and thoraco-lumbar or lumbar scoliosis	Observational	*n* = 50 (29 thoracic scoliosis, 14 thoraco-lumbar scoliosis and 7 lumbar scoliosis). The cervical lordosis (sagittal plane) and scoliosis (frontal plane) was assessed by angles in standing and sitting positions (software program developed by their multidisciplinary team)	The cervical lordosis was not different in the two postures and scoliosis angle was significantly lower in the standing position. No significant difference was found for the index scoliosis angle in groups of scoliosis
Annetts *et al*[18]	To investigate the difference in lumbar angle and neck angle when comparing four seating designs; and consider the postures adopted on the four chairs in relation to an "ideal" posture	Observational	*n* = 14. The lumbar and neck angle was assessed in sit posture in the four seating designs (Matlab programme)	All chairs also resulted in a negative value for the lumbar region indicating a lordotic posture was adopted. All chairs resulted in a positive value for neck angle demonstrating the extent of the forward head position. No chair seemed to consistently produce an ideal posture across all regions
Weber *et al*[19]	To evaluate the relationship between cervical lordosis, and forward head posture and head position	Observational	*n* = 80 women. The cervical curvature was measured by the horizontal distance from a vertical line tangent (postural assessment software - SAPO®). Three angles measured the position of the head: Head flexion/extension (between C7, tragus and palpebral commissure), forward head posture A1 (between line of the tragus-C7 with the horizontal), and forward head posture A2 (between the external acoustic meatus, chin and sternal notch)	There were negative moderate and significant correlation between cervical lordosis and forward head posture A1. There were moderate and significant correlation between cervical lordosis and head flexion/extension
Edmondston *et al*[20]	To examine the extension mobility of the thoracic spine; and to evaluate the influence of the thoracic kyphosis on the thoracic extension range of motion, and the end range extension position	Observational	*n* = 40. The thoracic mobility was measured by kyphosis angle between T1, T6 e T12, in standing, sitting, 4-point kneeling, and prone lying (ImageJ Software)	The total sagittal range of motion in standing was 20.2° ± 6.6°, consisting of 8.7° ± 5.8° of extension and 11.5° ± 3.7° of flexion. The mean amount of thoracic angle was 21.6° ± 5.6°. The magnitude of the thoracic kyphosis was associated with the end range extension position but not with the range of motion toward extension
Milanesi *et al*[21]	To verify the impact of the mouth breathing occurred in the childhood on the body posture in the adult age	Observational	*n* = 24 study group (subjects with history of mouth breathing during childhood) and 20 control group. The cervical and lumbar lordosis were assessed by angles and distances; and the thoracic kyphosis was assessed by angle (postural evaluation software-SAPO v 0.68®)	The cervical lordosis angle and the cervical distance measures were larger in the study group. The lumbar lordosis angle was smaller in the study group, meaning greater lumbar lordosis in these subjects. No significant difference was observed between the groups for thoracic kyphosis and lumbar distance

