World Journal of Rheumatology

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DOI: 10.5499/wjr.v5.i2.69

World J Rheumatol 2015 July 12; 5(2): 69-81
ISSN 2220-3214 (online)

REVIEW

Radiographic assessment of leg alignment and grading of knee osteoarthritis: A critical review

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Author contributions: Sheehy L designed and wrote the initial draft of the paper and revised it; Cooke TDV conceived the paper and revised it for critically important content. Both authors approve the final version.

Conflict-of-interest statement: Cooke TDV is the president and shareholder of Orthopedic Alignment and Imaging Systems (OAISYS) Inc.; Cooke TDV has received salary support from OAISYS Inc.; Sheehy L declares no conflicts of interest.

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Received: November 18, 2014
Peer-review started: November 19, 2014
First decision: February 7, 2015
Revised: February 25, 2015
Accepted: May 5, 2015
Article in press: May 6, 2015
Published online: July 12, 2015

Abstract

Knee osteoarthritis (OA) is a progressive joint disease hallmarked by cartilage and bone breakdown and associated with changes to all of the tissues in the joint, ultimately causing pain, stiffness, deformity and disability in many people. Radiographs are commonly used for the clinical assessment of knee OA incidence and progression, and to assess for risk factors. One risk factor for the incidence and progression of knee OA is malalignment of the lower extremities (LE). The hip-knee-ankle (HKA) angle, assessed from a full-length LE radiograph, is ideally used to assess LE alignment. Careful attention to LE positioning is necessary to obtain the most accurate measurement of the HKA angle. Since full-length LE radiographs are not always available, the femoral shaft - tibial shaft (FS-TS) angle may be calculated from a knee radiograph instead. However, the FS-TS angle is more variable than the HKA angle and it should be used with caution. Knee radiographs are used to assess the severity of knee OA and its progression. There are three types of ordinal grading scales for knee OA: global, composite and individual feature scales. Each grade on a global scale describes one or more features of knee OA. The entire description must be met for a specific grade to be assigned. The Kellgren-Lawrence scale is the most commonly-used global scale. Composite scales grade several features of knee OA individually and sum the grades to create a total score. One example is the compartmental grading scale for knee OA. Composite scales can respond to change in a variety of presentations of knee OA. Individual feature scales assess one or more OA features individually and do not calculate a total score. They are most often used to monitor change in one OA feature, commonly joint space narrowing. The most commonly-used individual feature scale is the OA Research Society International atlas. Each type of scale has its advantages; however, composite scales may offer greater content validity.

Responsiveness to change is unknown for most scales and deserves further evaluation.

Key words: Osteoarthritis; Mechanical axis angle; Knee; Radiography; Alignment; Grading scales; Assessment; Hip-knee-ankle angle; Femoral shaft-tibial shaft angle; Anatomic axis angle

Core tip: Radiographs are commonly used for the clinical assessment of knee osteoarthritis (OA) and to assess for risk factors. One risk factor for knee OA is malalignment of the lower extremities (LE). LE alignment is ideally measured from a full-length LE radiograph. While knee radiographs are sometimes used, the resulting angle is much more variable and should be used with caution. Knee radiographs are also used to assess the severity of knee OA. Global, composite and individual feature grading scales may be used. Each type of scale has its advantages; however composite scales may offer greater content validity.

Sheehy L, Cooke TDV. Radiographic assessment of leg alignment and grading of knee osteoarthritis: A critical review. *World J Rheumatol* 2015; 5(2): 69-81 Available from: URL: http://www.wjgnet.com/2220-3214/full/v5/i2/69.htm DOI: http://dx.doi.org/10.5499/wjr.v5.i2.69

INTRODUCTION

Osteoarthritis (OA) is a progressive joint disease hallmarked by cartilage and bone breakdown. In knee OA, excessive or prolonged force or instability leads to fibrillation and thinning of the articular cartilage[1]. Associated with cartilage changes, the periarticular bone remodels, causes osteophytes. Erosion of the subchondral bone occurs as the cartilage continues to wear. Deeper into the bone structure, areas of sclerosis and cysts form. It has been acknowledged recently that other tissues, such as ligaments, menisci and synovium are also affected in knee OA. These whole joint changes ultimately cause pain, stiffness, deformity and disability in many people.

The prevalence of knee OA ranges from 5.4% in Italy to 38% in South Korea[2-9]. These numbers show the rate at which the population is affected by knee OA, and suggest that a significant portion of older adults, at least one in twenty, and up to one in three, may be dealing with knee pain, stiffness and related disability.

