Radiographic Assessment in Osteoarthritis

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ABSTRACT. Plain film radiographs are widely used to quantify disease progression in osteoarthritis. Various methods proposed for assessing radiological progression include individual radiographic features (e.g., osteophytes), composite indices (e.g., Kellgren and Lawrence grading), and quantitative measures (e.g., joint space width measurement). We discuss the metrologic properties of these methods and suggest means for improving the quality of radiography in clinical trials. (*J Rheumatol 1997;24:786–91*)

Key Indexing Terms:
OSTEOARTHRITIS RADIOGRAPHY OUTCOME MEASUREMENT
JOINT SPACE WIDTH CLINICAL TRIALS

Radiographic assessment has been widely used as an outcome measure in osteoarthritis (OA), first to evaluate the natural history of the disease and more recently to determine either a deleterious or a beneficial effect of treatment[1–7]. In guidelines endorsed by the World Health Organization/ International League Against Rheumatism, slow acting drugs used for the treatment of OA were classified as either "symptomatic slow acting drugs" or "disease modifying drugs"[8]. The rate of cartilage loss over years determined by radiography or other methods has been proposed as the primary outcome criterion to classify a drug in the latter category.

Radiographic assessment, an objective method of quantifying disease progression, has several advantages. It is an integrated measure that reflects all the processes of the disease. The resulting films are a permanent record. They can be randomly assigned and read blindly to achieve greater objectivity in scoring. Furthermore, films taken at different times can be assessed simultaneously at the end of study.

Many abnormalities can be detected on plain film, particularly osteophyte formation, subchondral sclerosis, cysts, and joint space narrowing[9]. A number of methods of radiographic assessment have been proposed, each taking into account some of these factors. The method chosen must ideally be simple, reproducible, sensitive to change, and accurate, and must show good discrimination. We briefly review methods used for the sites most frequently involved in OA (knee, hand, hip, spine) and discuss their metrologic properties.

METHODS PROPOSED FOR RADIOGRAPHIC ASSESSMENT

For nearly 40 years, the Kellgren and Lawrence grading scale[1] has been accepted as the standard for cross sectional and longitudinal studies in OA[10,11]. This grading system has several defects, however, including ambiguous definition of grades and low sensitivity to change[9,12]. Another controversial point is its emphasis on the presence of osteophytes[9,12]. In recent years, a number of new criteria for classifying OA radiologically have been developed. Several authors proposed to record separate features, while others combined several features in a composite index[1,2,9,14–17] or used quantitative measures[2,5,7,8]. These criteria, which vary according to the studied site of OA, are described in Table 1.

REPRODUCIBILITY

Obtaining reproducible radiographs on successive visits is a prerequisite for reliable assessment of OA progression, particularly when using quantitative measures. The sources of variability in joint space width measurement are numerous (joint positioning, radiographic procedure, measurement process, etc.) and many, such as patient positioning or radiographic procedure, are frequently neglected[19].

These factors, which have been mainly studied for the tibiofemoral joint, are detailed in Table 2. For other sites (hand, spine, hip), variations inherent in serial radiography must also be taken into account[20]. The absence of a standardized radiographic procedure or joint positioning results in variable radiographic images and compromises the measurement of all radiographic features, particularly joint space width measurement. To be considered related to the evolution of the disease, the changes observed in joint space width must exceed the variability inherent in the measurement process[20] but also in repeat radiographs[21].

Radiographic procedure and joint positioning. Concerning patient positioning, the influence of weight bearing is well known for the tibiofemoral joint[22], and also seems relevant for hip joint space width assessment. Other factors, such as foot rotation or increased distance between the back of the knee and the film, are not standardized in most studies. In 5 postmortem subjects, Lynch found that the error for joint space width measurement was about 0.15 mm per 10° of internal or external rotation of the knee joint[23]. The effects of foot rotation on tibiofemoral joint space width measurement were also studied in healthy volunteers. A 30° external

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Table 1. Method

Site	
Hand	
Spine	
Hip and knee (tibiofemoral join	

Table 2. Sources o ment in tibiofemo

Sources of Variabi	
Radiographic proc	
Patient positioning	
Site of measureme	
Measuring methods	
Reader	

foot rotation sig 18%)[21]. Slight fl between the cen resulting in mag volunteers a 5° k 10%[21]. Conseque by Buckland-Wri nification must b fully extended vi the hip, the need for the effect of ra

Table 1. Methods for assessing radiological progression in OA.