de Oliveira Pezzan *et al*[22]	To analyze the influences of wearing wedge high-heeled shoes on lumbar lordosis angle among adolescents who were users and nonusers of high-heeled shoes and to correlate these angles with ages and the time of high-heel use	Observational	*n* = 50 UG and *n* = 50 NUG of high-heeled shoes. The photographs were taken in a barefoot condition and with high-heeled shoes. Lumbar lordosis was assessed by angle (Postural Analysis Software)	The UG had lower lordosis angles compared with the NUG. In the barefoot condition, the lumbar lordosis angle in the NUG decreases, whereas the UG increases. In the high-heeled condition, the lumbar lordosis angles in the UG increased and in the NUG decreases
Yang *et al*[23]	To analyze the correlation between cost density and cosmetic outcomes in the surgical treatment of AIS	Observational	*n* = 58 cases of IAS. Measurements: Photographic preoperative and follow-up and determination of cost. The scoliosis was assessed by angles (trunk shift and rib hump) and distances (waist line asymmetry) (Adobe Photoshop CS4)	On all post-operative photographic variables measured there was no statistically significant correlation between increasing cost density and change in cosmetic variables from pre-op to follow-up
Silveira *et al*[24]	To assess postural changes based on age and their association with the respiratory function in mouth breathing children	Observational	*n* = 17 nasal breathing and 17 mouth breathing children. The pulmonary function was assessed by forced spirometer. It was assessed the neck lordosis and lumbar lordosis angle (Fisiometer®3.0 Software)	Mouth-breathing children have neck hyperlordosis which increase with age, besides reduction in spirometry values. There was no difference in the lumbar lordosis between the groups
Iunes *et al*[25]	To analyze the efficacy of the Klapp method for treating scoliosis	Randomized clinical trial	*n* = 16 patients with scoliosis. The cervical lordosis, thoracic kyphosis and lumbar lordosis were assessed by angles (ALCimagem®-2000 software) before and after of treatment with 20 sessions of the Klapp method	Only the lumbar lordosis angle suffered modification post-intervention with Klapp method, with a trend to its decrease
Belli *et al*[26]	To assess the body posture of children with asthma compared to a non-asthmatic control group matched for gender, age, weight and height	Observational	*n* = 30 asthmatic children and 30 control group. The cervical lordosis, thoracic kyphosis and lumbar lordosis was assessed by angles (ALCimagem®-2000 software)	A significantly lower thoracic kyphosis angle value was observed in the asthmatic children. However, no significant differences were found between groups for the other angles
Chase *et al*[27]	To determine whether a sample of children and adolescents with STC had trunk musculoskeletal characteristics different from age- and sex-matched control subjects	Observational	*n* = 40 subjects with STC and 40 control subjects. The passive angle of the trunk flexion-extension was measured in the in prone-lying and trunk forward flexion and sagittal plane sitting posture was assessed by measurement of thoracolumbar flexion-extension angle (ImageJ Software)	There was no difference in spinal mobility between the two subject groups. The thoracolumbar flexion angle during sitting was statistically higher in the STC group than control group
Iunes *et al*[12]	To compare the agreement between the visual postural assessment carried out and the postural assessment carried out through computerized photogrammetry	Observational	*n* = 21. Evaluations: Visual postural assessment and computerized photogrammetry. In the photogrammetry, the cervical lordosis, thoracic kyphosis and lumbar lordosis were assessed by angles (ALCimagem®-2000 software)	For the cervical lordosis, thoracic kyphosis and lumbar lordosis it was not possible to compare the visual analysis with that from photogrammetry because there are not reports in the literature about normality values of the vertebral curvatures
Iunes *et al*[28]	To compare cervical spine alignment among individuals, with and without TMD	Observational	*n* = 90 (30 control group, 30 muscle signs and symptoms of TMD and 30 muscle signs and symptoms of TMD such as established diagnoses of dislocation and joint disorders). The cervical lordosis was assessed by angle (ALCimagem®-2000 software)	There were no differences among the three groups regarding cervical lordosis. The presence of TMD did not influence cervical posture, independent of TMD type or lack
Penha *et al*[29]	To quantitatively characterize spinal posture to verify any differences in the postural aspects analyzed and their possible correlation to sex or age in 7- and 8-year-old public school students in the city of Amparo, São Paulo, Brazil	Observational	*n* = 230 (115 in 7-year-old and 115 in 8-year-old). The thoracic kyphosis, lumbar lordosis and lateral spinal deviation were assessed by angles (CorelDraw v.11.0 software)	Only the group of 7-year-old boys showed lower angles in the lumbar lordosis from the other groups. In the thoracic kyphosis, there was a difference between the age groups, the 8-year-old children were more kyphotic than the 7-year-old. Eighty eight point seven percent of the children showed lateral spinal deviation. The most common side was to the left, the most frequent location was thoracic, and the proportion of the deviation was greater for boys (63%) than for girls (45%)

