Standing radiographs underestimate joint width

Comparison before and after resection of the joint in 34 total knee arthroplasties

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Background **Measurement or estimation of joint width is routinely used in the preoperative evaluation of gonarthrosis. To our knowledge, the validity and reproducibility of this procedure has not been adequately studied.**

Patients and methods **We measured joint width in 34 knees (medial arthrosis: n = 22, lateral arthrosis: n = 12) on preoperative weight-bearing radiographs and on radiographs of the corresponding part of the joint after knee arthroplasty. The bone/cartilage pieces were placed in anatomical positions and loaded in a jig made of perspex. High-density film was used to obtain maximum resolution.**

Results **In medial and lateral arthrosis, the minimum joint widths were median 0.3 and 0.2 mm smaller on the radiographs of the specimens (p = 0.05, 0.04). In lateral arthrosis the differences were more scattered (95% CI: lateral: 0.1 to –1.2 mm; medial: 0 to –0.5 mm), suggesting less precise determination.**

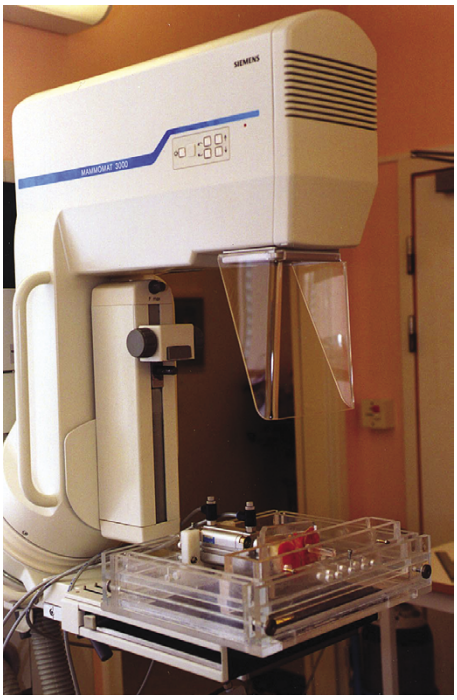
Interpretation **In medial arthrosis, the degree of underestimation is usually small and acceptable. More pronounced discrepancies could be found in lateral arthrosis, calling for the use of further diagnostic measures.**

Standing knee radiographs have evolved as a standard for evaluation of presence and degree of joint space narrowing and bone attrition in arthrosis of the knee. Plain radiographs have been shown to provide higher precision than ultrasonography and MR, even if the latter allow the most complete visualization of the joint cartilage (Jonsson et al. 1992).

In more advanced arthrosis, it is our clinical experience that weight-bearing radiographs do not always reflect the amount of wear observed during open surgical treatment of the knee. We compared routine clinical weight-bearing radiographs with radiographs of the articulation after removal during insertion of a total knee arthroplasty. An experimental model was developed to enable radiographic examination of removed bone pieces when subjected to compressive load. Knees with medial and lateral arthrosis were studied separately.

Patients and methods

We studied 34 knees (34 patients) operated between February 1998 and May 2000 at the Department of Orthopedics, Halmstad Hospital. All cases involved tricompartmental total knee prosthesis. There were 22 knees with medial arthrosis (14 women; median age: 73 (55–83) years; 8 men, 70 (55–89) years) and 12 women with lateral arthrosis (median age: 75 (59–83) years). Specimens were collected consecutively based on the willingness of the individual surgeons to participate. To be included, the tibial part of the joint should have been removed in one piece without any damage to the articular region. The study was approved by the local ethics committee.



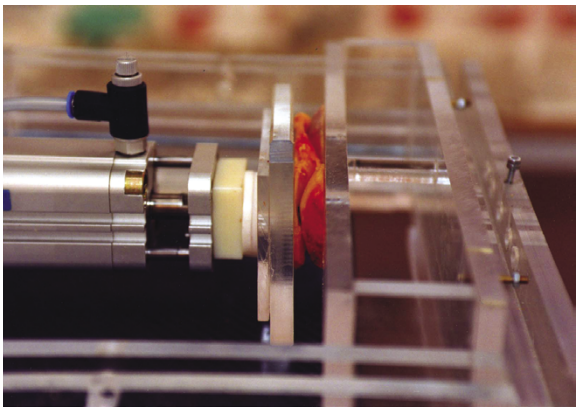


Figure 1. The experimental set-up. Exposure on the high resolution mammography x-ray film with the bone pieces under continuously pressure of the pneumatic piston with 40 kPa.

