A relationship between dynamic and static assessments of knee joint load

Gait analysis and radiography before and after knee replacement in 45 patients

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In a prospective study of 45 gonarthrosis patients treated with total knee arthroplasty, we performed gait analysis with the Vifor system preoperatively and 6 months and 2 years postoperatively. An evaluation was made of the relationship between dynamic measurements of knee joint load and static, radiographic measurements of alignment. Correlations were found between the knee joint moments in the frontal plane and the Hip-Knee-Ankle (HKA) angles on all measurement occasions, likewise between changes of moments and changes in HKA by the operation. Thus, static alignment reflects the loading conditions during gait.

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The forces in the knee joint are of interest when performing high tibial osteotomy and knee replacement operations, aimed at changing the loading conditions. The only available routine aid consists of frontal long-leg radiographs where the angle between the femoral and tibial axes is determined—i.e., the alignment. Whether these static measurements of alignment reflect the dynamic loading conditions is controversial (Johnson et al. 1980, Harrington 1983, Prodromos et al. 1985, Weinstein et al. 1986, Brugioni et al. 1990, Weidenhielm 1992, Catani et al. 1993, Goh et al. 1993, Wang and Olney 1994).

Methodological difficulties exist in the measurement of joint forces. Direct measurements with implantation of transducers are laborious and have been performed in only a few cases in the hip. Mathematical modeling is convenient with today's computer power, but many of the input variables are uncertain. Gait analysis provides a tool for indirect, dynamic assessments (Johnson et al. 1980, Harrington 1983).

We compared knee joint moments, obtained from gait analysis in 45 patients before and after total knee arthroplasty, with alignment measured on standing frontal long-leg radiographs.

Patients and methods

45 patients with gonarthrosis were operated on with total knee replacement between 1989 and 1992. They were selected according to strict criteria to form a homogeneous group for the purpose of radiostereometric analyses of 3 different tibial component designs (Hilding et al. 1995). The age was 60–75 years and the stage of arthrosis was 3–5 according to Ahlbäck (1968). Patients with an earlier osteotomy, knee arthroplasty or fracture were excluded. Patients with any impairment of the locomotor system other than gonarthrosis were also excluded, but varying levels of involvement of the opposite knee were accepted, due to the low incidence of severe monoarticular gonarthrosis. The operations were performed in a standardized manner by 2 experienced surgeons who took no part in analyzing the results.

Alignment in the frontal plane was measured as the Hip-Knee-Ankle (HKA) angle. Standing long-leg radiograms with a 120×30 cm cassette and 2 m film-focus distance were obtained preoperatively and at 6 months and 2 years postoperatively. Less than 180 degrees denotes varus alignment. The same radiologist made all the measurements. The interobserver variation was 0.5 degrees SD in 2 series of repeated measurements by 2 independent observers (or max. 1.4 degrees difference with 95 percent probability).

Table 1. Alignment as Hip-Knee-Ankle (HKA) angle (degrees) and averages of moments (Nm) in the frontal plane in 45 patients. Mean, *SD* (range)

	Preoperative	Postoperative	
		6 months	2 years
HKA	171 *10* (155–196)	179 *4* (172–188)	177 *4* (170–185)
Mean moments	32 *19* (–17–67)	16 *9* (0–36)	14 *8* (–2–36)
Peak adduction	51 *24* (–2–98)	30 *12* (10–59)	28 *11* (10–57)
Peak abduction	–1 *9* (–28–7)	–4 *4* (–13–3)	–4 *5* (–15–7)

The reproducibility in 7 double exposures on the same day was a 1 degree difference in 4 and no difference in 3 knees (0.5 degrees SD).

Preoperatively and twice postoperatively, at 6 months and 2 years, gait analysis was performed with the Vifor system. The system, including an error analysis, has been described previously (Lanshammar 1988). It consists of 2 synchronized video cameras, a force plate (Kistler), photo cells and a computer. The force plate is sampled synchronously with the 2 video cameras and the sagittal and frontal projections of the ground reaction force vector are superimposed onto the 2 (split-image) video images in real time. To obtain quantitative data, points of interest are digitized off-line by using a tracker ball and a cross-hair cursor overlaid onto the video images, frame by frame.

The gait analysis was performed on a 10 m walkway with a covered force-plate which registered the stance phase. Several trials were made prior to recordings, to facilitate a relaxed gait style with a stable, self-selected speed. The patients wore their own shoes and had no mounted instrumentation to reduce interference with normal gait. The hip joint was marked with tape (trochanter major laterally and 2 cm distal to the half-way point between the spina iliaca anterior superior and os pubis frontally). The knee and ankle joints were not marked but were kept free from clothing. The digitization included the position of the ground reaction force vector and the center of the ankle, knee and hip joints during the entire stance phase. To reduce the effects of internal/external rotation and skin motion on the estimated position of the knee joint center, the midpoint between the contour lines was used for digitization, instead of surface markers on the skin. Frames with 40 ms intervals were used. The external moments developed by the ground reaction force vector (and several other parameters) were calculated by the program VifDig (Lanshammar 1991). Gravitational and inertial forces were omitted in the calculations, because of their small contribution to ankle and knee joint moments at slow walking speed (Lanshammar 1988). The system is two-dimensional and cannot take rotations into account. The coordinate system is laboratory-fixed. The sagittal plane of the patient is supposed to coincide with the plane of progression. The frontal plane knee joint moments were calculated as mean values over the whole stance phase and as single maximum and minimum (peak) values, all from the averages of 3–6 recorded steps.