Rodrigues *et al*[30]	To measure the degree of thoracic kyphosis in older adult women with and without spinal osteoporosis and to verify the difference between the obtained values	Observational	*n* = 12 (6 women with a spinal osteoporosis and 6 women with a spinal osteopenia). The thoracic kyphosis was measured by angles (Autocad-2006)	The degree of thoracic kyphosis of the women with osteoporosis (66.8°) were higher when compared with the values of the women with osteopenia (53.0°)
Straker *et al*[31]	To evaluate the relationships between cervical, thoracic and lumbar sagittal sitting postures and adolescent prolonged NSP, with consideration of gender	Observational	*n* = 1593 adolescents. NSP was assessed by a questionnaire. It was assessed the cervicothoracic, lumbar and trunk angles in three static sitting postures: Looking straight ahead, looking down at their lap, and sitting slumped (Peak Motus motion analysis system v.8)	There were significant differences between gender in cervicothoracic, lumbar and trunk angles. Females showed more erect and lordotic postures when looking straight ahead. Adolescents with prolonged NSP sat with a more flexed cervicothoracic angle, a lower extended trunk angle, and a lower lordotic lumbar angle
Iunes *et al*[32]	To assess whether the frequency of high heel use has any influence on postural changes, and whether the type of high heel interferes in the posture	Observational	*n* = 40 (20 women that wore high-heeled shoes every day and 20 women that wore high heels occasionally to social functions). The subjects were photographed wore a two-piece swimsuit and no shoes. The cervical lordosis, thoracic kyphosis and lumbar lordosis were assessed by angles (ALCimagem® - 2000 software)	The frequency of use and type of high heel did not modify static posture in women
Smith *et al*[3]	(1) To determine whether photographic assessment could result in similar subgroups to previous, radiographically determined subgroups and clinically used subgroups of sagittal standing posture; (2) To explore the profiles of the clusters on gender, height and weight, and to explore the relationship of various spinal pain variables with identified clusters	Observational	*n* = 766 adolescents. Back pain experience was assessed by a questionnaire contained 130 questions. It was assessed the lumbar and trunk angle (Peak Motus motion analysis system)	Using 2-dimensional photographic images, the standing, sagittal thoraco-lumbo-pelvic alignment of adolescents can be classified into 4 groups: Neutral, sway, hyperlordotic, and flat. Adolescents classified as having non- neutral postures when compared with those classified as having a neutral posture demonstrated significantly higher odds for back pain ever
Yi *et al*[33]	To investigate the relationship between diaphragm excursion and spinal curvatures in mouth breathing children	Observational	*n* = 52 children (22 nose breathing group - control and 20 mouth breathing group). Images of diaphragm excursion were recorded using anteroposterior X-ray. The cervical lordosis, thoracic kyphosis and lumbar lordosis were assessed by angles (postural evaluation software-SAPO)	There is no relationship between spinal curvatures and diaphragm excursion in the groups studied
Min *et al*[34]	To describe the WBKA measured on preoperative clinical photographs and its significance in operative planning	Observational (retrospectively)	*n* = 11 patients who underwent lumbar spine osteotomy. The WBKA were measured in preoperative and at the last follow-up (mean 4 yr)	The average WBKA was 41 degrees (20 to 70 degrees) preoperatively and was 10.5 degrees (8 to 14 degrees) at the last follow up
Straker *et al*[35]	To test the hypothesis that the duration of computer use is associated with habitual postures in male and female adolescents	Observational	*n* = 884 adolescents. The computer use was assessed by questionnaire. The angles of thoracic flexion (line of C7 to T12 with respect to vertical), cervico-thoracic angle (angle between line of tragus to C7 and line of C7 to T12), trunk (angle between line of C7 to T12 and line of T12 to greater trochanter) and lumbar (angle between line of T12 to ASIS and line of ASIS to greater trochanter) were assessed in three sitting postures: Looking down, looking straight ahead and slumped position (Peak Motus motion analysis system)	Males - sitting looking straight ahead: no significant associations were observed between levels of computer use and variable postures. Males - sitting looking down: Significant but weak linear trend was observed, with thoracic flexion increasing with computer use. Females - sitting looking straight ahead: Increasing levels of computer use associated with increased lumbar lordosis. Females - sitting looking down: increasing levels of computer use associated with decreasing lumbar angle. Males and females - sitting slumped: Increasing of computer use associated with decreasing lumbar angle, only in females