Site	Individual Radiographic Features	Composite Indices	Quantitative Measures
Hand	Marginal osteophytes	Kellgren and Lawrence grading system[1]	Joint space width measurement using computerized image analysis[20]
	Joint space narrowing	Kallman score[15]	
		Lane score[14]	Area of osteophytes, area of juxtaarticular radiolucencies
	Subchondral erosion		
	Subchondral sclerosis	Anatomic phase progression score[18]	
	Malalignment	Anatomic lesion progression score[18]	
Spine	Osteophytes	Kellgren and Lawrence grading system[1]	Measurement of intervertebral disc height
	Disc space narrowing	Lane score[14]	
Hip and knee (tibiofemoral joint)	Joint space narrowing	Kellgren and Lawrence grading system	Joint space width measurement using non-automatic or automatic methods (computerized image analysis)[25,33]
	Marginal osteophytes		
	Subchondral lucencies (hip)		
	Subchondral sclerosis	Joint space narrowing weighted scale (knee)[17]	Joint surface area measurement using computerized image analysis[31]
	Malalignment (knee)	Lane score (hip)[14]	

Table 2. Sources of measurement variability in joint space width measurement in tibiofemoral OA.

Sources of Variability	
Radiographic procedure	X-ray beam inclination
	Tube to film distance
Patient positioning	Weight bearing or not
	Mono or bipodal
	Extended or semi-flexed knee
	Back of the knee to film distance
	Rotation of the feet
Site of measurement	Medial or lateral compartment
	Plane of measurement (narrowest point or midpoint)
	Boundaries of measurement (anterior or posterior articular margins of the tibial plateau)
Measuring methods	Measuring instrument used
	Automatic measurement or not
Reader	Training of reader(s)
	Number of readers

foot rotation significantly reduced joint space width (by 18%)[21]. Slight flexion of the knee led to increased distance between the center of the joint and the radiographic film, resulting in magnification of the shadow image. In normal volunteers a 5° knee flexion increased joint space width by 10%[21]. Consequently, in semiflexed views, as emphasized by Buckland-Wright[24], the extent of the radiographic magnification must be evaluated. For other views, such as the fully extended view for the knee or pelvic radiographs for the hip, the need for correction is not indicated. Correcting for the effect of radiographic magnification does not seem to significantly increase the reproducibility of measurement in the extended view of the knee in patients with OA (coefficient of variation: 8.9 versus 8.8%)[25].

Such a correction raises 2 problems: (1) The introduction of a 2nd measurement and therefore of a 2nd potential source of error in measurement, (2) the choice of an observed element of comparison, i.e., a fixed distance measured on the radiograph, such as length of the tibial plateau for the knee, or a reference radiopaque object of known size taped to the skin in relation to an anatomical landmark, such as a metal sphere placed at the head of the fibula[24].

Modification in the radiographic procedure (X-ray beam alignment, tube to film distance) also may modify radiographic assessment[19]. For the tibiofemoral joint, a 10° inclination of the X-ray beam compared to the ideal inclination significantly reduced (by 15%) the joint space width[21]. The effect of a modification of X-ray beam direction (X-ray beam directed at the center of joint space or 1 cm below) seems less pronounced[21]. The focus to film distance may also modify the measurement. The distance usually recommended is 100 cm. However, it is difficult to impose a fixed distance in multicenter trials, since this distance is an invariable technical characteristic of the radiographic equipment. Limiting the sources of variability by standardization of the radiographic procedure and joint positioning seems necessary to increase the capacity to detect relevant changes. For this purpose, 2 possibilities must be considered: (1) the use of a custom built apparatus or (2) the use of guidelines precisely defining the process[21].