Weight-bearing radiographs were performed on all patients (median: 4 (1–29) days) before surgery. The patients were standing with equal weight on both legs, and with their knees semi-flexed using the standard technique employed at the Department of Radiology, Halmstad Hospital. The patients were told to stand with their toes approximately at a vertical line from the X-ray film and to flex their knees until they touched the film cassette. The amount of knee flexion was estimated to be 20–30 degrees. A standing radiographic view of the whole leg with full extension of the knee (Hip-Knee-Ankle or HKA examination) was taken on the same occasion. This image was used to evaluate the joint space at full extension.

All patients received Freeman Samuelson total knee prosthesis (Sulzer, Switzerland). We used standard instrumentation with intramedullary guide on the femoral side and extramedullary guide on the tibial side. In all specimens, the tibial cut had been placed a few mm below the level of the location of the most worn part of the medial or lateral compartment. The femoral preparation usually consisted of two pieces, corresponding to each condyle. The cartilage/bone pieces were marked for orientation and were stored at –70 ºC.

Testing equipment

The bone/cartilage pieces were thawed and mounted anatomically in a jig (a Plexiglas box; Figure 1). This jig had been adapted to the equipment used at our mammography laboratory. The size of the box corresponded to the size of the envelopes for X-ray films. The box had been constructed to facilitate reproducible positioning of the specimens and constant distances between the X-ray tube, the object and the film. High-density mammography films were used to obtain maximum resolution. The box had double Plexiglas walls, each 1 cm thick, and separated by a 10-mm bolt parallel to the piston.

In our first series (n = 16), the pieces were pressed together by hand (at an estimated pressure of 5–10 kPa). In a second series (n = 18), we wanted to control the pressure at exposure more exactly. For this purpose, a pneumatic piston designed for industrial use was employed. Its performance was tested and found to be correct within ± 0.2%. This device produced a constant pressure of 40 kPa, which will roughly correspond to the force induced by adding 40 kg weight on one leg. The femoral bone pieces were allowed to slip into the deepest portion of the tibial plateau. An ante-

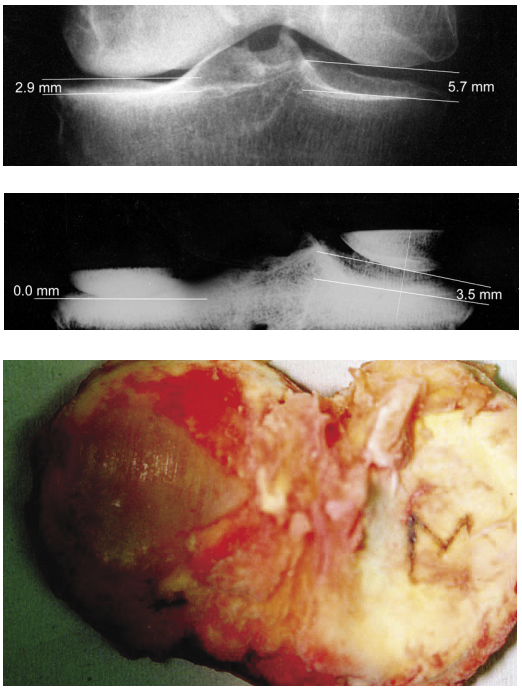


Figure 2. Standing clinical radiographs (top), radiographs from the experimental set-up (middle) and photography of the corresponding tibial plateau. The locations of lines drawn to measure joint width are illustrated.

rior-posterior view of the specimen was exposed (Figure 2).

All measurements were done with a ×10 magnifying lens fitted with 0.1 mm divisions. The minimum joint space width was measured on the 3 examinations (weight-bearing, HKA, experimental set-up). The degree of magnification was evaluated by exposure of a steel ball (Ø = 10.0 mm). The values obtainedvalues (6% on standing radiographs, 14% on HKA radiographs and 14% in the experimental set-up) were used to adjust the recorded values to the same magnification.