Despite the increasing use of magnetic resonance imaging (MRI) for knee OA research, radiographs are most commonly used for the clinical assessment of knee OA incidence and progression. Articular features of knee OA such as osteophytes, joint space narrowing (JSN), sclerosis and bony deformity may be observed on a knee radiograph, which is simple and fast to obtain. Radiographs are also used to assess frontal-plane alignment. This information may be used to identify the risk of knee OA incidence and progression and may be used for treatment planning. The first part of this review will address the measurement of tibiofemoral (TF) frontal-plane alignment. The measurement of knee OA severity and progression from knee radiographs will be discussed in the second part of this review.

Malalignment of the lower extremity (LE) has been identified as one factor associated with knee OA development[10]. Being bow-legged (varus, genu varum) is the most common frontal-plane malalignment; it leads to increased loading in the medial TF compartment[11]. Being knock-kneed (valgus, genu valgum) decreases the loading in the medial TF compartment but increases the loading in the lateral TF compartment. Increased loading is associated with an increased risk of OA in that TF compartment. Progression of existing knee OA is highly associated with varus [odds ratio (OR) 2.90 to 10.96, $P < 0.05$] and valgus (OR 3.42 to 10.44, $P < 0.05$) deformities[11-17]. The risk for progression increases with the degree of deformity[11,13,14,16,18]. The association of knee OA onset and malalignment is weaker (varus OR 2.1, $P < 0.05$; valgus OR 2.5, $P < 0.05$)[16,17].

It is important that LE alignment is measured accurately, so that interventions can be prescribed appropriately, and research studies which include LE alignment can be compared to one another. The presence of varus or valgus alignment may suggest the need for early intervention, for example, orthotics, braces or surgical correction (tibial osteotomy)[16,19]. An accurate measurement of alignment is also essential for proper placement of the implant during knee arthroplasty surgery. Proper placement resulting in restoration of neutral alignment ensures more even load distribution and prevention of premature wear and loosening of the implanted joints[20-25].

The diagnosis of knee OA is based on symptoms of pain and stiffness, and the presence of OA changes on a knee radiograph. Assessment of the knee by plain radiographs is routinely done to define the presence and severity of knee OA for diagnosis, to monitor progression and to guide treatment decisions[26-29]. In research studies, radiographic assessments are also used to guide participant eligibility and to stratify participants according to OA severity[5,30]. Individual characteristics such as biometrics (body mass index, age, *etc.*), involvement of other joints, malalignment, family history and history of injury are commonly correlated to measures of knee OA severity to investigate risk factors[30-36]. Studies of potentially disease-modifying OA drugs and other treatments also use knee OA assessments as outcome measures[37,38].

Grading scales are applied to knee radiographs to rate the severity of OA (Table 1). Current scales vary from poor to excellent in their reliability[26,39,40], poor to moderate in their sensitivity to change[41,42] and negligible to moderate in their relationship to other knee OA features (pain, alignment, function)[43-45]. Consistent use of a reliable, valid and responsive grading scale would

Table 1 Summary of knee osteoarthritis grading scales

Scale type	Ref.	Pros	Cons	Uses
Global	Kellgren and Lawrence[67,69]	Widely used Adopted by the World Health Organization (1961) and at the 3rd International Symposium of Rheumatic Disease (1966) Moderate to excellent reliability	Multiple descriptions of the levels have been published Emphasizes osteophytes Poor sensitivity to change	Epidemiological studies Outcome measure (research) Clinical use
	Ahlbäck[65] Galli[91]	One version uses a template, placed over a radiograph, to show typical bone contour	Poor reliability Emphasizes joint space narrowing	Epidemiological studies
	Sundaram *et al*[68]		No psychometric testing Defines early OA as osteophytes only	Epidemiological study for knee OA after tibial dome osteotomy
	Brandt *et al*[66]	Good correlation to damage seen at arthroscopy	No reliability testing performed Emphasizes joint space narrowing	Classify participants for research studies
Composite	Satku *et al*[97]	Includes a variety of features of knee OA	No psychometric testing	Used in research to describe OA development after anterior cruciate ligament tears
	Kannus *et al*[96]	Includes many features of knee OA, in a variety of locations in the knee Good reliability	Very complicated	Used in research to describe OA development after anterior cruciate ligament tears
	McAlindon *et al*[99]	Moderate reliability Includes several compartments of the knee	Assesses both knees at once	Research on the association between knee pain, disability, strength and radiographic evidence of knee OA
	Merchant *et al*[98]	Includes several features of knee OA	No psychometric testing	Research on the onset of knee OA after ankle or lower leg injuries
	Compartmental grading scale for knee OA (CG) Cooke *et al*[100]	Includes several features of knee OA Excellent reliability		Epidemiological studies Part of the Knee Surgery Triage Tool
Individual	Osteoarthritis Research Society International atlas Altman *et al*[26] Thomas *et al*[110] Cooper *et al*[105]	Most commonly-used individual OA feature scale Moderate reliability	Often used to assess only joint space narrowing No psychometric testing No psychometric testing	Epidemiological studies Monitor progression of knee OA
	Spector *et al*[30,34,109] Braga *et al*[116] O'Reilly *et al*[117]	Fair to excellent reliability		Epidemiological studies Classify participants for intervention studies
	Scott feature based scoring system Scott *et al*[82]	Scores 8 different OA features Fair to excellent reliability		Epidemiological studies Outcome measure
	Nottingham logically derived line drawing atlas Nagaosa *et al*[107]	Line drawings are meant to avoid problems using radiographs in an atlas Moderate reliability		Epidemiological studies Outcome measure (research)
	Knee images digital analysis Marijnissen *et al*[130] Muraki *et al*[131]	Uses continuous scales Excellent reliability	Only good-quality radiographs can be used	Epidemiological studies
	Knee OA computer-aided diagnosis Oka *et al*[81]	Uses continuous scales Excellent reliability		Epidemiological studies