For the choice of views, re-radiographing reliability is also an important criterion. For example, a fully extended view of the knee is probably easier to reproduce than a semi-

:d view in the absence of custom built apparatus or flu-
:opy. Compared with the fully extended view, the semi-
:d view does not significantly improve the precision and
racy of joint space width measurement in the medial
)artment of patients with OA, but only those of the lat-
:ompartment[25]. Several guidelines or protocols defining
)graphic procedure have been proposed, particularly for
ibiofemoral compartment of the knee (extended view or
flexed view) and the hip[19,21,25,26].

he use of a microfocal radiography unit allows high
)graphic magnification (× 5) without distortion[19], but its
icability is limited by the restricted availability of the
)ment and the radiation dose exposure[27]. Furthermore,
espective weights of quantitative microfocal radiogra-
and procedures to standardize positioning for improving
eproducibility of joint space width measurement on ser-
iacroradiographs are unknown[27].

) improve the quality of radiographic assessment in
icenter clinical trials, precise recommendations defin-
adiographic methods must be established. Radiology
)nnel involved in the study must be trained; all data on
)graphic procedures and joint positioning must be regis-
l for each patient on a data form, which is kept during
tudy and reproduced at each radiographic visit (Figure
Centralized control of radiographic quality also seems
il to eliminate incorrect radiographs (inadequate foot
ion, anterior and posterior margins not superimposed,
. Despite many precautions (guidelines, personnel train-
specific data form), more than 20% of radiographs
ined in a large multicenter study are excluded (personal
rvations).

surement process. All methods of assessment, such as
posite indices (i.e., Kellgren and Lawrence grading sys-
or Kallman score), individual radiographic features
t space narrowing, osteophytes), or measurement of
space width, usually show acceptable cross sectional
longitudinal reproducibility[2,14,16,28]. For quantitative
sures, the site of measurement most frequently chosen is
iarrowest point for the hip[29] and the narrowest point or
nidpoint for the tibiofemoral joint[26,30]. This site can be
:ted by either a manual procedure based on the investi-
r's judgment or automatically after digitization of the
19]. Measurement of the joint space area calculated after
ization of the films rather than the joint space width has
been proposed[31], but this technique may be less sensi-
to change[32].

or manual quantitative measurement, various measur-
instruments are used[34–36]. Measurements by all these
uments seem to be reproducible and the differences
'een them are limited[33]. Ruler and digitized assessment
1 more reproducible than the successive use of caliper
ruler, or of caliper and graduated magnifying glass[33].
'ever, the use of a magnifying glass directly laid over the
)graph gives different results.

All studies show better intra than interobserver reproducibility. Therefore, radiographs should be read centrally with one or more readers examining all films. The ideal number of readers is not established for quantitative measurement. For qualitative measurement, Altman, *et al* found that averaging 3 readers' scores improved results[2]. Reproducibility can be improved by the use of radiographic atlases illustrating the different grades of the scales, and by training sessions for readers[26]. As for the radiographic procedure, a manual defining the methodology is required[26].

SENSITIVITY TO CHANGE

OA generally progresses slowly. However, in studies conducted in selected subgroups of patients with symptomatic severe disease at entry, significant structural changes can be observed after a relatively short followup period. Statistically significant changes for joint space narrowing or joint space width evaluated in millimeters were observed after a single year in several studies using plain radiographs in knee or hip OA[5,28,29,31,32]. The population based studies point to a lower radiologic responsiveness[4,34]. Other studies strongly suggest that the level of symptomatic severity (i.e., pain, functional impairment) might be strongly predictive of structural progression[29]. Therefore, the ideal duration of trials performed to evaluate OA disease modifying drugs is not defined. For any trial it should be established on the basis of both previous data and the characteristics of the patients studied. Some authors propose that duration of such trials should be no less than 2 or 3 years[8]. However, in longterm trials, the percentage of withdrawals is sometimes very high[35]. Therefore, it may be more cost effective to study a larger number of subjects over a shorter time period, than a shorter number of subjects over a larger time period.

The sensitivity to change of an outcome variable can be evaluated by calculating the standardized response mean, which is the ratio of the mean change of the variable during the time of the study over the standard deviation of the change. Table 3 summarizes data recently obtained in studies of one year duration using different techniques at the knee and hip.