Joint width measurement

The width of the affected joint was measured according to Buckland-Wright et al. (1994). On the femoral side, we used the distal convex margin of the condyles. On the medial tibial side, we used a line extending from near the tibial spine to the medial or outer margin, across the centre of the floor of the articular fossa in the mid-coronal plane of the joint. This line was defined by the superior margin of the bright radio-dense band of the subchondral cortex, and appeared below the anterior and posterior articular margins of the tibial plateau.

On the lateral side, we used the proximal margin of the articular surface, defined by the superior margin of the bright radio-dense band in the subchondral cortex extending from near the tibial spine to the lateral or outer margin (Figure 2).

The interobserver variability was studied by two of the authors (JW, C-GC). They repeated their measurements on the same radiographs for all clinical examinations. The intraobserver error was evaluated by one of the authors (JW). These studies were extended to embrace radiographs of the experimental set-up also.

Measurements were done blind. The author who evaluated the intraobserver error (JW) repeated his evaluations at an interval of 4 weeks. Repeated measurements on clinical radiographs were done, corresponding to 28 examinations (intra- and interobserver variability). 29 examinations were used to study the intraobserver variability in the experimental set-up on mammography radiographs. To evaluate the influence of pressure, 9 cases were studied at 2 pressure levels (20 and 40 kPa). 8 further specimens were studied both with the manual and the pneumatic technique (40kPa).

Statistics

We used non-parametric tests (Wilcoxon sign rank test, Kendall tau).

Results

Intra- and interobserver variability

Repeated measurements of the minimum joint width on the standing (clinical) radiographs revealed an intra- and interobserver variability of ± 0.20 mm (1 SD) and –0.25 ± 0.40 mm (mean difference ±1 SD), respectively. The intraobserver error, when evaluated on the films from the experimental set-up, was 0.54 mm (1 SD).

Evaluation of test equipment

Comparisons between the 2 series using the same or different loads revealed a smaller variability when the diseased compartment was evaluated. Within the ranges of loads used, the errors observed errors

Table 1. Difference in joint space width (mm) between measurements using the same and different loads

	Type of compartment				
	With arthrosis			Without arthrosis	
	n	Mean difference	SD	Mean difference	SD
20 kPa vs. 40 kPa	8	–0.09	0.19	–0.23	0.63
40 kPa vs. 40 kPa	9	–0.01	0.38	0.17	2.08
Manual vs. manual	8	–0.04	0.23	0.46	1.20
Manual vs. 40 kPa	8	0.24	0.46	0.01	1.34

were within the same range as the intraobserver variability on the side with the most pronounced changes. On the side with no or minimum arthrosis, the variations were higher (Table 1).

Standing radiographs vs. experimental set-up

On standing radiographs, 17 cases had a joint space width of < 1 mm in the compartment with arthrosis, 10 cases had a width of 1–2 mm, and 7 cases had a width of > 2 mm (Table 2).

Overall, standing radiographs of cases with medial arthrosis revealed a wider joint width on the arthrotic medial side (median difference: 0.3 mm, p = 0.05) compared to the corresponding specimen. In 10 of 22 cases, the value of the absolute difference exceeded 0.5 mm. In 8 of these cases, weight-bearing radiographs demonstrated a wider joint line than was found on the radiographs of the specimens. On the lateral side with no (or minimum) arthrosis, the difference was still larger (median difference: 1.8 mm, p < 0.001) (Tables 3 and 4).

In cases with lateral arthrosis, standing radiographs also overestimated the joint width on the arthrotic lateral side (0.2 mm, p = 0.04). In 4 of 12 cases, the absolute difference exceeded 0.5 mm. In 3 of these cases, standing radiographs demonstrated a minimum joint space width that was 1.3–2.9 mm wider than that observed on the radiographs of the specimens. On the medial side, cases with lateral arthrosis demonstrated wider joint space on clinical radiographs in all but one of the 12 observations (median difference: 0.4 mm, p = 0.003).