Szopa *et al*[36]	To identify and define some compensatory postural patterns in children with CP in vertical positions	Observational	*n* = 18 children with CP. The angle of mechanical spinal axis deviation from the anatomical axis, the relation of the plumb line to the gluteal slitin was measured in these positions: Standing with both feet, and one (right and left) foot, two-knee kneeling, one-knee (right and left) kneeling and sitting (software manufactured by INFOMED)	Two main compensational postural patterns were distinguished on this basis in hemiparetic children, called antigravitational and progravitational posturing. The lateral curve of the spine in both types was directed towards the healthy body side, but in the antigravitational type the healthy side was the overloaded one, whereas in the progravitational type it was the unweighted one
Amsters *et al*[37]	To compare the posture of people with tetraplegia of short duration and long duration, in a static but functional position in a manual wheelchair	Observational	*n* = 30 people with tetraplegia; *n* = 30 control group. The thoracic kyphosis was assessed in sit posture in the wheelchair by chest angle	Significantly greater of the kyphosis thoracic were demonstrated for the tetraplegic group compared with able-bodied groups
O'Sullivan *et al*[38]	To examine whether a relationship exists between spinal posture and LBP in a specific sub-group of industrial workers who reported flexion-provoked pain	Observational	*n* = 21 control subjects and 24 LBP subjects. The low back pain was assessed by questionnaire. The lumbar lordosis was measured as the angle between the intersection of the tangents drawn through the T10/L2 markers and the L4/S2 markers. Positions: Natural sitting and maximal slumped sitting postures, natural standing and maximal sway standing postures, and lifting and maximal standing lumbar flexion postures (Scion Image analysis software)	No difference was observed between the two groups when comparing their "usual" sitting, standing and lifting lumbar flexion angles. When comparing the lumbar angle difference between "usual" sitting and maximal slumped sitting, the LBP group sat significantly closer to their end of range lumbar flexion in their "usual" sitting posture
Milosavljevic *et al*[39]	To determine whether adaptive postural and movement characteristics were evident in the thoracic and lumbar spine as well as the hips of shearers, and to determine whether any observed adaptive changes were associated with either current or previous LBP	Observational	*n* = 64 shearers and 64 non-shearers. Lumbar sagittal lordotic posture was determined by cord angular change between T12, L3 and the PSIS and it was expressed in radians per metre (rad/m). Mid-upper and mid-lower sagittal thoracic curves were also calculated and expressed in rad/m about the T1, T4, T8, and T4, T8, T12 respectively. Three positions were analyzed: Flexion, normal stance, extension (CAD program)	The mean value for lumbar extension for shearers (9.88) was significantly less than for non-shearers (14.08). Lumbar flexion demonstrated similar mean scores for both groups and no significant differences were noted. Lower thoracic curvature for shearers (2.14 rad/m) was significantly "flatter". than for nonshearers (2.48 rad/m). Comparisons of both lumbar lordosis as well as upper thoracic kyphosis did not demonstrate any significant differences between the two groups. In the non-shearing group, participants with previous LBP had significantly reduced ranges of lumbar extension and lumbar flexion. Shearers with previous LBP did not demonstrate any significant reduction of either of these ranges of lumbar motion. The mean lumbar extension in the non-shearing subgroup with previous LBP was still greater than that of the shearer group
Munhoz *et al*[40]	To investigate the relationship between internal derangements of the TMJ and body posture deviations	Observational	*n* = 50 (30 individuals with TMJ internal derangement and 20 control group). The cervical lordosis, thoracic kyphosis and lumbar lordosis were assessed by distances of the most prominent region until of the plumb line (CorelDraw v.9.0 software)	No statistically significant body postural differences between the groups were observed
Lima *et al*[41]	To determine and compare the posture of children with OMB and FMB in relation to NB children	Observational	*n* = 62 children (17 OMB group, 26 FMB group and 19 NB group). The cervical lordosis, thoracic kyphosis, lumbar lordosis and lateral deviation of the spine were assessed by angles (ALCimagem®-2000 software)	Significant alterations were observed in cervical straightening in the OMB group. Significant changes were observed in the thoracic kyphosis, indicating convexity in the OMB group. For the lumbar lordosis and lateral deviation of the spine, no significant alterations were observed in any of the groups

