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MIGRATION OF THE TIBIAL COMPONENT IN SUCCESSFUL UNICOMPARTMENTAL KNEE ARTHROPLASTY

A Clinical, Radiographic and Roentgen Stereophotogrammetric Study

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Migration of the tibial component in unicompartmental Marmor knee arthroplasty was measured by conventional radiography and roentgen stereophotogrammetry during a 2-year follow-up of six patients operated on for femoro-tibial arthrosis. The clinical course was satisfactory for all six patients. A radiolucent zone developed in all cases, the width of which was greater than 2 mm in one case. By radiography movements of two of the six prosthetic components could be detected. Roentgen stereophotogrammetry showed significant rotational and translatory movements in all six tibial components. In four cases these movements were small, not exceeding 1 mm for translation and 1.5° for rotation. The remaining two components showed larger migrations with maximum values of 2.7 mm for translation and 12.6° for rotation. Five of the components tilted backwards about the transverse axis, four tilted away from the centre of the knee about the sagittal axis, and four rotated with the anterior part away from the centre of the knee about the vertical axis.

The small movements of the four tibial components may be due to a semi-rigid fixation by connective tissue in the bone-cement interface. Since all knees were asymptomatic, neither the zones nor the minor movements seemed to have any clinical significance within the follow-up period.

Key words: gonarthrosis; knee arthroplasty; loosening; migration; radiography; roentgen stereophotogrammetry

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The bond between the tibia and the tibial component is the weak link of all knee endoprostheses; loosening of the tibial component in unicompartment arthroplasty causes problems in 3–20 per cent of the patients (Engelbrecht 1976, Insall & Walker 1976, Marmor 1979, Jónsson 1981). Assessment of the position, and of changes in position of prosthetic components has hitherto been made by radiography. However, the relation between clinical symptoms and radiographic signs of loosening is not always obvious; many patients have shown excellent results despite radiographic signs of loosening of the tibial component (Marmor 1979, Larsson & Ahlgren 1979). Radiographic loosening covers a wide range of movements, from gross displacement to minor ones or even indirect signs such as buckling of the tibial component, breakage of the indication wire or cement fracture. Also, the precision of radiography for assessment of movements between the tibia and the tibial component is not known. Especially in patients with only minor uncharacteristic symptoms of suspected loosening more accurate radiological methods would be valuable.

In Lund 1974 roentgen stereophotogrammetry combined with kinematic analysis was introduced for precise determination of movements in skeletal structures (Selvik 1974, 1983). The method has been applied to various orthopaedic problems such as spinal fusion stability, healing of tibial osteotomy and skeletal growth patterns (Olsson et al. 1977, Baldursson et al. 1979, Bylander et al. 1981, Tjörnstrand et al. 1981, Kärrholm et al. 1982). Other investigators have mainly used roentgen stereophotogrammetry for assessing hip joint prosthetic loosening (Lippert et al. 1978, Hunter et al. 1979, Probst 1980).

The purpose of the present investigations was to assess, in asymptomatic patients, the behaviour of the tibial component in relation to the bone in unicompartmental knee arthroplasty using roentgen stereophotogrammetry and to compare these findings with radiography.

PATIENTS

The material consists of six women (65–73 years of age) operated on for femoro-tibial arthrosis, in November 1978 through April 1979. Medial unicompartmental arthroplasty was done in five cases and lateral unicompartmental arthroplasty in one case. The Richard modular knee prosthesis was used (Marmor 1973). The degree of arthrosis, determined according to Ahlbäck (1968), was Stage 2 medial gonarthrosis in one case, Stage 3 medial gonarthrosis in four cases and Stage 3 lateral gonarthrosis in one case.

METHODS

Operative technique

The operation was done through an anterio-medial incision. The patients were operated on with a positioning jig (from the French Lotus prosthesis) and the bed for the tibial prosthesis was prepared by doing a horizontal resection of the entire tibial plateau (Lindstrand et al. 1982). A large tibial component, resting on as much bone as possible, was used. CMV bone cement was used for fixation of the prosthetic components.

Implantation of markers

Before cementation, three or more tantalum balls (diameter 0.8 mm) were implanted into the tibial metaphysis using a special instrument with needle and piston (Aronson et al. 1974). Three or more markers were also introduced about 3 mm into the polyethylene tibial component, from underneath, through holes made with a dentist's drill.