The differences in joint space width between the two methods tended to be more scattered in cases with lateral arthrosis (95% CI: lateral: 0.1 to –1.2 mm; medial: 0 to –0.5 mm).

Table 2. Joint space width (mm) in weight-bearing radiographs (WB) and radiographs of specimens (Spec.)

		Compartment with arthrosis			Compartment with no or minimum arthrosis		
Location [a]		WB	Spec.	Δ [b]	WB	Spec.	Δ [b]
1	M	1.2	0	–1.2	11.3	6.1	–5.2
2	M	1.2	0.2	–1.1	8.0	6.1	–1.9
3	M	1.6	0.6	–1.0	5.7	5.6	0
4	M	1.4	0.4	–1.0	9.4	6.3	–3.1
5	M	0.8	0.0	–0.8	4.2	5.4	1.3
6	M	1.7	0.9	–0.8	5.7	5.3	–0.4
7	M	2.5	1.8	–0.7	8.5	7.2	–1.3
8	M	3.4	2.8	–0.6	6.4	3.2	–3.2
9	M	0.5	0	–0.5	4.5	2.6	–1.9
10	M	2.4	1.9	–0.4	5.5	4.8	–0.6
11	M	0.5	0.2	–0.3	7.5	5.3	–2.2
12	M	1.4	1.1	–0.3	5.0	3.7	–1.3
13	M	0.5	0.4	–0.1	7.8	2.8	–5.0
14	M	1.2	1.1	–0.1	6.8	7.6	0.8
15	M	0.2	0.2	0	9.2	6.9	–2.3
16	M	0.1	0.1	0	3.3	0.9	–2.4
17	M	0	0	0	8.4	7.7	–0.7
18	M	0.2	0.5	0.3	5.2	4.4	–0.8
19	M	0.7	1.1	0.4	6.6	6.1	–0.5
20	M	0.2	0.6	0.4	5.2	1.9	–3.3
21	M	2.4	3.3	1.0	7.5	4.4	–3.1
22	M	0.4	1.4	1.0	6.6	4.8	–1.8
23	L	2.9	0	–2.9	5.7	3.5	–2.2
24	L	2.1	0	–2.1	6.0	4.0	–2.0
25	L	1.4	0.1	–1.3	4.9	0.8	–4.1
26	L	1.1	0.6	–0.5	5.8	5.7	–0.1
27	L	3.8	3.5	–0.3	4.9	4.6	–0.3
28	L	0.8	0.5	–0.2	5.2	5.3	0.1
29	L	2.0	1.8	–0.1	4.3	4.0	–0.3
30	L	0.9	0.9	–0.1	5.0	4.6	–0.4
31	L	0.5	0.4	0	5.6	5.2	–0.4
32	L	0	0	0	4.2	3.9	–0.3
33	L	0.4	0.4	0.1	7.1	3.1	–4.0
34	L	0.9	1.9	1.0	3.8	3.0	–0.8

[a] M medial arthrosis, L lateral arthrosis
[b] Δ = Difference between weight-bearing radiographs (WB) and radiographs of specimens (Spec.)

HKA radiographs vs. experimental set-up

In a corresponding comparison between measurement on HKA radiographs and on radiographs from the experimental set-up, the former overestimated the width of the most worn side of the joint with a median of 0.5 mm in medial (p = 0.002) and 1.5 mm in lateral arthrosis (p = 0.01).

HKA vs. standing radiographs

In the compartment with the most pronounced changes, radiographic examination with extended knee (HKA) showed (median) 0.5 mm wider joint

Table 3. Comparison of joint width (mm) between HKA (Hip-Knee-Ankle, knee in full extension) and weight-bearing (WB) radiographs with semi-flexed knee and between WB radiographs and radiographs of specimens