Raine *et al*[42]	To quantitatively describe the curvature of the thoracic spine in the sagittal plane	Observational	*n* = 160 asymptomatic men and women. The upper and lower thoracic kyphosis was assessed by the tangent angles in radians/mm between C7-T6 and T6-T12, respectively	Results of thoracic kyphosis were not shown
Christie *et al*[43]	To evaluate any static standing or sitting postural aberrations in chronic and acute low back pain patients in comparison with healthy individuals, in search of potential risk factors or associations for LBP	Observational	*n* = 59 (39 participants with LBP and 20 control group). Pain intensity was recorded using a VAS. The subjects were divided in acute and chronic pain. The lumbar lordosis and thoracic kyphosis was assessed by angles between C7-T12 and T12-L5, respectively, in standing and sitting positions	Standing positions: The chronic pain group had a significantly increased lordosis compared with the control group. The acute group had an increased kyphosis than the control group. Lumbar lordosis is the parameter most important in prediction of LBP group. Sitting positions: individuals with acute pain had an increased thoracic kyphosis. Thoracic kyphosis, indicated contribution to the prediction of study group
Watson[44]	To investigate possible relationships between the incidence of sports injury and the existence of body posture defects in football players	Observational	*n* = 52 football players (soccer, rugby, Gaelic football). The injuries were divided in four categories: Back injuries, knee injuries, ankle injuries and muscle strains. The assessment of the scoliosis, thoracic kyphosis and lumbar lordosis were not clear	Back injuries were associated with thoracic kyphosis, lumbar lordosis and scoliosis. Subjects who suffered from two, three or all four types of injuries had significantly lower scores for lordosis than subjects who sustained less than two types of injuries
Raine *et al*[45]	To identify gender differences in the thoracic kyphosis and to correlate thoracic kyphosis with head and shoulder position	Observational	*n* = 39. The upper (C7-T6) and lower (T6-T12) thoracic curvature were measured from the surface contour of the thoracic spine by the tangent angles in radians/cm (GTCO digitizer)	No significant difference between females and males for the measurement of upper thoracic, however the lower thoracic was significant higher in males. The sagittal plane head alignment was negatively correlated with upper thoracic curvature; there was increased curvature of the upper thoracic spine when the head was placed more anteriorly
Mitchell *et al*[46]	To report a new method of measuring the angle of curvature of the lumbar spine in pregnant women	Observational	*n* = 13 pregnant women. The lumbar lordosis was assessed by angle between T12-L1 and L5-S1	The degree of lumbar spine curvature in pregnant women was 33.9° (± 3.6°)
Dieck *et al*[47]	To examine the relationship between postural asymmetry and the subsequent development of back and neck pain	Observational	*n* = 903 women. Back and neck pain and risk factors were obtained by questionnaire. Deviation of the spine from de midline of the body to scoliosis measurement was assessed by angle	There was no evidence of a relationship between increasing midline deviation and subsequent low back pain

