Accurate quantitative measurements of micromovement immediately after operation would be a reliable indicator of the stability of an individual component. We have therefore developed a system for measuring micromovement of the tibial component using three non-contact displacement transducers attached to the tibial cortex during total knee arthroplasty (TKA). Using this system we measured the initial stability in 31 uncemented TKAs. All the tibial components were fixed by a stem and four screws. The initial stability was defined as the amount of displacement when a load of 20 kg was applied. The mean subsidence was 60.7 µm and the mean lift-off was 103.3 µm.

We also studied the migration of the tibial component using roentgen stereophotogrammetric analysis (RSA) for up to two years after operation. Most migration occurred during the first six months, after which all prostheses remained stable. We defined migration as the maximum total point motion (MTPM) at two years after operation. The mean migration was 1.29 mm at two years.

Our results show that there was a significant correlation between the initial stability and migration (p < 0.05) and emphasise the importance of the initial stability of the tibial component.

Patients and Methods

We performed TKA in 28 patients (34 knees) using the Kyocera Osaka City University model total knee system (OCU; Kyocera Inc, Kyoto, Japan) (Fig. 1). This has a proximal hydroxyapatite-coated tibial component which was fixed with a stem and four screws without cement. The femoral component was cemented and the patella was resurfaced.

Two patients were excluded because of technical problems in performing RSA and one because a bone graft was required. This left 25 patients (31 knees) for the final analysis. All were women with a mean age of 70 years (63 to 82). The diagnosis was rheumatoid arthritis in five knees and osteoarthritis in 26. We compared the initial stability of the tibial component determined during surgery with the migration, which was defined as the maximum total point motion (MTPM), measured at two years after operation using RSA. Informed consent was obtained from all the patients.

Initial stability. The system for measurement of micromovement of the tibial component has three non-contact displacement transducers. Direct measurement of micromovement of the component is the most reliable method for the evaluation of the initial stability, but the sensors (Keyence Inc, Osaka, Japan) must be set a minimum of 50 mm.
apart to avoid magnetic interference. As a result, the two opposing steel plates must be set away from the tibial component. Loads were applied with a load cell (Kyowa Inc, Tokyo, Japan) connected to an A-D converter. The position co-ordinates and the load were calculated from corresponding sampled voltage data on a personal computer (NEC 9801; NEC Co, Tokyo, Japan) which displays the micromovement of the tibial component during the load. This sensor unit is securely fixed by a Hoffman external fixator to the tibial cortex using two screw pins 40 mm below the tibial baseplate (Fig. 2).

The accuracy of the system depends on the resolution of the sensor itself and the deformity of the tibial component in response to the load. The sensor which we used has a resolution of 1 µm at intervals of 2 mm. We compared the output of this measurement system with the value detected directly by a strain-gauge sensor on a tibial component mounted on a plastic bone model. The linearity of the system seemed to be sufficient with a range of 20 µm mainly generated by the noise from the cables between the sensors and the A-D converter.

This system measures only the tilting of the tibial component using three vertical displacements but not rotation or horizontal translation, which may affect the accuracy of the vertical displacement. A surgeon can easily push a component with a force of around 20 kg. Displacement of any point on the tibial component as a result of vertical forces can be calculated by three-point measurement of vertical displacement. The medial and lateral sides of the tibial component were pushed separately and the measured displacement of the component and the force recorded automatically by the computer.

We analysed micromovement of the tibial component when the load was 20 kg perpendicular to it on the medial or lateral side.

**Roentgen stereophotogrammetric analysis.** We used RSA as described by Selvik to study micromovement.

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**Fig. 1**

The Kyocera Osaka City University model total knee system.

**Fig. 2**

Diagram of the apparatus for measuring micromovement of the tibial component.
During the operation tantalum-ball markers were inserted into the proximal part of the tibia and into the tibial polyethylene insert to obtain distinct points of identification on radiographs. We defined migration as displacement of the implant over time with respect to the bone and in the absence of external forces. RSA was performed immediately after implantation and at 1, 3 and 6 months and 1, 1.5 and 2 years after operation. We measured three directions of migration, distal, anterior and medial. The MTPM is the total three-dimensional vector translation of the marker which moved the most. The accuracy of our system as determined by multiple measurements is within 0.2 mm which is comparable to that reported in the literature.