OA: Osteoarthritis.

ensure relevant longitudinal clinical evaluations and the ability to compare results between research studies.

FRONTAL-PLANE LE ALIGNMENT

Determination of LE alignment using full-length radiographs

The criterion standard measure of frontal-plane LE alignment is the hip-knee-ankle (HKA) angle, also known as the mechanical axis angle, measured from a full-length LE radiograph[46-48]. This is the angle subtended by a line drawn from the centre of the femoral head to the center of the knee (femoral mechanical axis) with a line drawn from the center of the knee to the centre of the tibial plafond or ankle talus (tibial mechanical axis) (Figure 1). Varus angles are commonly designated negative and valgus angles positive[48]. "Normal" alignment in healthy adults is generally considered to be 1° to 1.5° of varus,

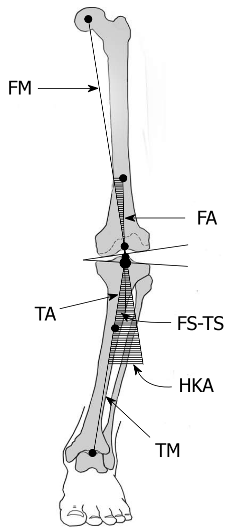

Figure 1 Diagram of a varus knee illustrating the mechanical and anatomic axes and angles. The FS-TS angle is 4° to 6° valgus compared to the HKA angle. (Modified from Cooke and Sled[46]). FM: Femoral mechanical axis; TM: Tibial mechanical axis; FA: Femoral anatomic axis; TA: Tibial anatomic axis; HKA: Hip-knee-ankle angle (mechanical angle); FS-TS: Femoral shaft-tibial shaft angle (anatomic angle).

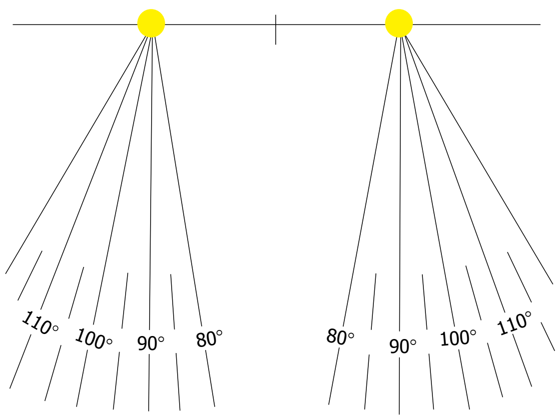

Figure 2 Calibrated template, used to position feet and to reliably measure lower extremity rotation. (Modified from Orthopedic Alignment and Imaging Systems, Inc.)

or -1° to -1.5°[49-51].

The points used for determining the HKA angle have varied, especially around the knee[47,48]. The centre of the femoral head is found by placing a circle template over the femoral head on the radiograph, then marking the centre of this circle. There are several locations which may be used for the points at the knee. Many use a single point, often the centre of the tibial spines[11,47,49]. Moreland *et al*[51] used a single point at the knee that was the average of several measured knee landmarks. Others used the centre of the femoral intercondylar notch as the distal point for the femoral mechanical axis, and the centre of the tibial interspinous groove as the knee point for the tibial mechanical axis[11,48,52,53]. Using two points at the knee is preferred because it allows for the identification of the femoral and tibial contributions to deformity, and to define the extent of knee subluxation[48] (Figure 1). The centre of the talus or tibial plafond at the ankle is determined using a ruler placed on the radiographic image.

LE positioning

Use of a standardized and replicable approach for LE positioning is important for reliable and accurate alignment measurements. Changes in limb rotation, foot position and knee flexion alter the HKA angle[46,48,54,55]. For example, external rotation has been shown to increase the appearance of varus malalignment[56]. Some authors use a self-selected stance or the Romberg stance position (with medial borders of feet touching)[57]. Others use anatomical landmarks based on such features as the patella and the tibial tubercle[46]. None of these methods account for the variability between individuals with respect to rotation of the femur and tibia, position of the bony landmarks, flexibility of the feet (for example, pes planus leads to internal rotation of the tibia) and the relative length of the hip musculature (for example, a tight piriformis can lead to excessive external rotation of the hip when in a self-selected stance position).

