THE EFFECT OF A STEM ON THE TIBIAL COMPONENT OF KNEE ARTHROPLASTY

A ROENTGEN STEREOPHOTOGRAMMETRIC STUDY OF UNCEMENTED TIBIAL COMPONENTS IN THE FREEMAN-SAMUELSON KNEE ARTHROPLASTY

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We studied the effect of a metal tray with an intramedullary stem on the micromotion of the tibial component in total knee arthroplasty. Of 32 uncemented Freeman-Samuelson knee arthroplasties performed in London and Gothenburg, nine had a metal backing and stem added to the tibial component. Micromotion of the tibial components, expressed as migration and inducible displacement, was analysed using roentgen stereophotogrammetric analysis up to two years follow-up.

The addition of a metal back and a 110 mm stem to the standard polyethylene component significantly reduced both migration over two years and inducible displacement.

The fixation of the tibial component of a knee arthroplasty is critical (Insall and Dethmers 1982; Thornhill, Dalziel and Sledge 1982); its alignment, coverage of the proximal tibia and position are important (Lotke and Ecker 1977; Bargren, Blaha and Freeman 1983; Ecker et al 1987). Roentgen stereophotogrammetric analysis (RSA) has shown that micromotion, expressed both as migration over time and inducible displacement caused by external forces, occurs in clinically successful knee arthroplasties. This has been shown for several knee prostheses,

including the Freeman-Samuelson pattern (Ryd 1986; Ryd et al 1988). The design of the prosthesis, or the addition of a metal support or a stabilising stem may effect such micromotion (Bargren et al 1978; Walker et al 1981).

We have investigated the effect of a metal tray with a 110 mm intramedullary stem on the magnitude and direction of micromotion of the tibial component of the cementless Freeman-Samuelson knee prosthesis.

PATIENTS AND METHODS

The study is prospective though neither consecutive nor randomised, but the patients were not specially selected. All have been followed for two years and all had their upper tibial bone marked at operation to allow consecutive stereoradiographic examinations. All arthroplasties were performed in laminar air flow and all patients were given prophylactic dikloxacillin for 48 hours. There were no perioperative or postoperative complications.

Group A. Nine Freeman-Samuelson arthroplasties were performed on eight patients at the London Hospital, five for osteoarthritis (OA) and four for rheumatoid arthritis (RA). One man had bilateral replacements and seven women unilateral ones. Mean age at the time of surgery was 62 years (35 to 74) and the operations were performed by two surgeons in a standardised manner. The components were fixed without cement, relying on the immedi-

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Fig. 1a

Fig. 1b

The tibial component of the Freeman-Samuelson prosthesis with and without the metal backing and stem.

Fig. 2

Postoperative radiograph showing tantalum markers in the tibial component and the tibial metaphysis.

ate interlock of flanged polyethylene pegs (Freeman et al 1981). A metal tray with a 110 mm intramedullary stem was clipped onto the standard polyethylene tibial component (Fig. 1a). Special care was taken to prevent the tip of the stem resting on cortical bone.

Group B1. In Gothenburg, 21 Freeman-Samuelson arthroplasties were performed on 20 patients but three knees were excluded because of inadequate marking of the upper tibia. Of the remaining 18 arthroplasties, 11 patients had RA and six had OA. There were 16 women (one with bilateral replacements) and one man. Mean age at the time of surgery was 66 years (40 to 77). These patients had the same uncemented Freeman-Samuelson prosthesis, but without the metal tray and stem (Fig. 1b). Three surgeons performed the arthroplasties in a standardised manner.

Group B2. In London nine other patients had the same prosthesis as group B1. Four were excluded because of inadequate marking, leaving two men and three women, two with RA and three with OA. Their mean age was 71 years (62 to 80).