Few data are available comparing the sensitivity to change of the various methods of measurement (quantitative or semiquantitative assessment) of various instruments (ruler or digitized image analysis), or of various radiographic procedures (extended or semiflexed view of the tibiofemoral joint). Data comparing the relative value of these options are needed to define the most sensitive outcome measure.

VALIDITY

It is well known that in cross sectional studies radiographic damage has only a weak correlation with pain and physical function[36]. Recently, correlation was revealed in a longitudinal study in hip OA between the changes in radiological

Figure 1

Table 3. Examples of sensitivi

OA Site	Study Duration	N
Hip	1 year[32]	
Hip	1 year[29]	
Knee	1 year[28]	

SRM: standardized response m

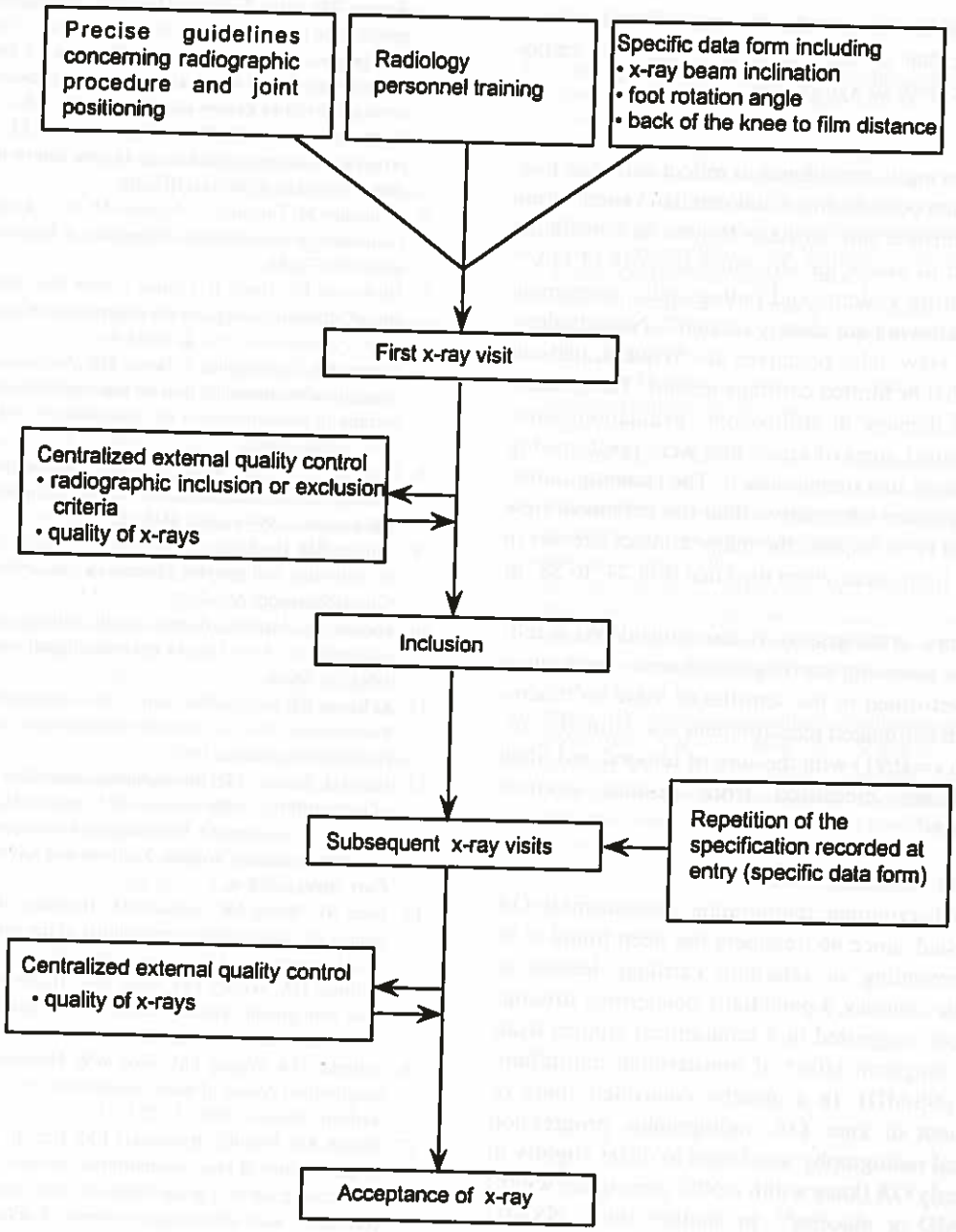

Figure 1. Suggested strategy for improvement of radiographic quality in OA trials.