According to the previous error analysis, the accuracy of the Vifor system has been calculated to be better than 9 Nm (maximal error) for moments at the knee joint during midstance in the frontal plane (Lanshammar 1988). The reproducibility of the results was estimated by calculating the standard deviation of the difference between 2 repeated measurements (steps) in all patients. On all 3 measurement occasions the SDs of peak and mean frontal plane moments were between 1.8 and 3.2 Nm. Digitization was performed by one author. The interobserver reproducibility for knee joint moments in the frontal plane was between 1.3 and 2.1 Nm (SD) when 2 series were digitized independently by 2 of the authors.

The statistical method used was Pearson correlation. P-values < 0.01 were considered significant.

Results

The mean preoperative HKA angle was 171 degrees, with a postoperative change to 179 degrees (Table 1). The mean adduction moments were 32 Nm preoperatively, with a reduction to 16 Nm postoperatively. The peak adduction moments were correspondingly reduced from 51 Nm to 30 Nm postoperatively (Table 1). No changes occurred between 6 months and 2 years.

There was a correlation between HKA angles and all frontal plane knee moments, both preoperatively and at the 2 postoperative occasions (Table 2). The correlations were slightly less in the peak abduction moments than in the peak adduction moments and the mean moments. The change in the HKA angle and

Table 2. Pearson correlations (r) between Hip-Knee-Ankle (HKA) angle (degrees) and averages of moments (Nm) in the frontal plane in 45 patients

	Preoperative HKA		Postoperative HKA				HKA change pre- to 6 months postop.	
			6 months		2 years			
	n 44		n 45		n 43		n 44	
Mean moments	–0.839	p<0.001	–0.561	p<0.001	–0.639	p<0.001	0.837	p<0.001
Peak adduction	–0.791	p<0.001	–0.490	p 0.001	–0.595	p<0.001	0.810	p<0.001
Peak abduction	–0.794	p<0.001	–0.371	p 0.01	–0.481	p 0.001	0.785	p<0.001

the change in the moments pre- to 6 months postoperatively also correlated (Table 2). The mean difference in HKA angle between 6 months and 2 years postoperatively was 1.6 degrees in absolute value (range –6° to 3°). No correlation was found between this additional change (generally towards the initial deformity) of the HKA angle and any moments, nor to the corresponding changes in moments.

Discussion

Correct alignment has been of importance for the clinical results, both after knee replacement in some studies (Bargren et al. 1983, Ecker at al. 1987, Jeffery et al. 1991) and high tibial osteotomy (Tjörnstrand 1981). Radiostereometric analyses have indicated a better fixation of prostheses in well aligned knees, with an optimum slightly in valgus (Ryd et al. 1995). Other studies, however, have failed to demonstrate a clear relationship (Tew and Waugh 1985, Smith et al. 1989). The value of alignment measurements is restricted to their ability to yield information on the forces across the joint. A correlation has been reported between knee joint force measurements and the durability and success rate in high tibial osteotomy (Prodromos et al. 1985, Wang et al. 1990), and the fixation of tibial components in total knee arthroplasty (Hilding et al., in press).

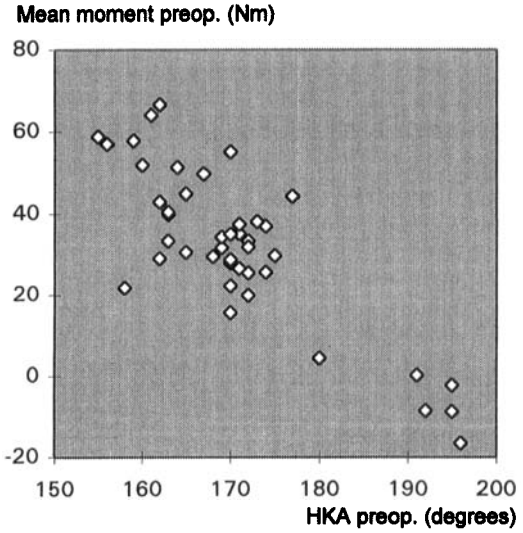

Figure 1. Correlation between alignment (HKA) and mean moment preoperatively in 44 patients (r –0.839).

Attempts to correlate force measurements to alignment have been made previously. By determining the distribution of force, Johnson (1980) and Harrington (1983) failed to show any correlation. Force distribution requires more calculations and assumptions beyond moments, which may render the results uncertain. When determining moments across the knee, Wang and Olney (1994) found no relationship to alignment but others have found one (Weinstein et al. 1986, Brugioni et al. 1990, Weidenhielm 1992, Goh et al. 1993). Still others have reported correlations only between recurrence of varus deformity and increased adduction moments (Prodromos et al. 1985, Wang et al. 1990, Catani et al. 1993).

We noted consistent correlations between frontal plane alignment and moments in the arthrotic knees, both before and after the arthroplasty. However, the variability in the dynamic measurements could only to some extent (roughly 30–70 percent) be explained by the static measurements. This may partly account for the inconsistently found correlations between alignment and clinical results. Further, the multifactorial etiology of failure in knee arthroplasty may obscure single factors like alignment. Thus, our results seem reasonable and compatible with previous clinical results.

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