In all cases spherical markers of tantalum were inserted into the tibial polyethylene component and the tibial metaphysis at operation (Fig. 2) and micromotion of the tibial component was measured by roentgen stereophotogrammetric analysis (RSA), carried out for all knees in Lund (Selvik 1974; Ryd 1986; Ryd et al 1987). Anteroposterior and lateral radiographs were

taken with the knee inside a plexiglass calibration cage, with markers of known position in each of its four walls. These radiographs were measured with a digitiser (an instrument used for cartography) (Wild A8, precision = 20 μ m) and the 3-D co-ordinates of the markers in the prosthesis and in the bone (Selvik 1974) were obtained by the computer program 'X-RAY'. The two groups of markers, in prosthesis and tibia, were modelled as rigid bodies so that their relative positions could be determined. The change of position, that is the movement between the postoperative reference examination and later ones performed at regular intervals, was obtained by kinematic analysis pertaining either to the entire prosthetic rigid body (segment motion) or to individual markers (point motion). Such movement was expressed either as cardinal axis or as total (vector) motion in the co-ordinate system defined by the calibration cage (Fig. 3). The point motion of the prosthetic marker that moved most (maximum total point motion MTPM) was used to express the *magnitude* of the motion, while segment motion about or along each cardinal axis was used to express the *direction* of the motion (Fig. 3).

The kinematic analysis depends on the actual rigidity of the theoretically 'rigid bodies'. Due to measurement errors or unstable bone markers, for example, the actual rigidity was never perfect. An evaluation of this rigidity was therefore included in the RSA system: the mean error of rigid body fitting (ME). The relationship between the ME and the accuracy of RSA applied to knee arthroplasty has been reported elsewhere (Ryd 1986; Ryd et al 1988). Should the criteria for rigidity not be met, an unstable marker or an entire case, can be excluded. In this study an ME < 200 was considered as rigid. In three cases the ME was greater than 200 at the two-year follow-up (Table III); however, they were not great enough to render the migrations found insignificant. The accuracy of RSA, applied to knee arthroplasty in this way has been determined to be 0.2 mm (Ryd 1986).

Migration. The longitudinal follow-up started on the first postoperative day and stereoradiographs were subsequently obtained at three, six, 12 and 24 months. Migration has been studied in all but five knees. For two knees in group A the first postoperative radiographs were taken too late. For three knees in group B1 the number of markers visible on the first postoperative radiographs were insufficient. These five knees are therefore only included in the study of inducible displacement.

Inducible displacement. At two years postoperatively stress examinations were performed on six knees in group A and 10 knees in group B1, to study inducible displacement. After a stereo exposure in the supine position, the calibration cage was mounted vertically and the knee was subjected to external forces of a physiological magnitude (Ryd et al 1988). The second stereo exposure was obtained while the patient was standing on the operated leg only. During the third exposure a 10 Nm outward torque was applied to a rotating plate on which

Fig. 3

The three-dimensional co-ordinate system for a left knee, where each cardinal axis is parallel to the corresponding plane in the body. For a right knee the directions of x-translation, y-rotation and z-rotation are reversed.

Fig. 4

Migration during the first two years for groups A and B, showing mean values and the standard error of the mean.

the patient was standing. The patient was told to resist this torque, using the hip rotators. During the fourth exposure the direction of the torque was reversed to the inward direction.

Student's *t*-test was used to compare RSA values between groups.

RESULTS

Clinical results. Clinical and radiological data for these knees are shown in Tables I and II.

Table I. Clinical and radiological data for knees in group A

Case	Age	Diagnosis	Sex	Postoperative					Migration at 2 yr	Inducible displacement studied
				HSS*	LH	PT	PTS			
1	74	RA	F	96	110	92	90	+	+	
2	64	RA	F	83	95	91	90	+	—	
3	57	OA	F	95	110	90	91	+	+	
4	35	RA	F	85	110	88	91	+	+	
5	62	OA	F	90	100	88	88	+	—	
6	66	RA	F	95	110	87	91	+	+	
7	68	OA	F	72	95	90	91	+	—	
8	64	OA	M	88	100	89	90	—	+ Left	
9	64	OA	M	88	100	87	91	—	+ Right	
Mean	62			88	103	89	90			

* HSS Hospital for Special Surgery score two years postoperatively

LH London Hospital score two years postoperatively

PT prosthesis-tibial-angle: medial angle between tibial component and tibial shaft on the A-P view