Clinical assessment

The assessment of the clinical result of the arthroplasty was done according to routine departmental methods (Jónsson 1981): a satisfactory result was defined as painfree walking distance of at least 500 m, a varus-valgus instability of less than 5° and a range of motion of at least 5°–90°. The results were also analyzed according to the Hospital for Special Surgery, HSS (Ranawat et al. 1976) and London Hospital, LH, point-scoring systems (Freeman et al. 1977). Follow-up, including clinical as well as radiological examinations both with conventional and stereophotogrammetric techniques, were done annually.

Radiographic examination

The examinations were always done with a true lateral exposure defined by a tangential appearance of the posterior aspect of both femoral condyles and a frontal exposure perpendicular to the lateral one. The central beam passed through the center of the knee. 24 × 30 cm cassettes were used. The postoperative examination (reference examination) was made in the supine position before the patient was allowed to put weight on the operated leg. The annual follow-up examinations were carried out with the patient standing on the operated leg only (Egund & Norman 1979). Rotations about the transverse and the sagittal axes were the only movements determined, since the determination of other movements would require tibial reference points which cannot be defined with any degree of accuracy by radiography.

Movements were defined as the change between examinations of the angle between the tangent of the articular surface of the tibial prosthesis and the longitudinal axis of the proximal tibia in the frontal and lateral projections (Figure 1).

To determine the error of measurement for the radiographic examination, three separate determinations on different occasions with several weeks interval were performed by the same person on each radiograph. To allow for unbiassed determinations, the identifications on the radiographs were covered and the films were randomly mixed. In this way 31 radiographs were measured. The results were analysed with two-way analysis of variance.

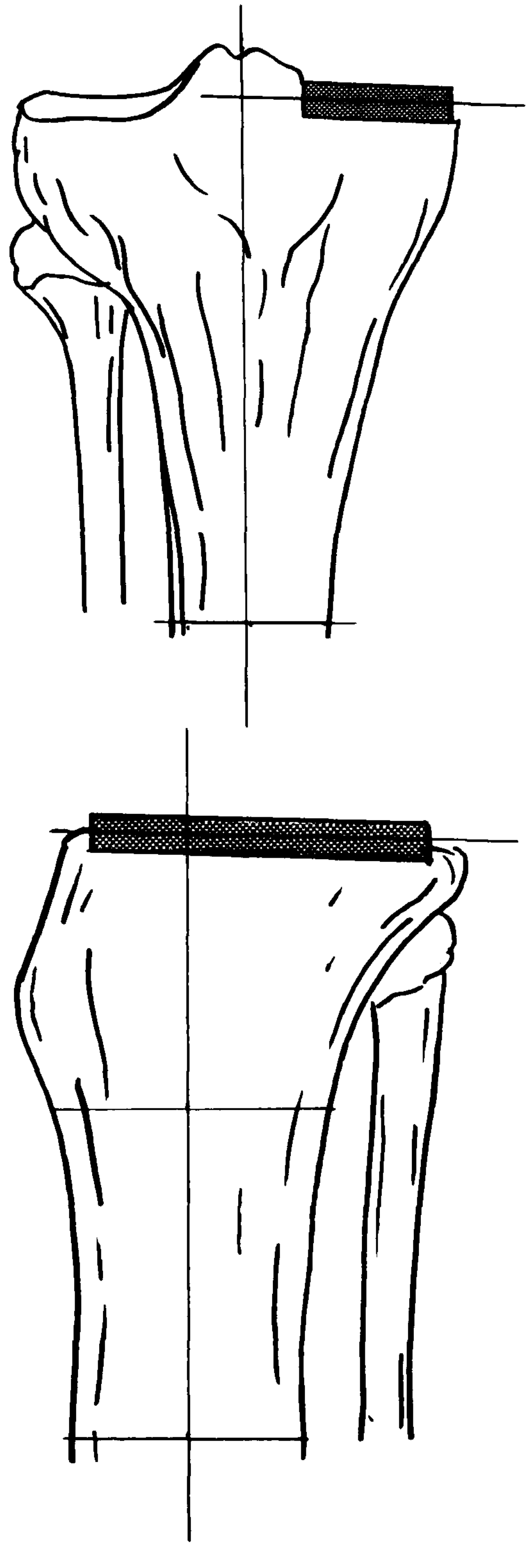

Figure 1. Definition of the PT and PTS angles. The longitudinal axis of the proximal tibia in the frontal plane is drawn between the midpoint of the eminence and a point in the middle of the diaphysis as far distally as possible. In the sagittal plane the longitudinal line is drawn between two points in the middle of the diaphysis, one just below the tuberosity and one as far distally as possible. The PT (prosthesis tibia) angle is the medial angle for medial prosthesis and the lateral angle for lateral prosthesis between the longitudinal axis of the tibia and the tangent of the prosthetic surface. The PTS (prosthesis tibia side) angle is the posterior angle between these two lines.