PAS: Postural Assessment Software; CP: Cerebral palsy; AIS: Adolescents idiophatic scoliosis; STC: Slow transit constipation; TMD: Temporomandibular disorder; UG: Users group; NUG: Nonuser group; NSP: Neck/shoulder pain; WBKA: Whole body kyphosis angle; LBP: Low back pain; TMJ: Temporomandibular Joint; OMB: Obstructive mouth breathing; FMB: Functional mouth breathing; NB: Nasal breathing; VAS: Visual analogue scale.

the samples comprise patients with asthma[15,26], tetraplegia[37], cerebral palsy[16,36] temporomandibular joint dysfunction[28,40], osteoporosis and osteopenia[30], low back pain[38,43], slow transit constipation[27] and children with mouth breathing[21,24,33,41].

With regard to the region of the spine evaluated, greater difficulty has been documented in evaluating the sagittal plane compared to the frontal plane. This may be explained by the fact that, in the frontal plane, symmetry between the right and left sides and straightness of the spine can be expected[6,12]. By contrast, in the sagittal plane, the spine presents physiological curvatures and changes characterized by an increase or decrease in the magnitude of the curvatures[50], which hinders visual and subjective evaluation. In an attempt to quantify the magnitude of the curvatures, various mathematical procedures have been proposed for evaluating the sagittal curvature of the spine. Possibly for this reason, about 80% of the studies found in this systematic review attempted to evaluate cervical lordosis, thoracic kyphosis and lumbar lordosis, while only eight articles evaluated the existence of scoliosis[16,17,23,29,36,41,44,47].

Nevertheless, in the literature, there is still a need for postural evaluation software that can be used to do more than quantify joint angles and the distances between the segments, which, in addition can, be used to provide a diagnostic classification of changes in the magnitudes of the spine in individuals. To achieve this, normality values of body segments need to be established in the literature. However, regarding the spine, there is some controversy in relation to the reference values for the angles of curvature in the sagittal plane in the ideal alignment[12].

The data collection protocols in the studies using

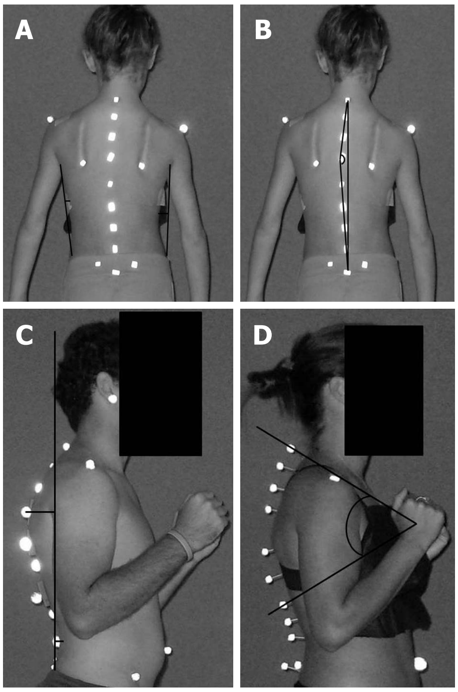

Figure 2 Examples of the techniques used to measure spinal curvature found in the articles composing the present systematic review. A: Linear values for scoliosis evaluation[23]; B: Angular values for scoliosis evaluation[17]; C: Linear values for thoracic and lumbar curvatures[21]; D: Angular values for thoracic curvature[30]. The images used are illustrations prepared for the present study.

photogrammetry as an evaluation tool tend to be very similar, differing minimally according to the purpose of each evaluation. All the methods are based on basic procedures such as: (1) preliminary preparation of the collection location with standardized location of the camera and the subject; (2) palpation and marking of anatomical reference points; and (3) photographic records of individuals in certain positions[2,8,9,45].