The LE should be positioned in neutral alignment such that the knee flexion angle is directly in the sagittal plane[46]. This is accomplished by positioning the patient or participant with the heels placed a standard distance apart (for example, 9 cm between the centres of the heels) and adjusting the rotation of the legs until the knee flexion axis, observed as the knee is flexed and extended, lies directly in the frontal plane. Foot position may be recorded from a template marked in degrees of internal and external rotation (Figure 2). Use of a template allows for reliable repositioning at subsequent assessments.

Determination of LE alignment using knee radiographs

Full-length LE radiographs are not always used. They require specialized equipment and technician training, are more costly and expose the patient to higher doses of radiation, particularly at the pelvis. As a result, knee radiographs are often used to estimate alignment and the HKA angle[17,58]. The angle calculated on a knee radiograph is called the femoral shaft-tibial shaft (FS-TS) angle, or the anatomic axis angle[47]. This is the angle subtended by a line drawn from the centre of the femoral shaft proximal to the knee (femoral anatomic axis) and a line drawn from the centre of the tibial shaft distal to the knee (tibial anatomic axis). The femoral and tibial shaft points are generally measured 10 cm from the knee joint, to accommodate the portion of the long-bone shafts commonly seen on a knee radiograph[47,51]. The tibial anatomic axis is similar to the tibial mechanical axis (Figure 1). Similar to the definition of the HKA angle, one or two points at the knee may be chosen to determine the anatomic axes[59]. The tibial interspinous point is frequently used as a single point reference at the knee[47,49].

There are concerns that the FS-TS angle does not

Type of scale	Representative scale					
Global scale	Kellgren-lawrence scale[67]	Grade 2				
Composite scale	Compartmental grading scale for knee OA[100]	Joint space narrowing 1	Femoral osteophytes 2	Tibial erosion 0	Subluxation 0	Total score 3
Individual OA feature scale	Osteoarthritis Research Society International atlas[26]	Joint space narrowing 2				

Figure 3 Knee radiograph assessed with representative global, composite and individual feature osteoarthritis grading scales. The knee is in neutral rotation and slight varus alignment. The medial tibiofemoral compartment is most-affected. OA: Osteoarthritis.

produce an accurate estimate of the HKA angle[53,60]. The FS-TS angle is offset towards valgus compared to the HKA angle by 4° to 6° for healthy individuals and 1.5° to 7° in individuals with knee OA[47,49,52,59,61], with a low to high correlation between the two measurements, r = 0.34 to 0.88, P < 0.005 in participants with knee OA[47,58,59,61,62]. The offset between the HKA and FS-TS angles is significantly greater in individuals with knee OA compared to healthy controls (t-test, P < 0.001)[52]. Two factors influence the relationship between the FS-TS and HKA angles. The first is the nature and severity of varus or valgus deformity[52,63,64]. The second factor is the length of the femoral and tibial shafts used when calculating the FS-TS angle[49,51]. In two studies, the FS-TS angle measured with a short femoral anatomic axis was 4.0° to 4.2° more valgus than the HKA angle, but with a long femoral anatomic axis the difference was 5.8° and when using the entire femoral shaft the difference was 4.9° to 5.9° [49,51]. In another study, the FS-TS angle measured with a short femoral anatomic axis for individuals with moderate to severe varus alignment, was an average of 7.4° more valgus than the HKA angle while for individuals with moderate to severe valgus alignment, the FS-TS angle was an average of 2.3° more valgus[60]. These studies illustrate how the shape of the femoral shaft impacts the relationship between the HKA and FS-TS angles. In order of importance, lateral bowing of the femoral shaft, tibial bowing and the angle between the tibial plateau and the tibial shaft all influence the relationship between these angles[52]. The FS-TS angle also shows more variability than the HKA angle[49,60]. The variability is increased when FS-TS angle measurements are calculated using a shorter amount of the femoral and tibial shaft lengths. Therefore it is recommended that the HKA angle, measured from a full-length LE radiograph, should be used to ensure an accurate measurement of LE alignment[62].

Summary and recommendations

Because frontal-plane alignment is an important risk factor for the onset and especially the progression of knee OA, it is regularly assessed for research and clinical purposes. The "gold standard" evaluation of frontal-plane alignment is the HKA angle measured from a full-length LE radiograph; however knee radiographs are often used to calculate the FS-TS angle, used to estimate the HKA angle. There is an offset between these angles of 4° to 6°, but this offset varies depending on the type and degree of malalignment of the individual, and the method used to calculate the FS-TS angle. For the above reasons, we strongly recommend that the HKA angle be used for clinical and research purposes whenever accurate information on alignment is needed. Attention to careful positioning of the limb with the knee flexion axis directly in the frontal plane will reduce rotational errors.