	HKA			WB radiographs			Radiographs of spec.	
	N	Mean (SD) Median (CI) [a]	P-value [b]	N	Mean (SD) Median (SD)	P-value [b]	N	Mean (SD) Median (CI) [a]
Arthrotic side								
Medial arthrosis	22	1.6 (1.2)		22	1.1 (0.9)		22	0.8 (0.9)
		1.3 (1.1–2.1)	0.02		1.0 (0.7–1.5)	0.05		0.6 (0.4–1.3)
Lateral arthrosis [c]	11	2.5 (1.0)		12	1.4 (1.1)		12	0.9 (1.1)
		2.2 (1.8–3.2)	0.02		1.0 (0.7–2.1)	0.04		0.5 (0.2–1.5)
Nonarthrotic side								
Medial arthrosis	22	6.4 (2.1)		22	6.7 (1.9)		22	5.0 (1.8)
		6.6 (5.5–7.4)	0.2		6.6 (5.9–7.6)	<0.001		5.3 (4.2–5.8)
Lateral arthrosis [c]	11	5.8 (1.4)		12	5.2 (0.9)		12	4.0 (1.3)
		6.1 (4.8–6.8)	0.2		5.1 (4.6–5.8)	0.003		4.0 (3.1–4.8)

[a] CI = 95% confidence interval
[b] Wilcoxon sign rank test
[c] Missing HKA radiograph in 1 case

Table 4. Correlation between 3 different methods used to measure joint space width. Statistics in Kendall's tau B

	Standing radiographs			HKA radiographs		
	N	Kendall tau	P-value	N	Kendall tau	P-value
Experimental set-up						
Medial arthrosis						
Medial side	22	0.49	0.002	22	0.37	0.02
Lateral side	12	0.49	0.002	11	0.45	0.004
Lateral arthrosis [a]						
Lateral side	12	0.17	0.45	11	–0.34	0.2
Medial side	22	0.27	0.22	22	0.13	0.6
Standing radiographs						
Medial arthrosis						
Medial side		–		22	0.37	0.02
Lateral side		–		11	0.64	<0.001
Lateral arthrosis [a]						
Lateral side		–		11	0.32	0.2
Medial side		–		22	0.38	0.1

[a] Missing HKA radiograph in 1 case

than on standing radiographs in cases with medial arthrosis (p = 0.02). The difference was more pronounced in cases with lateral arthrosis (1.1 mm, p = 0.02; medial vs. lateral differences: p = 0.05) (Tables 3 and 4).

On the non-arthrotic side, the measurement on the HKA radiographs did not differ from those obtained in the semi-flexed position in either medial or lateral arthrosis (p ≥ 0.2).

Discussion

Ahlbäck (1968) described the weight-bearing position as the most accurate way of determining the presence of knee arthrosis. This classification has been widespread for staging medial knee arthrosis. Leach et al. (1970) reported that flexion combined with weight-bearing is the best position to visualize the most narrow part of the joint. Since then, much effort has been made in analyzing the opti-

mum position when performing weight-bearing radiographs (Siu et al. 1991, Buckland-Wright et al. 1994, 1995, Leach et al. 1970, Messieh et al. 1990, Ravaud et al. 1996). We used a semi-flexed position (20–30 degrees), corresponding to the routines commonly used in Sweden when arthrosis is a diagnostic option. The so-called tunnel view (approximately 50 degrees of flexion) was initially exposed supine (Resnick and Vint 1980). According to Rosenberg et al. (1988), it more precisely detected joint space narrowing in medial arthrosis than any other view. This view is, however, not routinely used in Sweden. It might have added further information to our study and especially in lateral arthrosis, where the most pronounced wear is localized posteriorly (Weidow et al. 2002).

There are several possible reasons for why the semi-flexed position is superior to full extension in the diagnosis of arthrosis. Relaxation of the ligaments is probably important since many cases do not show any substantial difference of wear on the femoral condyles between the anterior and the more central part of the cartilage. In medial arthrosis, this observation may be explained by observations of a symmetrical anterior femoral extension facet articulating against the tibia between full extension and 30 degrees of flexion (Elias et al. 1990, Zoghi et al. 1992, Iwaki et al. 2000). When the tension in the ligaments decreases, the femoral condyle might slip more easily down into the most worn part of the tibia.

Some patients may actively avoid articulation of the most worn parts of the joint to reduce pain. This source of error was previously addressed by asking the patient to walk for some time immediately before the examination (Ahlback 1968). Now this technique has been abandoned, probably because of poor reproducibility, time limitations and ethical concerns.