However, concerning the data analysis procedures, various software and digital routines are used for scanning anatomical landmarks. Similarly, the mathematical procedures adopted in software or digital routines are very different[51]. Nevertheless, in most cases, the studies do not provide information on the mathematical procedures adopted in the software or in digital routines that support the evaluation results. Allied to this, in some cases the software is not freely available, which makes it difficult to reproduce the evaluation method in other studies.

Therefore, we emphasize the wide divergence of software and mathematical procedures found in this review. Among the known and validated software packages used repeatedly in the selected articles are ALCimagem®-2000[12,25,26,28,32,41], Postural Assessment Software (PAS)[15,19,21,22,33], Peak Motus Motion Analysis System[3,31,35], CorelDraw[29,40], AutoCad[16,30] and Image J Software[8,27].

As regards the various mathematical routines embedded in these systems, angular and linear values have been the most widely used to measure alterations of the spine in the frontal and sagittal planes, *i.e.*, to determine the magnitudes of scoliosis and anteroposterior curvatures, respectively. Figure 2 illustrates some of the techniques used to measure the spinal alterations.

The angular values are often used, since the gold standard of postural assessment uses an angular calculation to measure the degree of scoliosis and the magnitude of the sagittal curvature of the spine. In other words, in the X-ray examination of the spine it is possible to calculate the so-called Cobb angle, which is widely used for diagnosis of spinal posture[52].

Some of the selected studies evaluate the angles of scoliosis using photogrammetry in a similar way to the Cobb angle[17,23]. However, while the Cobb angle uses the vertebral bodies for evaluation, photogrammetry calculates the magnitude of the curve through the spinal processes of the vertebrae of interest. For this evaluation, two lines are drawn joining the spinous processes and the angle between these lines gives the angle of curvature[17,23].

The linear values in the frontal plane are established according to the statement that the spine should be a straight line[6]. Hence, methodologies calculate postural alteration by the degree to which marked points, referring to the spinous processes, deviate from the vertical line[23,29,36,47].

In the sagittal plane, angular values are more often used than linear values for evaluating the anteroposterior curvatures of the spine.

Similar to the Cobb angle, photogrammetry is recommended for use in evaluating the spinal curvature based on the calculation of the angle between two points on the spine[30,43,46]. However, it uses the spinous processes as a reference, while radiography uses the vertebral bodies.

Nevertheless, it should be noted that the spinous processes have an angle of inclination in relation to the vertebral body[53] and that this angle may interfere with obtaining the angle of curvature by photogrammetry. Thus, caution is recommended when using a similar method to the gold standard in the mathematical procedures of postural evaluation software, since palpated anatomical landmark and used with reference is totally different.

When the photogrammetric evaluation software resembles the way of measuring the magnitude of the curves, they diverge in relation to vertebral levels used or anatomical landmarks. When distinct marked points are used, the calculation of curvatures will be modified, making it difficult to compare studies. In the studies included in this systematic review, some vertebral levels reported for thoracic kyphosis were between: C7-T12[43], T1-T4-T8[39], T4-T8-T12[39] and T1-T6-T12[20]. For lumbar lordosis they were between T12-L5[43], T12-Anterior superior iliac spine - femur greater trochanter[3,31,35].

Besides the similarity with the calculation of Cobb angle, some recurring angular values were calculated angles for the three curvatures: (1) cervical lordosis: the union of three lines passing through occipital, C4 and C7 until a later vertical line; (2) thoracic kyphosis: The union of three lines passing through C7, T7 and T12 until a posterior-vertical line; and (3) lumbar lordosis: Union of three lines passing through T12, L3 and L5 posterior to a vertical line[12,22,25,26,28]. Among these possibilities for measuring sagittal curvature, routines based on other types of calculations were also found, such as the curvatures of the contour tangent[38,42,45], torso angle[3,16,31,35], and chest angle[37].

According to the theories that use linear values to evaluate the spine in the sagittal plane, alterations in the curvature can be quantified by measuring the distance from the spinous process to a vertical reference line. In rectified curvatures, the distances decrease, while in increased curvatures the distances increase[6].

