SOFT-TISSUE BALANCE AND RECOVERY OF PROPRIOCEPTION AFTER TOTAL KNEE REPLACEMENT

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Decreasing proprioception of the knee is multifactorial and is a function of age and degenerative joint disease. Soft-tissue release during total knee replacement may have an influence. We have quantified soft-tissue imbalance at the time of knee replacement and attempted to eliminate it at full extension, using established methods.

We studied the influence of residual soft-tissue imbalance on postoperative proprioception, assessing this in 38 patients before total knee replacement and at three and six months postoperatively.

We found that proprioception improved in varus knees at three and six months after soft-tissue balancing procedures. Knees balanced in full extension and in flexion (<±2°) showed a significant improvement in proprioception (p<0.0005) whereas those which were not balanced in flexion but fully balanced in extension had no significant improvement. We conclude that soft-tissue balance in both flexion and extension is important to allow satisfactory postoperative proprioception of the knee.

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Recent studies have measured the effects of ageing, degenerative joint disease and arthroplasty on proprioception at the knee (Skinner, Barrack and Cook 1984; Corrigan, Cashman and Brady 1992; Warren et al 1993). It is now generally accepted that this decreases with age and with degenerative joint disease.

The sense of position of a joint depends on afferent signals from joint, muscle and skin receptors (Gandevia and McCloskey 1976; Gandevia, McCloskey and Potter 1980; Gandevia et al 1983; Johansson, Sjölander and Sojka 1991), but the role of the cruciate ligaments is uncertain. Skinner et al (1984) suggested that the loss of proprioception due to arthritis was not improved by operation. By contrast, Barrett, Cobb and Bentley (1991) claimed that when joint alignment and the ‘joint space height’ had been reconstituted the sense of position improved, indicating that the reloading of lax collateral tissues at the time of the operation may be beneficial. They also stated that patients with semiconstrained total knee replacements showed more improvement in proprioception than those with hinge replacements, which suggests that retained receptors within the ligaments and the capsule are important.

The length and tension of the posterior cruciate ligament (PCL) increase with increasing knee flexion so that the PCL acts as a transducer modifying antagonistic activity in the muscles around the knee (Solomonow et al 1987). There is reported to be more improvement in proprioception when the PCL is retained; this suggests that mechanoreceptors within the ligament play a significant role in the feedback signals via the CNS. Alteration of the other soft tissues around the knee may also be a factor in the change in postoperative proprioception (Warren et al 1993). Barrack et al (1984) reported that ballet dancers with knee joint laxity had a loss of proprioception compared with a normal healthy control group; this suggests that the PCL may not be solely responsible for the loss in proprioception of the knee.

Recently, we quantified the extent of the soft-tissue deformity in arthritic knees by measuring soft-tissue imbalance during total knee replacement (Sambatakakis, Attfield and Newton 1993; Attfield et al 1994; Wilton, Sambatakakis and Attfield 1994). This imbalance is surgically corrected using well-established techniques (Insall 1984), so that postoperatively the collateral structures retain the same amount of tension. Our present aim was to establish how proprioception is affected by the soft-tissue deformity and the surgical release performed to achieve balance.

PATIENTS AND METHODS

We recruited 51 patients with a varus deformity who were to have a total knee replacement. We excluded patients who had had a previous operation on the knee or had any neurological, metabolic or vascular disease.
Measurement of proprioception. We assessed proprioception in the 51 patients about two weeks before their operation. The patient was seated on a couch with the leg fully supported in a below-knee pneumatic splint and encouraged to relax fully. The leg was positioned sufficiently far off the edge of the couch to exclude proprioceptive input from the action of the hamstrings on the edge of the couch. The splint was inflated to an even pressure so that sensation on the foot and ankle was constant at varying angles, and then connected by a pulley system to a supporting frame that allowed angular placement of the leg. A rotary (spirit-level type) goniometer with an accuracy of ±0.5° attached to the leg recorded the position of the knee (Fig. 1). This method allows quantification of flexion of the knee in the sagittal plane without restriction of movement in any other planes.

A large model of a leg was positioned close to the subject (Fig. 2). It had a pivot at the centre of the knee and was connected to a rotary electrical transducer. A previously calibrated signal was displayed as an angular deviation on a screen visible only to the examiner. The model had a straight line on it to represent the level position in full extension of the limb, but no other indications of angular deviation.

The leg, screened from the patient’s view, was placed in full extension to represent the level or parallel position on the model. It was then moved at a constant velocity of approximately 0.5°/s to 10° flexion and held in this position before the subject was asked to move the model to represent this new position. The angular deviation shown on the screen was noted, and the leg was then moved to 25° and 40° in the same manner. The whole procedure was repeated twice to give a mean value for each angular deviation.