Roentgen stereophotogrammetric examination

Roentgen stereophotogrammetry is a method to define the three-dimensional coordinates of structures in the body (Selvik 1974). To ensure sufficiently distinct points for highly accurate identification, tantalum balls are inserted into the object of interest.

The exposures were made in a supine position with the knee inside a plexiglass calibration cage supplied with tantalum markers of known position (Figure 2). Exposures in the frontal and lateral projections were done simultaneously. The film coordinates of the tantalum markers in the patient and in the calibration cage were determined by means of an instrument for cartography. The three-dimensional coordinates were subsequently determined using a computer. The tantalum markers in the tibia and in the prosthetic compo-

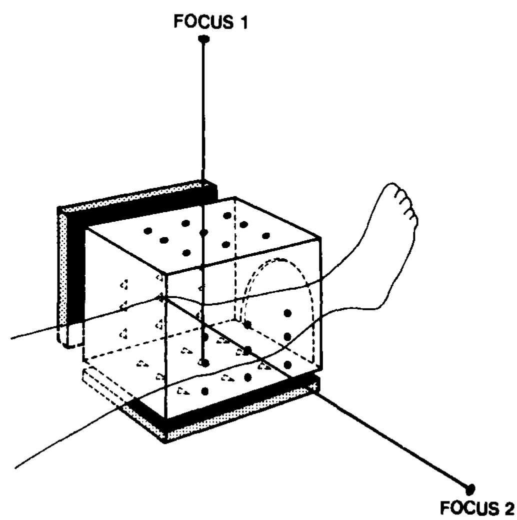

Figure 2. Stereophotogrammetric investigation of a knee. Tantalum markers in the four walls of the calibration cage and the two cassettes for 24 × 30 cm films are indicated. Film-foci distances are about 1 mm.

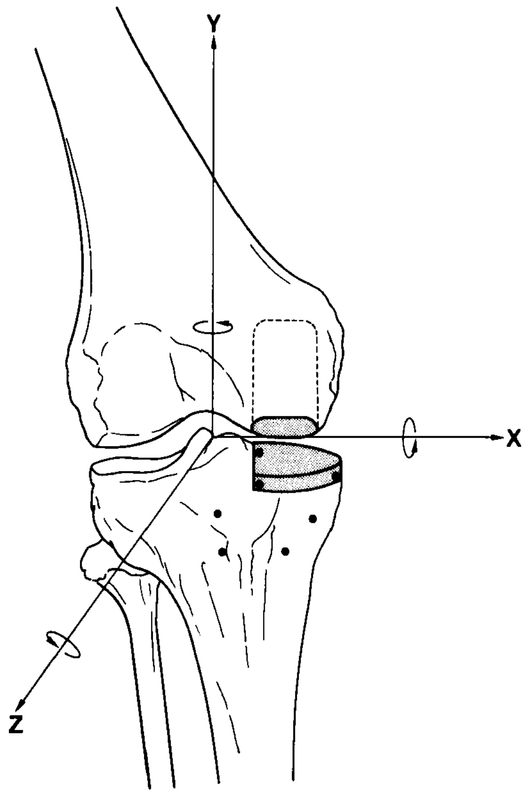

Figure 3. The directions of the coordinate axes shown for a medial prosthesis in the right knee. To obtain the same interpretation of movements in relation to the centre of the knee joint for a medial left or a lateral right prosthesis changes are made in the computed signs to satisfy the concepts according to Table 1.

nent were modelled as two rigid bodies, the relative movement between which was calculated. A reference examination was done in the immediate postoperative period, before the patient was allowed to put weight on the operated knee, and displacements of the prosthesis were expressed in relation to this postoperative examination.

Every stereophotogrammetric evaluation includes a test of the rigid bodies in order to exclude loose tantalum balls from the calculation. Should the whole rigid body be unstable the patient is excluded from the investigation. In this study no patient was excluded.