Table 3. Examples of sensitivity to change of different radiological techniques in hip and knee OA.

OA Site	Study Duration	No. of Joints	Radiologic Features	Entry Visit	Final Visit	Change	SRM
Hip	1 year[32]	34	Joint space width (mm)	3.9 ± 1.8	3.6 ± 1.9	−0.3 ± 0.9	0.37
Hip	1 year[29]	461	Joint space width (mm)	2.4 ± 0.8	2.0 ± 1.0	−0.3 ± 0.5	0.62
Knee	1 year[28]	55	Joint space width (mm)	3.7 ± 1.6	3.2 ± 1.6	−0.5 ± 0.9	0.53

SRM: standardized response mean.

and clinical variables (area under the curve)[29]. Moreover, there is evidence that asymptomatic OA diagnosed radiologically is a precursor of symptomatic disease[37,38].

ACCURACY

Joint space narrowing is considered to reflect cartilage loss. Arthroscopy, which permits direct and detailed visualization of the articular surface and cartilage lesions, is considered the gold standard to assess the structural severity of OA[39]. Arthroscopic scoring systems and radiographic assessment of joint space narrowing are closely related[40]. Nevertheless, for the extended view, false negatives are frequent, particularly for superficial or limited cartilage lesions. The greatest area of cartilage damage in arthroscopic evaluation corresponds to the contact areas of knees that were positioned in about 30° flexion, as in a tunnel view[41]. The standing tunnel view is probably more informative than the extended view or the semiflexed view because the major contact stresses in the tibiofemoral joint occur when the knee is in 24° to 28° of flexion[42].

Double contrast arthrography is also considered a reliable method for assessing cartilage thickness. Joint space measurement performed in the semiflexed view on macroradiographs with automated measurement was strongly correlated (Pearson r = 0.91) with the sum of femoral and tibial cartilage thickness measured from double contrast macroarthrograms[43].

CAPACITY TO DISCRIMINATE

The capacity to discriminate radiographic assessment in OA has not been tested, since no treatment has been found to be effective in preventing or retarding cartilage lesions in humans[44]. To the contrary, a potentially deleterious structural effect has been suggested in 2 randomized clinical trials evaluating the longterm effect of nonsteroidal antiinflammatory drugs (NSAID). In a placebo controlled study of NSAID treatment of knee OA, radiographic progression using microfocal radiography was found to differ slightly in patients with early OA (knee width > 50% joint space width) receiving NSAID or placebo[45]. In another study, NSAID was found to increase the rate of radiological deterioration of the joint space in patients with knee OA[6]. In this study, radiographic progression was assessed using joint space narrowing measured by a 6 point grading scale using plain radiographs.

Based on recently published data, plain radiographic techniques are a new tool permitting evaluation of osteoarthritic progression. However, means to better limit sources of variability by standardization of the radiographic procedures, joint positioning, and the measurement process need to be further evaluated.