Measurement of soft-tissue balance at operation. A standard operating technique was used to implant either the Genesis cruciate-retaining (Smith and Nephew Richards Ltd, Cambridge, UK) or the PCL-retaining prosthesis (Howmedica, Rutherford, New Jersey). Soft-tissue imbalance was measured using the Derby soft-tissue Balancer (Attfield et al 1994) after the distal tibial and femoral matched subjects who had no or only early signs of arthritis of the measured knee. They were tested twice at a six-month interval to examine the effect of the learning process of the experimental procedure and the six-month delay in the repeat measurement. In addition, we evaluated the system in 10 normal subjects aged between 25 and 40 years.

A single comparative figure was calculated from the mean of the difference between the actual and perceived angular deviations according to the equation:

$$\phi_m = \left( \sum (\phi_p - \phi_a) \right)/n$$

where $\phi_m$ = mean angular deviation, $\phi_p$ = perceived angular deviation, $\phi_a$ = actual angular deviation, and $n$ = number of trials.
ostotomies had been performed, but before the femoral chamfer cuts had been made. Measurement was made both at full extension with the balancer acting against the distal femoral and proximal tibial cuts or at 90° flexion using the posterior femoral cut and the proximal tibial surface (Fig. 3).

The Derby Balancer consists of two metallic plates that are positioned on to the distal ends of the tibia and femur. They are then tensed apart by the surgeon against the action of the soft tissues. One of the plates has a central pivot in the coronal plane, allowing it to rotate to find an equilibrium position between the forces exerted by the medial and lateral soft-tissue structures. This rotation is the measurement of soft-tissue imbalance.

We defined soft-tissue balance as shown by an angulation of less than ±2°. Satisfactory balance at both full extension and at 90° flexion was considered to show full ‘balancing’, since the instrument does not allow measurements at other positions of flexion.

If soft-tissue imbalance was shown, sequential soft-tissue releases were performed in the following order: PCL, medial collateral ligament, posteromedial capsule, pes anserinus tendon and semimembranosus. The PCL was released first because its influence on the medial and lateral structures is particularly difficult to assess. Balance of the PCL alone is almost impossible to measure. The medial collateral ligament was the next to be released since this is sometimes sufficient to obtain soft-tissue balance in a varus knee, and has been found to give the most consistent correction. Release of the posteromedial corner of the capsule is the next stage; this helps to balance the flexion gap. The pes anserinus tendon is then released either partially or completely and finally the semimembranosus if necessary. We avoid this extensive release if possible, because it leaves the medial tibia exposed and divested of soft-tissue attachments.

Details of soft-tissue imbalance and soft-tissue releases were noted at the time of operation. The patients were reviewed at three and at six months after operation.

RESULTS

Of the 51 patients, 38 completed the experimental procedure; the other 13 were excluded from the study because of failure to attend for review within two weeks of the three- and six-month postoperative measurement sessions.

Our results were recorded as the mean error for the nine readings obtained from each session. The mean error at 10° flexion, however, was always lower than that at 25° which in turn was lower than that at 40°. This suggests that there was an exponential relationship between the mean error and angular deviation. We therefore also analysed the data in terms of percentage error at each angular deviation to give a more linear approximation at the three angular displacements. These two sets of data showed little statistical or numerical difference.

The mean positional error for the 18 non-arthritic control subjects was plotted against age in years (Fig. 4). The result agrees with previous studies which suggest that proprioception at the knee deteriorates with age. The 12 age- and sex-matched control patients (eight female) with a mean age of 71.6 years and a minimum age of 69 years showed only a slight mean improvement in their mean error from 14.6° to 14.1° when they were retested six months after their initial examination.

Figure 5 shows soft-tissue imbalance in 38 varus knees in extension before and after soft-tissue releases had been performed. All but one knee was within ±1° of complete soft-tissue balance in extension at the end of the releases. Soft-tissue imbalance at 90° flexion was less controllable; 24 knees were thought to be balanced in flexion and 14 knees were unbalanced (> ±2° of imbalance) at the time of implantation. This difference between balance in flexion and extension was because we considered that complete
balance in extension was more important; in some cases a compromise had to be accepted in flexion. The alternative would have been to adjust the flexion gap by modification of the rotational alignment of the femoral component.

Figure 6 shows the change in the mean error in proprioception of the 38 varus knees. The standard deviations decreased from 12.27° preoperatively to 11.88° after three months and 11.48° after six months. We analysed the percentage improvement in proprioception between knees which had sequential soft-tissue structures released (Table I and Fig. 7). These data were not analysed statistically because of the very small numbers in some of the subgroups.