In order to obtain comprehensive directions of the movements, the knee was positioned in the calibration cage so that its main axes were parallel to the coordinate axes of the cage, i.e. so that the plane parallel to the tangent of the femoral condyles was a frontal plane parallel with the cage XY-plane (Figure 3). In earlier investigations with the same radiographic technique and comparable tantalum ball configurations the precision of the method has been calculated to about 0.1°

Table 1. Stereophotogrammetric results. Movements of the tibial component in reference to the tibia. Positive translations are defined as being directed away from the centre of the knee along the transverse (X) axis, cranial along the longitudinal (Y) axis and forward along the sagittal (Z) axis. The translations pertain to the geometric centre of the implants in the prosthesis. Positive rotations are defined as movement downward of the anterior part of the prosthesis (X-axis), movement peripheral of the anterior part of the component (Y-axis) and movement downward from the central part of the prosthesis (Z-axis)

Patient No.	Length of follow-up, years	Rotatory movement in degrees about X axis	Y axis	Z axis	Translatory movement in mm along X axis	Y axis	Z axis
1	1	−0.4	−0.5	−0.4	0	−0.1	−0.3
	2	−0.5	−0.4	−0.6	0	0	−0.3
2	1	−0.8	1.3	−1.4	0.3	0.6	−0.4
	2	−0.5	1.3	−0.8	0.1	0.7	−0.3
3	1	−1.2	0.1	0.3	0.1	0	−0.1
	2	−1.6	−0.1	0	0.2	−0.1	−0.1
4	1	−0.7	3.0	1.9	1.2	−1.0	−0.2
	2	−0.6	4.1	2.4	1.4	−1.0	−0.5
5	1	1.7	2.3	−11.7	1.2	−2.4	0
	2	1.3	2.3	−12.6	1.0	−2.7	0
6	1	−0.6	0.4	−1.2	0.4	0.2	0.1
	2	−0.5	0.4	−1.4	0.5	0.2	0.1

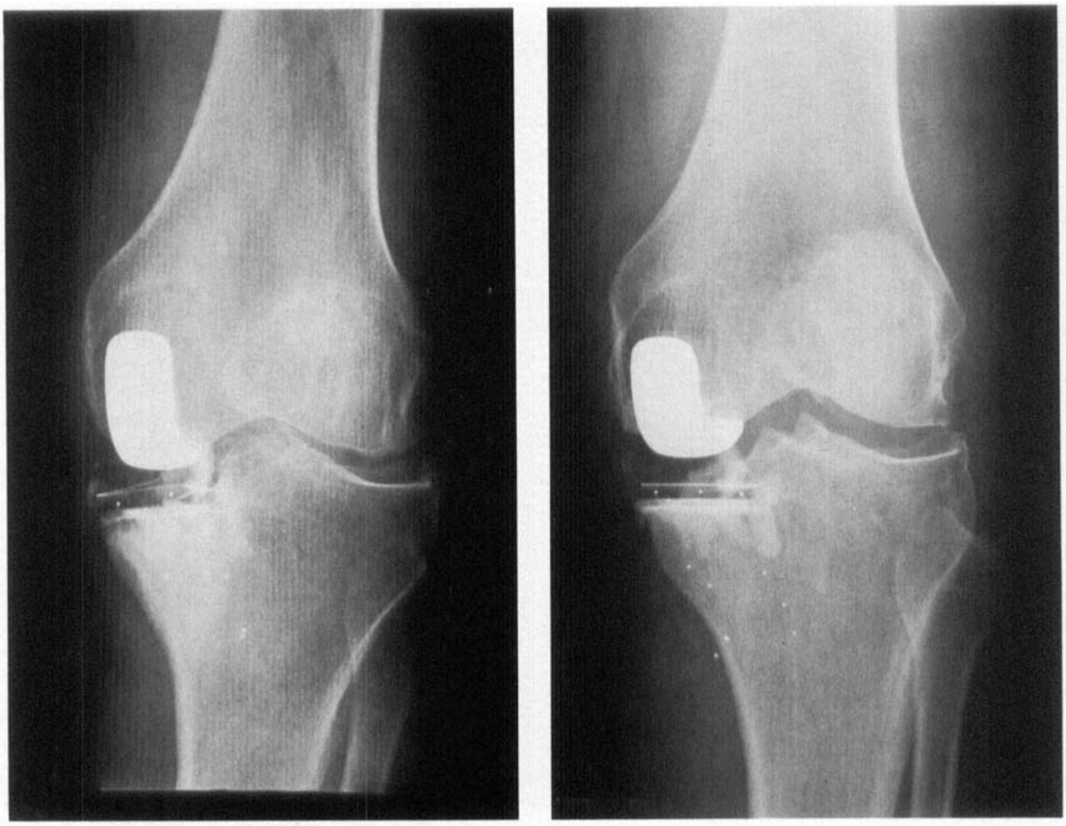

Figure 4. Frontal projections of Knee 5, showing the major migration about the sagittal axis between the post-operative control (A) and the 2-year follow-up (B).

for rotations and slightly better than 0.1 mm for translations (Tjörnstrand et al. 1981).