GRADING THE SEVERITY OF TF OA

Global scales

Global scales are ordinal scales that have specific descriptions for each grade[65-68]. Each level describes one or more features of OA that must be met for that particular level to be ascribed to a radiographic image. Global scales require an individual's particular presentation of OA to "fit" all of the criteria for a given level of the scale. The earliest and by far the most commonly-used global scale is the Kellgren-Lawrence (KL) grading scale[67] (Figure 3). Others include those developed by Ahlback[65], Sundaram *et al*[68] and Brandt *et al*[66].

KL Grading scale

The KL scale, first described in 1957, gives an overall score of OA severity from zero to four[67,69]. Their scale was applied widely for any joints affected by OA and served as an important screening tool in epidemiological studies. In their initial publication the authors considered the following features evidence of OA: osteophytes on the joint margins or the tibial spines; periarticular ossicles; narrowing of joint space associated with sclerosis of subchondral bone; small pseudocystic areas, usually in the subchondral bone; and altered shape of the bone ends[67]. Both TF compartments of the knee were assessed using a standard set of radiographs for reference. Considering all features of OA, a grade of zero (no OA), one (doubtful OA), two (minimal OA), three (moderate OA), or four (severe OA) was given. Inter-rater reliability was reported (Pearson's $r = 0.83$), but the authors acknowledged that one of the two readers consistently assessed the radiographs as showing more severe OA, illustrating the difficulty of using Pearson's correlation coefficients to adequately assess reliability. Intra-rater reliability was the same (Pearson's $r = 0.83$).

In 1963 an atlas (republished in 2005[70]) was produced by Kellgren *et al*[69] which included written descriptions of each grade: Grade 1: doubtful narrowing of joint space and possible osteophytic lipping; Grade 2: definite osteophytes and possible narrowing of joint space; Grade 3: moderate multiple osteophytes, definite narrowing of joint space and some sclerosis and possible deformity of bone ends; and Grade 4: large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone ends.

Later, in a 1977 publication, Lawrence[71] described the grades as such: Grade 1: minute osteophyte of doubtful significance the only feature; Grade 2: definite osteophyte, joint space unimpaired; Grade 3: moderate diminution of joint space; and Grade 4: joint space greatly impaired, subchondral sclerosis.

The KL scale was adopted by the World Health Organization in 1961 and has remained the most prominent scale for screening OA and grading disease severity[72]. Its use as a standard evaluation for radiographic knee OA was reconfirmed at the third International Symposium on Rheumatic Disease in New York in 1966[73]. OA incidence is defined by a KL grade of two[67].

Despite its widespread use, there are continuing concerns about the KL scale[72,74,75]. As evident in the above descriptions, osteophytes must be present for a KL grade greater than zero to be given. The radiographic presentations of knee OA vary. Some show JSN but lack osteophytes; they would be assessed as grade zero on the KL scale[66]. For the Framingham OA Study, Felson *et al*[76] modified the KL scale by adding a second grade two category for radiographs showing JSN without osteophytes. None of their participants actually fit this new category, highlighting the difficulties of using the KL scale for assessment of knee OA[76].

A second important issue is that there are multiple descriptions of the KL grades which create variability in their interpretation[40,74,77,78]. This variability may allow individual research participants to be misidentified as having, or not having, OA, and creates difficulty in comparing research studies[74,79].

Several authors have assessed the intra- and inter-rater reliability of the KL scale[39,40,80-83]. Intra-rater reliability [Cohen's weighted kappa 0.50 to 0.88; Cohen's kappa 0.84 to 0.99; Spearman's correlation coefficient 0.89; Intraclass correlation coefficient (ICC) 0.85 to 0.93] and inter-rater reliability (Cohen's weighted kappa 0.56 to 0.80; Cohen's kappa 0.59 to 0.76; Spearman's correlation coefficient 0.85; ICC 0.68 to 0.84) generally fall in the moderate to excellent range[39,40,80-85].

A lack of sensitivity to change using the KL scale has been reported[41], and although it was not created to follow change in OA severity over time, but rather to be used as a screening tool for epidemiological studies, it is frequently used for this purpose[74,86]. There are only five grades, and the scale is not linear. Differentiating between grades zero and one, and one and two can be especially difficult[74,79,87]. To illustrate this point, the border between "possible osteophytic lipping (grade one)" and "definite osteophytes (grade two)" is very subjective and the "narrowing of joint" in the grade three description can include joints with almost no joint narrowing to joints with almost no joint space left[74]. In order to increase its sensitivity to change, Felson *et al*[74] proposed two changes to the KL scale: grade two to include the requirement of both osteophytes and JSN, and a new grade, two/osteophyte, which describes a knee with osteophytes but no JSN. They do admit that further changes, while addressing some of the problems, might also add to the confusion created because of different definitions of the scale.