Our main purpose was to compare routine radiography of gonarthrosis with a more accurate standard. One problem has been to find such a standard. Previous observations have indicated that the resolution of other methods such as CT and MRI are insufficient. In the experimental set-up, we also tried to use contrast fluid on one of the cartilage surfaces but noted no improvement in resolution. We also discussed the use of a histological technique. Such an approach would imply further destruction of the bone and difficulties in applying load in a reproducible way, making the results difficult to interpret.

Our current model was developed to allow reproducible loading, precise positioning of the central beam, optimum exposure and utilization of high-resolution mammography film. When it was tested, a number of problems had to be addressed. One was to orient the resected femoral condyles in a proper way during the initial phase of loading. This problem was solved by temporary fixation with elastic rubber until the load had reached a certain level. The use of the pneumatic technique supplied with regulation valves implied that the piston applied pressure more slowly, which seemed to facilitate adjustment of the bone pieces to each other in an anatomical way. This might have resulted in joint space widths closer to reality, but, interestingly, was not associated with a smaller data scatter (magnitude of standard deviations) than was observed in the manual tests of reproducibility. This finding of equal scatter indicates that further improvement of our experimental model would probablywould require a more accurate way of measuring joint space width.

Our model was developed to enable recordings of the "true" width of the joint. Nonetheless, any experimental set-up will be subject to different sources of error. Possible reasons for failure to visualize complete attrition with our model might be that the two bone pieces are not optimally aligned, or that the sclerotic bone is very uneven. At examination of the position of the bone pieces, they were probably close to full extension since the equipment did not allow any flexion. Their positions were guided by the angle of the cut performed during surgery. The model should allow the bone pieces to translate in the horizontal plane and to thereby slip into a position with maximum contact, corresponding to the most worn part of the joint. We could not test whether this actually occurred, or alternatively, whether the two pieces obtained a position in relation to each other which could not occur in the patient. Despite these possible sources of error, we believe that our finding of a wider joint line on clinical compared to laboratory radiographs is relevant.

Standing radiographs overestimated the joint space width. In medial arthrosis, this overestima-

tion is small and probably acceptable for clinical use. In lateral arthrosis, some cases showed large differences between clinical radiographs and our experimental set-up. The increased scatter observed in lateral arthrosis may reflect the fact that weight-bearing on the most eroded part of the joint is difficult to achieve. In these cases, maximum wear is often located posteriorly on both the tibia and the femur (Harman et al. 1998, Weidow et al. 2002). Flexion to 20–30 degrees is often not sufficient to reach this part of the joint, resulting in a more pronounced underestimation of the true progression of the disease. According to MRI observations, flexion up to approximately 50–60 degrees would be necessary to visualize the most worn part of the joint on an AP view (Boegard et al. 1997). Morphologically, we have observed a more spherical wear in lateral than in medial arthrosis, perhaps because the posterior part of the lateral femoral condyle has a smaller radius and shows a pattern of motion during flexion/extension which is different from that observed medially (Elias et al. 1990, Zoghi et al. 1992, Iwaki et al. 2000, Saari et al. 2003). Also, patients with lateral arthrosis may actively avoid loaded flexion, which will further-will compromise the radiographic visualization.

The difference between the experimental set-up and clinical radiographs was greater on the unaffected side. There are several possible explanations for this. One reason could be separation between the bones on the unaffected side, when the joint is loaded in vivo. Another explanation could be that the articulating parts of the joint are positioned differently. In the clinical situation, joint instability and pain may imply that certain positions are difficult or impossible to achieve, or are actively avoided due to pain.

Determination of joint width is an important part of the evaluation of degenerative disease. It also constitutes the basis for decisions between osteotomy, uni- or bi/tricondylar prosthesis when surgical treatment is intended. We found that conventional radiography underestimates the extent of cartilage wear, which explains why weight-bearing radiographs sometimes contain insufficient information in the preoperative planning. In medial arthrosis, the degree of underestimation is usually small and acceptable. In lateral arthrosis, more pronounced discrepancies may be found, calling for the use of further diagnostic measures. Examination at 50–60 degrees of flexion may also be of value, but further studies are required to validate this recommendation.

No competing interests declared.

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