PTS prosthesis-tibial-sagittal-angle: posterior angle between tibial component and tibial shaft on the lateral view

Table II. Clinical and radiological data for knees in group B

				Postoperative						
Case	Age (yr)	Diagnosis	Sex	HSS*	LH	PT	PTS	Migration at 2 yr	Inducible displacement studied	
Group B1										
10	76	RA	F	92	110	91	86	+	+	
11	66	RA	F	88	110	88	90	+	+	
12	69	OA	F	95	110	87	87	+	+	
13	71	OA	F	88	110	83	88	+	+	
14	48	RA	F	89	110	88	90	+	+	
15	61	RA	F	94	110	90	91	+	—	
16	70	RA	F	85	105	87	90	+	+	
17	63	RA	F	82	85	86	92	+	—	
18	71	RA	F	75	70	85	94	+	+	
19	40	RA	F	95	110	85	87	+	—	
20	77	RA	F	88	110	87	91	+	—	
21	59	RA	F	89	100	87	88	+	—	
22	74	OA	F	83	100	89	89	+	—	
23	67	OA	M	96	110	90	91	+	—	
24	64	RA	F	92	110	85	91	+	—	
25	77	OA	F	90	110	90	90	—	+ Left + Right	
26	77	OA	F	90	110	88	88	—		
27	65	OA	F	86	110	88	84	—		
Mean	66			89	105	87	89			
Group B2										
28	62	RA	F	90	110	90	90	+	—	
29	66	OA	F	76	100	90	90	+	—	
30	76	OA	M	86	105	92	91	+	—	
31	71	OA	M	76	80	92	90	+	—	
32	80	RA	F	76	85	90	91	+	—	
Mean	71			81	96	91	90			
Mean B1 + B2	67			87	103	88	89			

* for legend see Table I

All knees in group A were clinically successful at the two-year follow-up with a mean London Hospital score (Freeman, Todd and Cundy 1977) of 103 (range 95 to 110) and a Hospital for Special Surgery score (Ranawat, Insall and Shine 1976) of 88 (72 to 96). Case 7 had a low clinical score after an injury in a road traffic accident which did not involve her replaced knee.

The clinical results in group B were similar, with a

mean London Hospital score of 103 (70 to 110) and an HSS score of 87 (75 to 96) at the latest observation. Case 18 has severe generalised rheumatoid arthritis which accounts for the low clinical score, but the replaced knee is pain-free and stable. Cases 29, 31 and 32 also have low clinical scores for reasons other than the replaced knee.

Migration. The RSA data for all knees are listed in Table III. All prostheses migrated, predominantly during the

first year (Fig. 4). At the two-year follow-up the mean migration (MTPM) was smaller for the stemmed than for the non-stemmed prostheses: 1.3 mm (0.7 to 1.6) versus 2.4 mm (1.3 to 4.9) ($p = 0.02$). The principal direction of migration was subsidence of not quite 1 mm down into the tibia along the y-axis (Fig. 5). The stem was found to have no influence on the magnitude of such subsidence. The remaining migration was found in both directions about or along the transverse and sagittal axes.

The absolute value for rotation about the transverse axis (the x-axis; or anteroposterior tilt) in either direction, was smaller for the stemmed prostheses $0.6^\circ \pm 0.2^\circ$ than for non-stemmed ones $1.8^\circ \pm 1.3^\circ$ ($p < 0.03$). The difference for rotation about the sagittal axis (the z-axis; or varus-valgus tilt), $0.4^\circ \pm 0.4^\circ$ versus $1.3^\circ \pm 1.1^\circ$, was also significant ($p < 0.05$), as well as the translation along the x-axis, 0.1 ± 0.1 mm versus 0.4 ± 0.4 mm ($p < 0.04$) (Fig. 5).

Inducible displacement. Inducible displacement was found in all cases. The mean maximum total point motion (MTPM) was 0.9 mm (0.7 to 1.2) for the stemmed and 1.3 mm (0.8 to 2.1) for the non-stemmed prostheses ($p =$

Fig. 5

Absolute rotation (R) and translation (T) about and along the three axes at two years postoperatively.