**Initial stability v migration.** It is possible that both knees in one patient may have a positive correlation. We therefore reduced the data to one measurement of each type for each patient by taking the mean lift-off, subsidence and MTPM for the implants in each of the six patients with bilateral TKAs. We made a prospective comparison of the level of micromovement during the operation (initial fixation) and the migration at two years after (MTPM) to determine if there was any correlation between them.

**Statistical analysis.** This was performed using the Statview 4.5 statistical package (Abacus Concepts, Berkeley, California). The mean and ±sd were calculated. The difference between osteoarthritis (OA) and rheumatoid arthritis (RA) was determined by the unpaired *t*-test and between micromovement and migration by the paired *t*-test. A p value of less than 0.05 was considered significant.

The relationships between continuous variables were determined by inspection of scatter plots and linear regression analysis. Pearson’s correlation coefficient was calculated to determine the correlation between variables. A p value of less than 0.05 was considered significant.

**Results**

The mean preoperative standing femorotibial angle (FTA) was 182.4° (139 to 195). We classified alignment as either varus (FTA >175°), normal (170°< = FTA< = 175°) or valgus (FTA <170°). Of those patients with OA all except one

### Table I. Details of the patients and of the initial stability and migration

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr)</th>
<th>Side</th>
<th>Diagnosis*</th>
<th>Preoperative standing FTA (degrees)</th>
<th>Initial fixation</th>
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<td>Subsidence (µm)</td>
<td>Mean</td>
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<td>OA</td>
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<tr>
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<td>67</td>
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<td>OA</td>
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<td>RA</td>
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</table>

* OA, osteoarthritis; RA, rheumatoid arthritis
had varus deformity. The exception (case 10) had valgus deformity. In those with RA, the alignment was normal in two (cases 22 and 23) and two had varus deformity (cases 24 and 25; Table I).

The position of all the prostheses was satisfactory and the postoperative FTA was normal. At two years the fixation of the prostheses remained clinically sound and all patients were satisfied with the result.

Initial stability. The mean subsidence was 54.1 µm (17 to 119) in OA and 94.8 µm (50 to 135) in RA. The difference was significant (unpaired t-test, \( p = 0.0046 \)). The mean lift-off was 54.1 µm (40 to 156) in OA and 151.2 µm (87 to 195) in RA. Lift-off in RA was worse than that in OA (unpaired t-test, \( p = 0.0038 \)) and the mean difference was 57.12 (95% confidence limits 20.05 to 94.19). Fixation was achieved under 200 µm in all cases including both subsidence and lift-off (Fig. 3).

In the patients with OA, the lateral side showed more micromovement than the medial side in all except one (case 10) with valgus deformity in whom there was more micromovement on the medial side.

In those with RA, the lateral side showed more micromovement than the medial side except in one patient (case 23) whose alignment was normal but showed more movement on the medial side.

Migration. The mean MTPM was 0.76 mm at one month, 1.06 mm at three months, 1.20 mm at six months, 1.25 mm at one year, 1.27 mm at 1.5 years and 1.29 mm at two years after operation. The MTPM at six months after operation was about 93% of that at two years. Most of the migration occurred during the first three to six months, after which all the prostheses remained stable. The MTPM in RA was greater than that in OA at each period of evaluation from one month to two years (Fig. 4). Migration after six months, however, was stable in both. No knee showed migration of more than 0.2 mm between 12 and 24 months after operation.

The mean direction of migration was 1.26 mm distally, 0.24 mm medially and 0.05 mm anteriorly at two years after operation (Fig. 5). For the most part the direction of migration was distally (paired t-test, \( p < 0.0001 \)).
Initial stability v migration. There were 25 patients (4 RA, 21 OA) in this analysis. A significant correlation was found between subsidence and MTPM (Pearson’s correlation coefficient 0.480, \( r^2 = 0.231 \), \( p = 0.0141 \), MTPM(\text{mm}) = 0.775 + 0.814*subsidence(100 \text{ µm})). The expected increase in MTPM predicted by an increase in subsidence of 100 µm is 0.814 (95% confidence interval 0.194 to 1.434) (Fig. 6).

A significant but weak correlation was found between lift-off and MTPM (Pearson’s correlation coefficient = 0.423, \( r^2 = 0.179 \), \( p = 0.0345 \), MTPM(\text{mm}) = 0.742 + 0.505*lift-off(100 \text{ µm})). The expected increase in MTPM predicted by an increase in lift-off of 100 µm is 0.505 (95% confidence interval 0.053 to 0.957) (Fig. 7).