Despite the wide range of mathematical procedures that can be used to quantitatively evaluate the spine, inserted in photogrammetry, in clinical practice and research, health professionals and students are often faced with a scarcity of tools that allow them to classify an individual's posture. In other words, the angular or linear results provided by software often lack clinical significance because they are not equivalent to the gold standard. Thus, the benefits, limitations, target audience, and use characteristics of photogrammetry need to be carefully considered when selecting the software and/or mathematical procedure in order to facilitate the correct choice of evaluation methodology for different situations, both in clinical and in scientific research.

The present systematic review shows that photogrammetry can be widely used in the scientific research environment, because it facilitates the collection and analysis of detailed data, thus permitting assessment not only of the spine but also of other body segments in both the sagittal and frontal planes. On the other hand, in the school environment, data collection should prioritize simplified protocols, thus facilitating the assessment of large populations. Moreover, the software and mathematical procedures for the postural analysis should be easily available, as are PAS and ALCimagem®-2000. In the clinical environment, the choice of photogrammetric data collection and of the assessment protocol will depend on the purpose of the postural evaluation, as well as the health professional's investigative focus, so that a simplified or more complete assessment protocol can be used.

A wide range of studies was found to use photogrammetry as a tool for non-invasive evaluation of the spine, both for measurement of anteroposterior and lateral alterations. However, most of the selected articles were observational studies, only one being a randomized clinical trial.

Yet, it was also observed that, although the data collection methodologies used are similar across the studies, they are very different concerning aspects of data analysis, especially with regard to the mathematical routines that support the different software packages for postural evaluation. Finally, even though photogrammetry is a viable, valid and reproducible option for the evaluation of the spine, there is still a lack of studies in the literature showing software whose results provide both the magnitude of the curvatures and the diagnostic classification of the posture of the spine, certified with clinical significance.

COMMENTS

Background

Photogrammetry is a widely used non-invasive technique for measuring aspects of the spine for the purpose of postural evaluation. Its use undoubtedly contributes to reducing exposure to radiation and thus enables the monitoring of postural treatment. However, the application of this technique in postural evaluation is directly dependent on both the collection procedures and the mathematical methods used to provide measurements and postural diagnoses. Although the use of photogrammetry in spinal evaluation is widespread, its applicability may be questioned, as it remains unclear how this technique is being used to monitor postural treatment or to map attitudes among populations in observational studies.

Research frontiers

Essentially, the problem is two different researchers can look at the same image and arrive at different conclusions regarding diagnosis because they use distinct mathematical methods. Hence, there is a need to identify the best method of using photogrammetry to accurately measure spinal curvatures.

Innovations and breakthroughs

To be best of the authors' knowledge there is no systematic review which brings together the protocols and mathematical methods involved when it is applied in the assessment of spinal posture. Hence, the aim of this study is to present, in a concise way, the articles dealing with the application of photogrammetry in postural evaluation, so researchers can more easily discuss the suitability of the procedures currently being applied.

Applications

With photogrammetry, the aim of the assessment, whether it is for clinical, research or collective health purposes, must be considered when choosing which protocol to use to evaluate spinal posture. When using photogrammetry in scientific research, a protocol or software that provides detailed postural analysis should be the first choice. In the clinical environment, the choice of protocol will depend on the objectives established for the patient by the physiotherapist. When dealing with a collective health situation, such as groups of schoolchildren, it is necessary to prioritize simpler protocols.

Terminology

Photogrammetry: Is the technique of determining measurements based on photographs. The Cobb angle: Is used to measure the spinal curvatures, defined as the angle formed between a line drawn parallel to the superior endplate of one vertebra above the curvature and a line drawn parallel to the inferior endplate of the vertebra one level below the curvature.

Peer-review

This article demonstrates an in-depth review of the available literature on the application of photogrammetry in postural evaluation.

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