KL grades are moderately to poorly correlated with cartilage lesions (Spearman's correlation $r = 0.55$, $P < 0.01$) and cartilage volume (Pearson's correlation $r = -0.30$ to -0.49 depending on location, $P < 0.01$) as measured from MRI[44,88]. Correlations of KL grade to cartilage damage seen at arthroscopy are similar to those measured from MRI (Pearson's correlation $r = 0.49$, CI: 0.38 to 0.59), with a higher association for the medial compartment[89,90]. These results suggest that the KL scale, with its emphasis on osteophytes, has significant limitations for the grading of knee OA severity.

Other Global scales

Global scales other than the KL scale tend to focus on one feature of knee OA. Ahlback[65] published descriptions of six stages of knee OA based on the combination of JSN and bone attrition only[65,91]. Stages zero to two describe JSN only, with progressive bone attrition described in stages three to five. Ahlback and Rydberg[92] described the stages in a further publication with altered wording. Thirty five years after the initial description, two studies showed that intra-rater (Cohen's weighted kappa 0.17 to 0.35; Cohen's kappa 0.15 to 0.76) and inter-rater reliability (Cohen's weighted kappa 0.18 to 0.45; Cohen's kappa -0.01 to 0.21) of the Ahlback scale were variable but tended to be poor[91,93]. Dieppe *et al*[94] subsequently improved the reliability by using a template showing typical bone contour, to be laid over a knee radiograph.

Sundaram *et al*[68] created a seven-point radiographic scale to assess the entire TF joint for knee OA after tibial dome osteotomy. Their grading system was very similar to the KL scale in that osteophytes were considered the initial presentation of the disease, with JSN being identified at grade three. Psychometric testing was not performed on this scale.

Finally, Brandt *et al*[66] created a JSN-weighted scale that they contrasted to the KL scale. Secondary features included subchondral sclerosis, geodes and osteophytes. Brandt scale scores were compared to cartilage damage seen at arthroscopy; the Pearson's correlation coefficient was r = 0.56 (CI: 0.46 to 0.65)[89]. This scale has been used to classify research participants for orthopaedic surgical outcomes research[95].

Composite scales

Composite scales score several features of OA individually, then add them to create a total score[96-100]. Felson *et al*[101] studied several radiographic features of OA and found that a combination of one or two features (osteophytes alone, or JSN and a bony feature such as a cyst, sclerosis or small osteophyte), each scored individually, correlated best with clinical symptoms of pain and crepitus, lending support to the usefulness of composite scales. Altman *et al*[26] also discovered that a sum of the individual scores for JSN, bone spurs, sclerosis, attrition and alignment was more sensitive to change over time than each individual score alone. Unlike global scales, composite scales are able to follow the course of several separate OA features, and can respond to change in individuals with a variety of radiographic presentations.

Two scales were designed to follow the development of knee OA in individuals with anterior cruciate ligament tears[96,97]. Satku *et al*[97] scale grades osteophytes, peaking of the tibial spine, JSN and subchondral sclerosis or cysts in several locations in the knee, each on a scale of zero to one or two, to give a total score of 14. Kannus *et al*[96] created a complicated scale that measured osteophytes, subchondral sclerosis, flattening of the femoral condyles, subchondral cysts, ligament calcification, JSN and angular deformity at a variety of locations within the knee. Individual scores were out of three to 12, for a total score of 100[96]. Lower scores denoted more severe disease. It was reported to have good to excellent intra-rater reliability (Cohen's kappa 0.70) and inter-rater reliability (Pearson's correlation 0.94; Spearman's correlation 0.90)[102].

McAlindon *et al*[99] created a scale to investigate the association between knee pain, disability, knee strength and radiographic score. They scored JSN, osteophytes and sclerosis in several compartments of both knees to sum to a possible score of 30[99]. Intra-rater reliability was moderate (Cohen's kappa of 0.57)[99]. Another scale was created by Merchant *et al*[98] to follow individuals after ankle or lower leg injuries to investigate the onset of knee OA changes. A "normal" joint was given a score of ten and points were subtracted for osteophytes, JSN, degenerative cysts and subchondral sclerosis observed in both TF compartments[98]. Psychometric testing was not reported.