Table III. Roentgen stereophotogrammetric data for all knees

Case	Migration (MTPM) in mm					Rotation in degrees round axis			Translation in mm along axis			Induced displacement (MTPM) in mm	
	3M	6M	1Y	2Y	ME*	X	Y	Z	X	Y	Z		
Group A													
1	0.7	-	1.0	0.9	ok	-1.0	-0.4	1.1	-0.3	-0.4	0	1.2	
2	-	-	1.1	2.0	ok	-0.6	-1.7	0.3	0	-1.0	0.6		
3	-	1.5	1.6	1.6	ok	-0.8	0	0.5	0	-1.0	-1.0	0.8	
4	0.3	1.1	1.2	1.5	†	cannot be evaluated							1.0
5	0.6	1.6	1.6	-	ok	-0.7	0.8	0	0	-1.5	0		
6	-	0.5	0.7	0.7	ok	-0.3	0.5	0.5	0.2	-0.4	-0.4	0.7	
7	-	-	0.9	0.8	ok	-0.5	1.1	0	0	-0.4	0		
8 right												0.7	
9 left												0.9	
Group B1													
10	1.2	1.1	1.6	1.7	281	-0.5	0	0.8	0.4	-0.7	0.2	0.8	
11	-	1.6	2.0	2.0	ok	0	1.7	1.4	-1.0	-1.0	0.5	1.4	
12	1.7	1.2	1.0	1.5	ok	0.3	-1.6	1.7	0	-0.4	0.5	2.1	
13	0.9	0.9	0.9	1.3	361	0	1.0	1.8	-0.4	-0.4	0.2	1.5	
14	-	2.0	2.0	1.9	ok	3.1	-0.8	1.5	1.0	-0.4	0.9	1.1	
15	1.4	1.2	-	1.9	250	1.8	1.3	2.8	0.8	0.5	1.3		
16	0.8	1.4	1.4	1.5	ok	2.9	-0.3	1.8	0	-0.5	0.7	1.0	
17	3.8	3.8	4.6	4.0	ok	2.3	8.0	1.2	0.6	-0.8	-0.5		
18	-	2.0	2.5	2.4	ok	2.4	3.8	1.0	0	-0.4	0	1.0	
19	1.2	1.6	-	2.2	ok	0.6	1.5	2.6	0	-0.7	0.4		
20	1.7	2.0	-	2.9	ok	3.1	-1.1	1.0	0.2	-1.9	0.5		
21	-	1.7	2.2	2.7	ok	0.9	3.3	1.3	0.4	-1.7	-0.3		
22	1.5	2.3	3.2	4.9	ok	-5.0	-2.4	2.3	-0.4	-3.5	0.6		
23	0.9	1.7	1.5	2.2	ok	0.7	2.1	0.4	0	-0.4	1.0		
24	-	-	2.9	4.0	ok	2.3	4.3	0	0.3	-0.7	1.8		
25 left												1.2	
26 right												5.0	
27												1.5	
Group B2													
28	0.7	-	0.9	1.0	ok	-0.6	-0.3	0.7	-0.2	0.6	0.0		
29	0.8	1.7	3.1	4.7	ok	2.1	5.1	3.9	-1.2	-1.1	0.2		
30	-	1.4	2.3	2.4	ok	3.2	-1.5	1.1	-1.0	-0.4	0.8		
31	-	1.2	2.2	3.9	ok	1.7	-1.9	3.5	-0.8	-1.5	0.7		
32	0.5	1.2	1.5	1.2	ok	3.4	0.9	0.7	0.6	-0.1	0.1		

* mean error of rigid body fitting, cf text

† only two markers visible in the tibial component on reference radiograms

0.03), that is, the stem significantly reduced inducible displacement. The rotatory stress positions were the most revealing, especially the difference between results for external and internal rotational forces.