RESULTS

The clinical results were satisfactory in all six patients according to the Lund assessment system. The mean HSS score was 82 points (range 76–87) whereas the LH-point-scoring system gave 100 points or more to all six patients at the 2-year follow-up. This means excellent or good clinical results for all six patients.

Roentgen stereophotogrammetry showed rotational as well as translatory displacement of varying degrees in all six knees (Table 1). In four of the knees the movements were small, not exceeding 1 mm for translations and 1.5° for rotations. Two knees showed major movements of the tibial component. In Knee 4 the anterior part of the prosthesis rotated inwards 4° about the vertical axis and the component also translated 1.4 mm away from the centre of the knee along the transverse axis. In Knee 5 there was a 12.6° tilting away from the centre of the knee about the sagittal axis whereas the anterior part of the prosthesis rotated away from the centre of the knee 2.3° about the vertical axis (Figures 4 and 5). In this knee the prosthetic component had sunk down 2.7 mm into the tibia after 2 years.

There were certain patterns of movement to which most of these tibial components complied. Five components tilted backwards about the transverse axis and four components rotated with the anterior part away from the center of the knee about the vertical axis. Also four components tilted outwards, away from the center of the knee, about the sagittal axis.

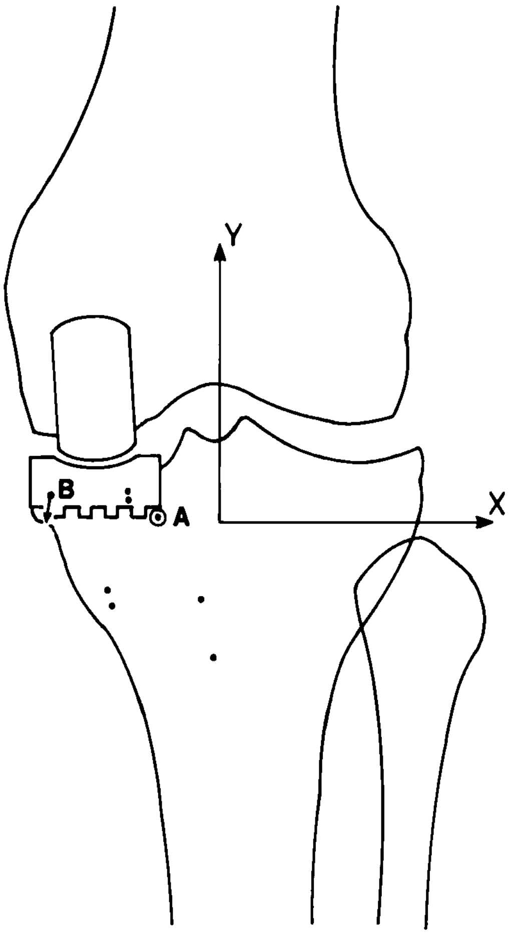

Figure 5. Schematic presentation of the movements in Knee 5. (A) represents the intersection of the screw axis with a mid-frontal plane, (B) represents the lateral tantalum ball in the prosthesis. The screw axis was rather close to an anteriorly directed sagittal axis, pointing slightly downwards (11°) and laterally (5°). The rotation about it was 12.8° and the translation along it was 0.5 mm.

On three separate occasions two subsequent examinations were performed in the unloaded position. The standard deviation for the rotation of angle was calculated to be 0.1°, the corresponding value for translation along any coordinate axis was 0.06 mm. Standard deviation = $\sqrt{\Sigma d^2/3 \times 3}$ where d is the difference of the rotation angle between the two subsequent examinations. Three rotation angles (about the X, Y and Z axes) and examinations on three occasions gives 9 degrees of freedom.