REFERENCES

1. Kellgren JH, Lawrence JS: Radiological assessment of osteoarthritis. *Ann Rheum Dis 1957;*16:494–501.
2. Altman RD, Fries JF, Bloch DA, *et al:* Radiographic assessment of progression in osteoarthritis. *Arthritis Rheum 1987;*30:1214–25.
3. Dieppe PA, Cushnaghan J, Young P, Kirwan J: Prediction of the progression of joint space narrowing of the knee by bone scintigraphy. *Ann Rheum Dis 1993;*52:557–63.
4. Spector TD, Dacre JE, Harris PA, Huskisson EC: Radiological progression of osteoarthritis: An 11 year follow up study of the knee. *Ann Rheum Dis 1992;*51:1107–10.
5. Dougados M, Gueguen A, Nguyen M, *et al:* Longitudinal radiologic evaluation of osteoarthritis of the knee. *J Rheumatol 1992;*19:378–84.
6. Huskisson EC, Berry H, Gishen P, Jubb RW, Whitehead J: Effects of antiinflammatory drugs on the progression of osteoarthritis of the knee. *J Rheumatol 1995;*22:1941–6.
7. Dieppe PA, Cushnaghan J, Jasani MK, McRae F, Watts I: A two-year, placebo-controlled trial on non steroidal anti inflammatory therapy in osteoarthritis of the knee joint. *Br J Rheumatol 1933;*32:595–600.
8. Lequesne M, Brandt K, Bellamy N, *et al:* Guidelines for testing slow-acting and disease modifying drugs in osteoarthritis. *J Rheumatol 1994;*(suppl 44)21:65–73.
9. Altman RD, Hochberg M, Murphy W, Wolfe F, Lequesne M: Atlas of individual radiographic features in osteoarthritis. *Osteoarthritis Cart 1995;*(suppl A)3:3–71.
10. Spector TD, Hart DJ, Byrne J, *et al:* Defining the presence of osteoarthritis of the knee in epidemiological studies. *Ann Rheum Dis 1993;*52:790–4.
11. Kellgren JH, Jeffrey MR, Ball J: *The Epidemiology of Chronic Rheumatism: Atlas of Standard Radiographs.* vol 2. Oxford: Blackwell Scientific, 1963.
12. Hart DJ, Spector TD: Radiographic criteria for epidemiologic studies of osteoarthritis. *J Rheumatol 1995;*(suppl 43)22:46–8.
13. Spector TD, Cooper C: Radiological assessment of osteoarthritis in population studies: Whither Kellgren and Lawrence? *Osteoarthritis Cart 1994;*1:203–6.
14. Lane NE, Nevitt MC, Genant HK, Hochberg MC: Reliability of new indices of radiographic osteoarthritis of the hand and hip and lumbar disc degeneration. *J Rheumatol 1993;*20:1911–8.
15. Kallman DA, Wigley FM, Scott WW, Hochberg MC, Tobin TD: New radiographic grading scales for osteoarthritis of the hand. *Arthritis Rheum 1989;*32:1584–91.
16. Kallman DA, Wigley FM, Scott WW, Hochberg MC, Tobin TD: The longitudinal course of hand osteoarthritis in a male population. *Arthritis Rheum 1990;*33:1323–32.
17. Brandt KD, Fife RS, Braunstein EM, Katz B: Radiographic grading of the severity of knee osteoarthritis: Relation of the Kellgren and Lawrence grade to a grade based on joint space narrowing and correlation with arthroscopic evidence of articular cartilage degeneration. *Arthritis Rheum 1991;*34:1381–6.
18. Verbruggen G, Veys EM: Numerical scoring systems for the anatomic evolution of osteoarthritis of the finger joints. *Arthritis Rheum 1996;*39:308–20.
19. Buckland-Wright JC: Quantitative radiography of osteoarthritis. *Ann Rheum Dis 1994;*63:268–75.
20. James MF, Heald G, Shorter JH, Turner RA: Joint space measurement in hand radiographs using computerized image analysis. *Arthritis Rheum 1995;*38:891–901.
21. Ravaud P, Auleley GR, Chastang C, *et al:* Knee joint space width measurement: An experimental study of the influence of radiographic procedure and joint positioning. *Br J Rheumatol 1966* 35:761–6.
22. Leach RE, Gregg T, Siber FJ: Weight-bearing radiography in osteoarthritis of the knee. *Radiology 1970;*97:265–6.
23. Lynch JA, Buckland-Wright JC, MacFarlane DG: Precision of joint space width measurement in knee osteoarthritis from digital image