Case 26 with bilateral replacements for osteoarthritis showed an exceptionally large inducible displacement in the right knee with a MTPM of 5 mm. This was a combination of movement at the bone-prosthesis interface and reversible and totally painless distortion of the prosthesis. Unfortunately it has not been possible to study migration in this knee, but after three years the patient cannot detect any difference between her two replaced knees. Ordinary radiographs have been negative. We do not consider this knee to be representative; these results are not therefore included in the mean value for group B. Were this knee to have been included, the mean inducible displacement for the non-stemmed knees would rise to 1.7 mm.

Group A and B together have been studied according to diagnosis. We found no significant differences between cases with RA and those with OA for migration or for inducible displacement.

DISCUSSION

The original Freeman-Samuelson prosthesis, without metal support or a central stem on the tibial side, has been shown to be 'elastically' bonded to the bone, allowing inducible displacement of about 2 mm in most cases (Ryd et al 1988). This configuration also results in migration, especially in the form of subsidence but also as varus-valgus or anteroposterior tilt (Ryd 1986). The stemmed version of the tibial component was originally used for revision arthroplasty (Bertin et al 1985), but the good clinical and radiological results obtained led to the introduction of a slightly thinner version for primary replacement. The hypothesis behind a long central stem was that it would 'guide' migration so that it occurred predominantly along the vertical axis, thereby minimising the risk of recurrent malalignment and loosening due to tilting. It was also hoped that the presence of a third rigid metal 'peg' would reduce inducible displacement.

To exclude such factors as operative routines we included an internal control of the hospitals and surgeons involved. Group B included patients operated on in both London and Gothenburg; no difference in micromotion was found between these two subgroups, who were comparable with respect to age and diagnosis. All RSA measurements were made in Lund.

Our results tend to confirm the hypothesis. As with other types of prostheses (Ryd 1986; Ryd et al 1987, 1988), both cemented and non-cemented, initial migration occurred. The magnitude of this migration was about the same for the non-stemmed Freeman-Samuelson prostheses as for non-cemented PCA prostheses (Ryd et al 1989), while the migration for the stemmed prostheses was smaller. The difference between our two groups

increased with time: migration after six months was negligible for the stemmed prostheses. As predicted by the hypothesis, anteroposterior and varus-valgus tilt were the directions of migration most effectively controlled by the stem. The absence of continuous migration and the reduction of varus-valgus tilt in the stemmed group conforms with the recent demonstration that continuous migration after two years is correlated with malalignment (Ryd et al 1988), which in turn is an important factor leading to bad clinical results (Ecker et al 1987).

A rigid bond between prosthesis and bone has been considered a prerequisite for lasting good results (Ducheyne, Kagan and Lacey 1978; Lewis et al 1985). Although the possibility of micromotion within the radiolucent lines which correspond to fibrous membranes has been acknowledged (Kaufer, Matthews and Sonstegard 1978; Radin et al 1982; Tibrewal, Grant and Goodfellow 1984), the incidence of such movement has been unknown. RSA has now shown that micromotion between prosthesis and bone is normal (Ryd 1986) and in nearly 300 knee arthroplasties examined, total rigidity has yet to be found. The clinical importance of micromotion, in terms of future loosening, remains to be determined. Our current study confirms the universal presence of micromotion and demonstrates that it can be reduced by appropriate prosthetic design.

In every evolutionary process the initial stages represent great steps forward. But with increasing refinement of, for example, prostheses and fixation systems, each system becomes progressively less different from the preceding one. The detection of differences then requires more accurate assessment methods. RSA is such a method, since it has an accuracy about ten times better than conventional radiography (Ryd et al 1983). In our study RSA detected significant differences in micromotion between two rather small patient groups which differed in only one detail of the prosthetic design. No differences could be detected by conventional radiographic or clinical observations. We therefore consider RSA to be the method of choice for detecting differences between prostheses or types of fixation, since its accuracy reduces both the number of prostheses that have to be assessed and the duration of the follow-up required before significant differences can be detected.

Conclusion. The addition of a metal back and a stem to the tibial component of a non-cemented Freeman-Samuelson knee prosthesis provides: 1) a significant reduction of the inducible displacement, 2) a significant reduction of varus-valgus and of anteroposterior tilt and 3) seems to render migration non-progressive after six months.

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