Radiography revealed buckling in three and wire breakage in five of these six cases. Movements were found in the frontal plane (PT angle) in all except Knee 3, and in the lateral projection (PTS angle) in all except Knee 1 (Table 2). The difference in movements between stereophotogrammetric determination and radiography and the mean value and standard deviation for these differencies were calculated (Table 3). Thus, based on the stereophotogrammetric results, the error of method for radiography as measured by the standard deviation of the difference was found to be ± 1.8°. When multiple blind measurements were performed on the radiographic films and these data were subjected to a two way analysis of variance, a significant difference was found between the individual radiographs but not

Table 2. Results of conventional radiography. The angles are given for the initial postoperative examination and for the 1- and 2-year follow-ups. Results regarding zones, buckling and wire breakage represent the state at the 2-year follow-up

Patient No.	Compartment	Stage of arthrosis	PT angle	PTS angle	Zone (mm)	Buckling	Height of prosthesis (mm)	Wire breakage
1	Medial	2	86,84,83	90,90,90	<1	No	9	Yes
2	Medial	3	89,86,85	87,86,88	1	No	9	Yes
3	Lateral	3	94,94,94	85,85,83	<1	Yes	9	No
4	Medial	3	85,87,87	85,81,78	2	Yes	15	Yes
5	Medial	3	96, – ,84	80, – ,82	2.5	Yes	12	Yes
6	Medial	3	90,88,89	90,88,88	2	No	12	Yes

Table 3. Comparison between results of radiography and of roentgen stereophotogrammetry in analysis of tibial component motion. The change in the PT angle versus rotation about the Z-axis and the change in PTS angle versus rotation about the X-axis, respectively, given for each patient and follow-up period

Patient	Follow-up period (years)	Stereophotogrammetry	Radiography	Difference
1	1	−0.4	−2	−1.6
		−0.4	0	+0.4
	2	−0.6	−3	−2.4
		−0.5	0	+0.5
2	1	−1.4	−3	−1.6
		−0.8	−1	−0.2
	2	−0.8	−4	−3.2
		−0.5	1	+1.5
3	1	0.3	0	−0.3
		−1.2	0	+1.2
	2	0	0	0
		−1.6	−2	−0.4
4	1	1.9	2	+0.1
		−0.7	−4	−3.3
	2	2.4	2	−0.4
		−0.6	−7	−6.4
5	1	–	–	–
		–	–	–
	2	−12.6	−12	+0.6
		1.3	2	+0.7
6	1	−1.2	−2	−0.8
		−0.6	−2	−1.4
	2	−1.4	−1	+0.4
		−0.5	−2	−1.5
			Mean ± s.d.	−0.82 ± 1.81

Table 4. Analysis of variance for values of angles (degrees) determined by conventional radiographic measurement on three different occasions on the same radiographic films

Source of variation	Sum of squares	df	Mean square	F
Occasion of determination	0.3	2	0.15	0.37^{NS}
Radiographs	1876.5	30	62.55	142.5***
Residual	26.3	60	0.44	
Total	1903.1	92	20.69	

*** $P < 0.001$.
NS, $P > 0.05$.

between the occasion of determination (Table 4). Thus, the radiographic determination resulted in stable values as compared with the variations caused by differences between patients. The error of measurement for radiography as determined by the standard deviation for repeated measurements was thereby found to be ± 0.7° (Table 4). The other part of the error of radiography would then consist of variations in positioning of the leg and exposure. Radiography is thus not precise enough to allow detection of the true movements found by stereophotogrammetry in four of the knees in this investigation.

DISCUSSION

Loosening of the tibial component in unicompartmental knee arthroplasty, with clinical signs of failure, is common. Radiography, however, reveals loosening also for asymptomatic patients. Marmor (1979) performed reoperations on six out of 11 patients showing radiographic loosening of the tibial component. Jónsson (1981) reported 16 radiographic loosenings in 102 consecutive arthroplasties. Of these only four had clinical signs of loosening and three were reoperated. Laskin (1978) reported a settling of more than 1 mm in more than 50 per cent of his patients, but only one had clinical loosening and was reoperated on. Thus, it appears that the occurrence of radiographic signs of loosening is a serious threat to the arthroplasty, but is not synonymous with a failure.

In most previously published studies the accuracy of the radiographic examinations can be questioned. The projections are seldom defined and are thus not reproducible. Also the position of the components, as well as comments on buckling, are judged from the image of the indication wire, which often breaks. In this study, five out of six wires were broken and buckling was reported in three cases, in two of which the wire was broken. The stereophotogrammetric test of the integrity of the rigid body of the tibial prosthesis showed that the rigid body concept was valid in all these six knees. These findings strongly indicate that there was no buckling. An explanation of the discrepancy between radiography and roentgen stereophotogrammetry on this point might be that when the indication wire breaks it can snap loose, since it is only wrapped around the prosthesis. In these cases the image of the wire, and indirectly of the prosthesis, might be distorted on radiographic films even though the distortion does not involve the prosthesis itself.