analysis of high definition macroradiographs. *Osteoarthritis Cart 1993;*1:209–18.
24. Buckland-Wright JC: Protocols for precise radio-anatomical positioning of the tibiofemoral and patello femoral compartments of the knee. *Osteoarthritis Cart 1995;*(suppl A)3:71–80.
25. Buckland-Wright JC, MacFarlane DG, Williams SA, Ward RJ: Accuracy and precision of joint space width measurement in standard and macro-radiographs of osteoarthritic knees. *Ann Rheum Dis 1995;*54:872–80.
26. Dieppe PA: Recommended methodology for assessing the progression of osteoarthritis of the hip and knee joint. *Osteoarthritis Cart 1995;*3:73–7.
27. Spector TD: Measuring joint space in knee osteoarthritis: Position or precision? *J Rheumatol 1995;*22:807–8.
28. Ravaud P, Giraudeau B, Auleley GR, *et al:* Radiographic assessment of knee osteoarthritis: Reproducibility and sensitivity to change. *J Rheumatol 1996;*23:1756–64.
29. Dougados M, Gueguen A, Nguyen M, *et al:* Radiological progression of hip osteoarthritis: Definition, risk factors and correlation with clinical status. *Ann Rheum Dis 1996;*55:356–62.
30. Dieppe PA, Cushnaghan J, Young P, Kirwan J: Prediction of the progression of joint space narrowing of the knee by bone scintigraphy. *Ann Rheum Dis 1993;*52:557–63.
31. Conrozier TH, Tron AR, Mathieu P, Vignon E: Quantitative assessment of radiographic normal and osteoarthritic hip joint space. *Osteoarthritis Cart 1995;*(suppl A)3:81–7.
32. Dougados M, Villers C, Amor B: Sensitivity to change of various roentgenological severity scoring systems for osteoarthritis of the hip. *Rev Rheum Eng Ed 1995;*62:169–74.
33. Ravaud P, Chastang C, Auleley GR, *et al:* Assessment of joint space width in patients with osteoarthritis of the knee: A comparison of four measuring instruments. *J Rheumatol 1996;*23:1749–55.
34. Schouten JSAG, van Den Ouweland FA, Valkenburg HA: A 12 year follow-up study in the general population on prognostic factors of cartilage loss in osteoarthritis of the knee. *Ann Rheum Dis 1992;*51:932–7.
35. Dougados M: Clinical assessment of osteoarthritis in clinical trials. *Curr Opin Rheumatol 1995;*7:87–91.
36. Adams ME, Wallace CJ: Quantitative imaging of osteoarthritis. *Semin Arthritis Rheum 1991;*(suppl 2)20:26–39.
37. David MA, Ettinger WH, Neuhaus M, Mallon KP: Knee osteoarthritis and physical functioning: Evidence from the NHANES I epidemiologic follow-up study. *J Rheumatol 1991;*18:591–8.
38. Hochberg MC, Lawrence RC, Everett DF, Cornoni-Huntley J: Epidemiologic associations of pain in osteoarthritis of the knee: Data from the National Health and Nutrition Examination Survey. *Semin Arthritis Rheum 1989;*(suppl 2)18:4–9.
39. Ayral X, Dougados M, Listrat V, *et al:* Chondroscopy: A new method for scoring chondropathy. *Semin Arthritis Rheum 1993;*22:289–97.
40. Dougados M, Ayral X, Listrat V, *et al:* The SFA system for assessing articular cartilage lesions at arthroscopy of the knee. *Arthroscopy 1994;*10:69–77.
41. Messieh SS, Fowler PJ, Munro T: Anteroposterior radiographs of the osteoarthritic knee. *J Bone Joint Surg 1990;*72B:639–40.
42. Maquet PGJ: Biomechanics of the knee with application to the pathogenic and the surgical treatment of osteoarthritis. Berlin: Springer Verlag, 1976.
43. Buckland-Wright JC, MacFarlane DG, Lynch JA, Jasani MK, Bradshaw CR: Joint space width measures cartilage thickness in osteoarthritis of the knee: High resolution plain film and double contrast macroradiographic investigation. *Ann Rheum Dis 1995;*54:263–8.
44. Brandt KD: Toward pharmacologic modification of joint damage in osteoarthritis. *Ann Intern Med 1995;*122:874–5.
45. Buckland-Wright JC, MacFarlane DG, Lynch JA, Jasani MK: Quantitative microfocal radiography detects changes in OA knee joint space width in patients in placebo controlled trial of NSAID therapy. *J Rheumatol 1995;*22:937–43.