Figure 8 shows the improvement in proprioception between the balanced and unbalanced knees at the end of the operation and Figure 9 and Table II give the improve-

Table I. Improvement (percentage) in proprioception in 38 varus knees at three and six months after total knee replacement

<table>
<thead>
<tr>
<th>Soft-tissue structures released (cumulative)</th>
<th>Number</th>
<th>3 months</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>5</td>
<td>4.6</td>
<td>15.4</td>
</tr>
<tr>
<td>PCL</td>
<td>8</td>
<td>17.5</td>
<td>35.3</td>
</tr>
<tr>
<td>Medial collateral ligament</td>
<td>7</td>
<td>13.7</td>
<td>54.3</td>
</tr>
<tr>
<td>Posteromedial capsule</td>
<td>4</td>
<td>3.37</td>
<td>23.3</td>
</tr>
<tr>
<td>Pes anserinus tendon</td>
<td>4</td>
<td>3.14</td>
<td>12.7</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>10</td>
<td>34.9</td>
<td>5.4</td>
</tr>
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</table>
ment in proprioception in knees with either retained or excised posterior cruciate ligaments. Unpaired $t$-tests between the PCL excised and retained, and between balanced and unbalanced groups preoperatively and at three and six months showed no significant differences, presumably because the sample size was too small to isolate a common mean proprioception. There were no significant differences in proprioception between patients with the two prostheses.

**DISCUSSION**

The results of our control study confirmed previous reports that the accuracy of proprioception decreases with age in non-arthritic healthy knees and provided a calibration for the measurement system to compare the results in arthritic subjects. They also showed a mean improvement of 0.5° across the measurement range due to a learning process, but since this affects all the groups equally its influence can be ignored.

The standard deviations of the results for the varus knees were large indicating that many factors have an influence, but there was some decrease in the range when only knees balanced in both extension and 90° of flexion were considered. This suggests that some variance had been reduced in this group, which also showed a more predictable and significant improvement in postoperative proprioception compared with the knees which had retained some soft-tissue imbalance (paired $t$-test, $p < 0.0005$). There was no significant improvement in proprioception in the 14 knees which were not balanced in extension or flexion.

Similar results were achieved in the groups with either retained or excised PCLs. Those who had the PCL excised had more preoperative deformity but a lower mean error in proprioception at the preoperative, three-month, and six-month measurement times. This apparent discrepancy may be because the proprioceptive information gained from both collateral structures and the PCL could lead to some form of mismatch of proprioceptive information. This suggestion is supported by the significant improvement in the PCL-excised knees at the preoperative and six-month stages.

We found a large improvement in proprioception in the patients who required only PCL excision and distal release of the medial collateral ligament to obtain soft-tissue balance in extension. Six of the seven knees in this group were also balanced in flexion at the time of implantation.

Our results suggest that there is a functional feedback mechanism via the collateral soft-tissue structures around a knee replacement after the PCL has been excised. Any difference in the tension of the medial and lateral collateral structures may therefore be perceived as a varus or valgus movement of the leg and produce an antagonistic and corrective action from the hamstring and quadriceps muscle groups.

Any soft-tissue imbalance still present after total knee replacement would have a negligible effect on the position of the resultant force vector through the knee during dynamic activity, but could be perceived proprioceptively as a varus or valgus deviation of the bony alignment. This could then produce a reflex antagonistic action from the muscles, resulting in a large corrective load being applied to the knee replacement. Such loading may affect the direction of the dynamic force vector through the knee, and move it medially or laterally so that it is applied solely compared with the knees which had retained some soft-tissue imbalance (paired $t$-test, $p < 0.0005$). There was no significant improvement in proprioception in the 14 knees which were not balanced in extension or flexion.

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**Table II. Results of paired $t$-tests for all the subgroups**

<table>
<thead>
<tr>
<th>$t$-tests (paired)</th>
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<th>Preop $v$ three months</th>
<th>Preop $v$ six months</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>38</td>
<td>NS</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>PCL-retained</td>
<td>10</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>PCL-excised</td>
<td>28</td>
<td>&lt;0.05</td>
<td>&lt;0.0005</td>
<td></td>
</tr>
<tr>
<td>Balanced</td>
<td>24</td>
<td>&lt;0.05</td>
<td>&lt;0.0005</td>
<td></td>
</tr>
<tr>
<td>Unbalanced</td>
<td>14</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 8**
Comparison of improvement in proprioception in varus knees assumed to be balanced and unbalanced at operation.

**Fig. 9**
Proprioception in knees with or without retention of the PCL.

**Fig. 10**
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<td></td>
</tr>
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through one condyle. This sequence of events is a possible mechanism for the premature failure of total knee replacement; it may help to explain the sometimes poor correlation between the bony alignment of the knee replacement and its tendency to subsequent mechanical failure (Tew and Waugh 1985).

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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