The error of method for radiography was found to be ±1.8° determined as the discrepancy between the results of roentgen stereophotogrammetry and those of radiography. This value could be said to represent the precision of the radiographic technique used in this series, since the precision of roentgen stereophotogrammetry is within 0.1°, which in this comparison is regarded as negligible. However, small films were used in the radiographic examination, not allowing a definition of the mechanical axis of the tibia from the centre of the knee to the centre of the ankle joint. Also, the stereophotogrammetric examinations as well as the radiographic reference examination were done in the supine position, whereas the radiographic follow-ups were taken in the weight-bearing position. These technical flaws in the investigation may have influenced the findings as regards buckling and the precision of radiography. Presumably, the precision is between ± 1.8° and ± 0.7°, the latter value being the precision of the film measuring process of the radiographic technique here used.

Stereophotogrammetric evaluation revealed movements in all six components. The direction of the movements followed a pattern to a certain extent. Thus, five components tilted backwards, which we interpret as an incipient "nut-cracker" phenomenon previously pointed out by Walker et al. (1978). Four components tilted away from the centre of the knee about the sagittal axis. This could indicate that the major part of the load is taken up by the periphery of the prosthesis. Both these patterns of migration emphasize the importance of optimal positioning of the prosthetic components, the need for good cortical bone support and also correct alignment of the leg.

Radiolucent zones in the bone-cement interface develop very frequently, and incidences of 75–100 per cent have been reported (Ahlberg & Lindén 1977, Laskin 1978, Jónsson 1981). Zones were found in all six of our knees. The radiolucent zones are known to represent soft tissue ingrowth, subsequent to bone necrosis and resorption (Charnley 1970, Willert et al. 1974, Revell et al. 1978). The minor but significant movements of the components of knees 1, 2, 3 and 6 could possibly be explained by deformation of the soft tissue constituting this zone, implying a semi-rigid "suspension" of the implant within the bone. These prostheses, we think, are not loose in the gross sense of the word, but show a "normal" degree of micromovement. The movements in Knees 4 and 5, however, were of a magnitude which could not be normal, and these patients may in the future progress to clinical failure.

Since this investigation is a longitudinal one without repetitive examinations under different kinds of stress, the magnitude of the compliance of the semi-rigid bond can not be determined. A large compliance would allow the component to change position, for example with every step the patient takes, whereas a low compliance would result in a slow, flow-like migration, corresponding to stress being put on the prosthesis over a long period of time. By using different cementation techniques (Miller 1979) as well as no cement at all (Hungerford et al. 1982, Blaha et al. 1982), differences in both the development of zones as well as the patterns of movement can be anticipated.

The present study shows that even in successful unsymptomatic knee arthroplasty there are movements of the tibial component, in some cases to a considerable degree. The precision of radiography is not sufficient to permit detection of the movement found in most of the components studied here. In symptomatic knee arthroplasty that has failed because of loosening, radiography is probably sufficiently precise for clinical use. At the developmental and experimental level, however, roentgen stereophotogrammetry offers improved precision as well as the chance to determine movements in all six degrees of freedom.

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REFERENCES

Ahlbäck, S. (1968) Osteoarthrosis of the knee. A radiographic investigation. *Acta Radiol.*, Suppl. 277.

Ahlberg, Å. & Lindén, B. (1977) The radiolucent zone in arthroplasty of the knee. *Acta Orthop. Scand.* **48**, 687–690.

Aronson, A. S., Holst, L. & Selvik, G. (1974) An instrument for insertion of radiopaque bone markers. *Radiology* **113**, 733–734.

Baldursson, H., Hansson, L.-I., Olsson, T. H. & Selvik, G. (1980) Migration of the acetabular socket after total hip replacement determined by roentgen stereophotogrammetry. *Acta Orthop. Scand.* **51**, 535–540.

Blaha, J. D., Insler, H. P., Freeman, M. A. R., Revell, P. A. & Todd, R. C. (1982) The fixation of a proximal tibial polyethylene prosthesis without cement. *J. Bone Joint Surg.* **64**-B, 326–335.

Bylander, B., Selvik, G., Hansson, L.-I. & Aronson, S. (1981) A roentgen stereophotogrammetric analysis of growth arrest by stapling. *J. Pediatr. Orthop.* **1**, 81–90.

Charnley, J. (1970) The reaction of bone to self-curing acrylic cement. A long-term histological study in man. *J. Bone Joint Surg.* **52**-B, 340–353.

Egund, N. & Norman, O. (1979) Pre- och postoperativ röntgenundersökning vid hög tibiaosteotomi. Nord. Kongr. Med. Radiol., Stockholm.