Compartmental Grading scale for knee OA

The compartmental grading scale for knee OA (CG) was created in 1999 by Derek *et al*[100], who wished to create a scale that was correlated with changes in alignment and deformity caused by OA. The CG scores femoral osteophytes (out of three), JSN (out of three), tibial erosion (out of four) and subluxation (out of three) for a total possible score of 13 (Figure 3). Only the most-affected TF compartment is scored. Tibial osteophytes are excluded in order to prevent over-weighting the scale with osteophytes and because tibial osteophytes frequently decrease in size as OA worsens and the knee subluxes. Tibial erosion is included because it is common and may contribute to joint instability as it progresses. Similarly subluxation, a feature unique to the CG, is incorporated because it also contributes to joint instability and disability. The CG is highly correlated to frontal-plane alignment (Pearson's correlation r = 0.77, P < 0.001). Sclerosis is not included because bone density is highly variable between people and is affected by obesity and variations in image quality. Equal weight is given to osteophytes, JSN and subluxation, and slightly more weight to tibial erosion. This approach was intended to reduce the emphasis of one feature (*i.e.*, osteophytes) over another and provide for a balanced opportunity for sensitivity to change in those with different presentations of OA.

Initial results showed an inter-rater reliability (Cohen's weighted kappa) of 0.92 using anteroposterior full-extension radiographs[100]. The CG has been used for research[103] and is a component of the Knee Surgery Triage tool, which incorporates disability evaluation and radiographic grading to guide clinicians in surgical decision-making[104].

Individual OA Feature Grading scales

Apart from the KL scale, the most common method to assess knee OA severity is to assign grades to individual features of OA such as osteophytes, JSN and sclerosis[26,82,105-110]. An atlas is used to guide interpretation of each feature. Even though each individual feature only describes one aspect of OA, individual feature scales are often used to monitor change over time. The most-often used individual OA feature scale was described by Altman *et al*[26].

OA Research Society International Atlas

The most commonly-used individual OA feature scale is the OA Research Society International (OARSI) atlas, which was created by Altman *et al*[26] (the San Francisco Conference Group) in 1987 (Figure 3). For the knee, five OA features were assessed [JSN, spur formation, loss of bone stock (attrition), subchondral bony sclerosis and frontal-plane alignment] and each scored from zero to three. Medial and lateral TF compartments were assessed separately (except for alignment), giving nine individual scores. A total score was not calculated. Initial intra-rater reliability scores (measured with ICCs) for each feature varied from 0.40 to 1.0, although it is important to note that only three radiographs were used for this analysis[26]. Inter-rater reliability scores (measured with ICCs) were slightly lower, varying between 0.32 and 0.86, with JSN having the best reliability. In all cases medial compartment scores were more reliable than lateral compartment scores. JSN and bone spurs were most sensitive to change over time.

In order to standardize the interpretation of radiographs, OARSI published another radiographic atlas in 1995 showing the spectrum of severity of three osteoarthritic features (JSN, marginal osteophytes and subchondral sclerosis), each scored from zero to three[111]. An updated atlas, available electronically, was published in 2007, emphasizing OA changes of medial and lateral femoral and tibial plateau osteophytes, medial and lateral JSN, medial tibial attrition, medial tibial sclerosis and lateral femoral sclerosis[112]. A modified version of the OARSI JSN scale was also created by Felson *et al*[13], whereby if JSN had increased over time, but not enough to warrant the next grade on the zero to three scale, a one-half grade was assigned. This modification enhanced sensitivity to change[13].

Grades assessed using the OARSI atlas have moderate to good reliability, with JSN more reliable than osteophytes[107]. Intra-rater reliability (Cohen's kappa 0.57 to 0.91 for osteophytes, 0.77 to 0.83 for sclerosis and 0.68 to 0.80 or ICC 0.79 to 0.95 for JSN) is somewhat higher than inter-rater reliability (Cohen's kappa 0.33 to 0.88 for osteophytes, 0.77 for sclerosis, and 0.48 to 0.70 or ICC 0.66 to 0.87 for JSN)[39,78,84,107,113,114].

Comparison of the OARSI atlas to findings from arthroscopy has been performed[115]. Osteophytes show moderate sensitivity (49% to 67%) compared to arthroscopy however the other OA features show fair to poor sensitivity (3% to 46%). Specificity of all features is good to excellent (73% to 100%) relative to arthroscopic findings.

Other Individual OA Feature Scales

Thomas *et al*[110] and Cooper *et al*[105] created ordinal scales for individual features of knee OA, similar to the OARSI scale. Thomas *et al*[110] scored osteophytes, JSN, sclerosis and cysts, each on a scale of zero to three. Cooper *et al*[105] scored these same four features, plus abnormality of the bony contour, each on a scale of zero to two. Neither scale has been used extensively. More extensive use was made of an atlas produced by Spector *et al*[30,34,109,116,117] which scored TF osteophytes, sclerosis, JSN and cortical collapse, each on a scale of zero to one or three. Intra-rater reliability (Cohen's kappa 0.41 to 0.96) and inter-rater reliability (Cohen's kappa 0.30 to 0.90) for osteophytes and JSN scored according to this scale ranged from fair to excellent[40,118].