Discussion

Without cement, all prostheses should be mechanically stable in order to minimise stress at the bone-implant interface. Achieving initial rigid fixation of components is one of the most important factors in promoting ingrowth and reducing the migration of components. Various efforts to reduce the migration of components, such as the addition to the standard polyethylene component of a metal back,\(^4\) porous coating, a long stem,\(^5,6\) screws and a sleeve,\(^7,8\) proximal hydroxyapatite coating\(^9\) or cement,\(^10,11\) have significantly reduced both migration and displacement. In normal clinical practice we cannot determine if the tibial component is stable immediately after operation.

Initial stability. Measurable migration and inducible displacement may be the rule rather than the exception in TKA. Rigid fixation may not be necessary for the successful function of a TKA.

The load which was applied for the measurement was restricted to that which is acceptable within the operative procedure. We chose a load of 20 kg which gave excellent reproducibility of the measurement. Simulation of the load of a walking cycle is extremely difficult to achieve with manual loading. Under an asymmetrical stress, the tibial component was displaced much more than it would be under a balanced, normal load and therefore may have been more responsive to the quality of the underlying cancellous bone.

The initial stability of the tibial component could be measured by our system. Subsidence changes the distribution pattern of stress. Lift-off leads to a gap between the bone and the implant, which gives failure of bone ingrowth and reduces the area of contact between the implant and the surface of the bone.\(^1\) The axial strength of trabecular bone at the knee is critical for the fixation of the prosthetic components after TKA, but it is difficult to translate bone strength into stability of the component, which is influenced by the design and the surgical technique. We are now able to measure accurately the micromovement of the tibial component immediately after operation, and to control the
quality of fixation. Detection of such micromovement must be the most reliable measurement. Hvid measured trabecular bone strength during operation and reported that a higher proportion of knees with RA than with OA had low tibial bone strength and that varus malalignment invariably resulted in higher medial bone strength. In our study, the initial stability in RA was worse than that in OA (p < 0.01) (Fig. 3), and the lateral side showed a higher level of micromovement than the medial side in knees with varus deformity. Our results agree with those of Hvid. 12

Migration. We used RSA as described by Selvik7 to study micromovement and, recently, there have been several studies on prostatic fixation using RSA. 3,10,13,14 The MTPM at six months after operation was about 93% of that at two years. Most of the migration occurred during the first three to six months, after which all prostheses remained stable, as Ryd3,13 and Ryd et al14 have reported. The initial migration occurring in the first year probably represents bone remodelling.

The MTPM in RA was larger than that in OA (p < 0.05) (Fig. 4). In patients with RA who are less physically active there may be less migration. In our study, all our five patients with RA were physically active. Six months after operation, however, migration was stable both in those with OA and with RA.

Migration of knee implants within two years as measured by RSA can predict the risk of later aseptic loosening. Ryd et al14 showed that migration of the tibial component of more than 0.2 mm between 12 and 24 months was associated with an increased risk of subsequent loosening. In our study, no knees showed migration of more than 0.2 mm between 12 and 24 months after operation which suggests that the risk of mechanical loosening will be decreased.

For the most part the direction of migration was distal (Fig. 5). Migration may be stable in rotatory displacement as a result of the four-screw fixation and also the proximal hydroxyapatite coating.

Initial stability v migration. Volz et al15 have suggested that in order to avoid subsidence of the tibial component lift-off must be prevented. In our study, there was a significant correlation between subsidence and MTPM (correlation coefficient = 0.480; \( r^2 = 0.231; p = 0.0141 \), Fig. 6), and a significant but weaker correlation between lift-off and MTPM (correlation coefficient 0.423; \( r^2 = 0.179; p = 0.0345 \)) (Fig. 7).

It is still uncertain how much micromovement is acceptable for bone ingrowth. An initial stability of 200 µm was expected in our study including both subsidence and lift-off, and this was achieved. No knee showed migration of more than 0.2 mm between 12 and 24 months after operation. Under this asymmetrical stress therefore the establishment of 200 µm for the initial stability is thought to be sufficient.

Grewal, Rimmer and Freeman16 reported that the measurement of early migration can predict late aseptic loosening. We found a significant relationship between the initial stability and migration (p < 0.05) and to some extent we can estimate the migration of the tibial component during the operation. The results emphasise the importance of the initial stability of the tibial component for TKA.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References