Engelbrecht, E., Siegel, A., Röttinger, J. & Buchholz, H. W. (1976) Statistics of total knee replacement; partial and total knee replacement design St. George. A review of a 4-year observation. *Clin. Orthop.* **120**, 54–64.

Freeman, M. A. R., Todd, R. C. & Cundy, A. D. (1977) The presentation of the results of knee surgery. *Clin. Orthop.* **128**, 222–227.

Hungerford, D. S., Krackow, K. A. & Kenna, R. V. (1982) Preliminary experiences with the porous coated anatomic (PCA) total knee replacement with and without cement. Paper no. 169, read at AAOS.

Hunter, J. C., Baumrind, S., Genant, H. K., Murray, W. R. & Ross, S. E. (1979) The detection of loosening in total hip arthroplasty. Description of a stereophotogrammetric computer assisted method. *Invest. Radiol.* **14**, 323–329.

Insall, J. & Walker, P. (1976) Unicondylar knee replacement. *Clin. Orthop.* **120**, 83–85.

Jónsson, G. T. (1981) Compartmental arthroplasty for gonarthrosis. *Acta Orthop. Scand.*, Suppl. 193.

Kärrholm, J., Hansson, L. I. & Selvik, G. (1982) Roentgen stereophotogrammetric analysis of growth pattern after supination – eversion ankle injuries in children. *J. Pediatr. Orthop.* **1**, 25–37.

Larsson, S.-E. & Ahlgren, O. (1979) Reconstruction with endoprosthesis in gonarthrosis. A report of 111 consecutive cases operated upon from 1973 through 1977. *Clin. Orthop.* **145**, 126–135.

Laskin, R. S. (1978) Unicompartmental tibio-femoral resurfacing arthroplasty. *J. Bone Joint Surg.* **60**-A, 182–185.

Lindstrand, A., Boegård, T., Egund, N. & Thorngren, K.-G. (1982) Use of a guide instrument for compartmental knee arthroplasty. *Acta Orthop. Scand.* **53**, 633–639.

Lippert, F. G., Veress, S. A., Tiwari, R. S. & Harrington, R. M. (1978) The measurement of total joint loosening by X-ray photogrammetry. *Proc. Soc. Photo-Opt. Instr. Eng.* **166**, 108–111.

Marmor, L. (1973) The modular knee. *Clin. Orthop.* **94**, 242–248.

Marmor, L. (1979) Marmor modular knee in unicompartmental disease (minimum 4-year follow-up). *J. Bone Joint Surg.* **61**-A, 347–353.

Miller, J. E., Burke, D. L. et al. (1979) Experimental studies on the pathogenesis of the fibrous membrane which develops at the interface between implants and bone. Proceedings 25th Annual ORS, p. 302.

Olsson, T. H., Selvik, G. & Willner, S. (1977) Mobility in the lumbosacral spine after fusion studied with the aid of roentgen stereophotogrammetry. *Clin. Orthop.* **129**, 181–190.

Probst, K. J. (1980) *Stereo-Röntgen-Analyse (SRA) von Lockerungsvorgängen alloplastischer Hüftgelenkimplantate.* F. Enke Verlag, Stuttgart.

Revell, P. A., Weightman, B., Freeman, M. A. R. & Vernon-Roberts, B. (1978) The production and biology of polyethylene wear debris. *Arch. Orthop. Traum. Surg.* **91**, 167–181.

Ranawat, C. S., Insall, J. & Shine, J. (1976) Duo-condylar knee arthroplasty. *Clin. Orthop.* **120**, 76–82.

Selvik, G. (1974) A roentgen stereophotogrammetric method for the study of the kinematics of the skeletal system. Thesis, University of Lund, Lund.

Selvik, G. (1983) Roentgen stereophotogrammetry in orthopaedics. *Proc. Soc. Photopt. Instr. Eng.* in press.

Tjörnstrand, B., Selvik, G., Egund, N. & Lindstrand, A. (1981) Roentgen stereophotogrammetry in high tibial osteotomy for gonarthrosis. *Arch. Orthop. Traum. Surg.* **99**, 73–81.

Walker, P. S., Ranawat, C. & Insall, J. (1976) Fixation of the tibial components of condylar replacement knee prosthesis. *J. Biomech.* **9**, 269–275.

Willert, H. G., Ludwig, J. & Semlitsch, M. (1974) Reaction of bone to methacrylate after hip arthroplasty. A long time gross, light microscopic and scanning electron microscopy study. *J. Bone Joint Surg.* **56**-A 1368–1382.

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