Scott *et al*[82] published an atlas similar to the OARSI atlas which scored eight individual features of knee OA (medial and lateral osteophytes, medial and lateral JSN, medial and lateral subchondral sclerosis, osteophytes of the tibial spines and chondrocalcinosis) each on a scale from zero to one or three. Both medial and lateral TF compartments were included. This atlas was created for the Baltimore Longitudinal Study of Aging and is now referred to as the Scott Feature Based Scoring System[119]. It has been used in epidemiological studies and as an outcome measure[120-122]. Intra-rater reliability (ICC 0.80 to 0.89) and inter-rater reliability (ICC 0.40 to 0.87) have been tested for osteophytes, JSN and sclerosis scored with this system and ranged from fair to excellent[82,85].

The nottingham logically derived line drawing atlas (LDLDA) consisted of line drawings rather than photographs of radiographs[107]. JSN and osteophytes were scored on a scale of zero to three. The authors felt that line drawings could overcome some issues with the OARSI atlas[26], such as differences in magnification between radiographs and more than one OA feature shown on a particular radiograph. The LDLDA has been used to describe the participant sample in epidemiological studies[123], and as an outcome measure[124]. Also tested were variations of the scoring system described in the LDLDA, using grading scores from minus one to three, four and five[125], and from minus three to three, minus four to four, and minus five to five[126]. The authors expected that sensitivity to change might be enhanced with some of these variations, but did not actually test this hypothesis[125,126]. Finally, one of the modified scales was tested using an acetate overlay placed directly on the radiograph, to aid in determining the grades[127]. Reliability for each of these modified scales was as good as or better than the original scale[125-127].

Digital evaluations

Two scales used computer software to quantitatively assess knee radiographs for OA changes[81,128]. The knee images digital analysis was an interactive software tool created for the cohort hip and cohort knee study[128,129]. Joint space width, osteophyte area, subchondral bone density, joint angle and tibial eminence height were measured using continuous scales[128,129]. While intra- and inter-rater reliability were excellent, only good-quality radiographs could be fully analyzed by the software, and careful participant positioning was particularly important[129,130].

Knee OA computer-aided diagnosis was a fully automated diagnostic system that measured joint space area, minimum joint space width, osteophyte area and TF angle on continuous scales[81]. It was created for the research on OA against disability (ROAD) study[81,131,132]. The intra-rater reliability (ICC) for all parameters was 1.0[81]. Sensitivity to change has not been investigated, but the authors claimed that quantitative radiograph analysis could be as sensitive as quantitative MRI.

Summary and recommendations

The accurate and reliable assessment of knee OA severity as seen on a radiograph is important for diagnosis and monitoring of disease progression. Since 1957, many global, composite and individual feature scales have been developed towards these goals. Global scales, while commonly used, may not be as valid or sensitive to change as other types of scales. Composite grading scales have the advantage that they can be responsive to different presentations of knee OA. Individual OA feature scales are often used to monitor the progression of knee OA, but only respond to changes in a particular OA feature.

The consistent use of one scale is useful to enable comparison of participant groups in research studies and the identification of risk factors. The KL grading scale has been most-commonly used in epidemiological and outcomes research to group and describe participants; however the KL scale has not always been applied consistently, limiting comparison between studies. The OARSI JSN scale is also commonly used, especially to monitor change in JSN, which is used as a proxy for worsening knee OA. However, the selective use of individual feature scales does not allow a variety of presentations of knee OA to be described and monitored. To overcome the above shortcomings, the use of a composite scale is suggested. Several individual features of OA are included, but a single total score gives an indication of the overall severity of arthritic change in the joint.

Many of the existing scales have not had adequate psychometric testing. Reliability, validity (concurrent, content) and sensitivity to change (responsiveness) need to be documented for a scale to be used confidently. However, in recent work, the authors, in collaboration with investigators from the multicenter OA study, evaluated the psychometric properties of the KL, OARSI and CG scales using MRI as a gold standard[133] (Unpublished observations). The findings indicate comparable reliability, validity and sensitivity to change. However the CG scale, which is not subject to the ceiling effects exhibited by the other two scales, suggested responsiveness to more severe joint changes. Further studies are required to establish this. Researchers using scales which do not have adequate testing should perform and report appropriate psychometric assessments as part of their study. In conclusion, the variation in grading scales indicates that a single method is not yet established that will meet the requirements of all needs. Careful consideration of the different grading scales is recommended before one is chosen for a clinical or research application.

The use of grading scales for clinical use is not widespread. Radiologists practicing in the clinical realm typically describe knee OA changes seen on radiographs and make a conclusion about the presence or absence and severity of disease, but do not use a specific grading scale. This practice can reduce the objectiveness of radiologists' observations and make it difficult to detect change over time and compare reports by different radiologists. We recommend that grading scales be used to ensure consistency in interpreting and reporting radiographic knee OA for clinical use.

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P- Reviewer: Garip Y, Singh A, Tawonsawatruk T
S- Editor: Ji FF **L- Editor**: A **E- Editor**: Jiao XK

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