Joint line position correlates with function after primary total knee replacement

The role of computer-assisted surgery in maintaining the level of the joint in primary knee joint replacement (TKR) has not been well defined. We undertook a blinded randomised controlled trial comparing joint-line maintenance, functional outcomes, and quality-of-life outcomes between patients undergoing computer-assisted and conventional TKR. A total of 115 patients were randomised (computer-assisted, n = 55; conventional, n = 60).

Two years post-operatively no significant correlation was found between computer-assisted and conventional surgery in terms of maintaining the joint line. Those TKRs where the joint line was depressed post-operatively improved the least in terms of functional scores. No difference was detected in terms of quality-of-life outcomes. Change in joint line was found to be related to change in alignment. Change in alignment significantly affects change in joint line and functional scores.

The effects of changes in the joint line in primary total knee replacement (TKR) are well documented, affecting stability, range of movement, the mechanics of the patellofemoral joint and the functional outcome.

Changes in the joint line have various effects on stability. Instability associated with an altered joint line is most evident in mid-flexion, and can be seen with as little as 5 mm deviation of joint line. This has clinical implications as the majority of implant designs are guided by stability at the limits of flexion and extension alone. In a study of cadaveric knees with a knee replacement placed proximally and anteriorly by 5 mm, raising the joint line resulted in significant mid-flexion loosening. However, these knees remained stable at full extension and 90° flexion. In the long term, this instability can affect the survival of the prosthesis, patient satisfaction and function.

Minimising alteration of the joint line may lead to increased flexion. A change of even 2 mm can reduce this. However, this reduction can be partially offset by excision of the posterior cruciate ligament (PCL), with a significant increase in PCL strain noted with 4 mm or more of joint line elevation. This makes the position of the joint line even more important when using a cruciate-retaining design. However, Snider and MacDonald failed to find any significant association between range of movement and the joint line in a study of 200 primary knee replacements.

The patellofemoral joint can be adversely affected by a change in joint line. Pain and subluxation has been associated with distal displacement of the joint line by as little as 3 mm. This is probably due to increased strain on the patellar and altered quadriceps function. Elevation of the joint line can result in impingement of the patella and the patellar tendon on the tibial component, with patellar tendon damage a possible consequence. Patellofemoral contact force is also sensitive to joint line change, increasing by 60% with elevation of the joint line by 10 mm. It was a landmark study by Figgie et al that defined the standard for maintaining the joint line. In that series, of those patients with a joint line which was maintained within 8 mm, none required manipulation or revision or suffered from patellofemoral pain.

Functional outcomes have been linked to joint line placement. This has been found not only in revision surgery but also primary TKRs, with better functional scores in those with less than 8 mm of joint line elevation. Better Bristol knee scores and functional scores have been associated with a maintained joint line five years post-revision surgery when compared to those elevated by more than 5 mm. Controversy still exists regarding the effect of the joint line on functional outcomes as measured by the International Knee Society score (IKSS). This score was found to be significantly better in knees with a maintained joint line in one study, but not in another.
The relationship between joint line and quality of life, using, for example, the Short-Form 12 (SF-12) survey, is also lacking.

It has been shown that computer-assisted surgery (CAS) improves alignment in TKR, but little is known about its effect on the position of the joint line. One study found that it was maintained (defined as being < 3 mm change) in 60% of computer-assisted TKRs, resulting in no significant change in functional outcome when using a mobile-bearing cruciate-retaining prosthesis. Another study found CAS to be effective in restoring the joint line in revision surgery when compared with conventional methods.

The primary aim of this study was to determine whether computer assisted TKR when compared with conventional surgery, improved post-operative maintenance of the joint line. Our secondary aim was to determine if there was a correlation between the post-operative level of the joint line and functional and quality of life outcomes.

Patients and Methods
A blinded randomised controlled trial was conducted within two tertiary centres, comparing CAS with conventional primary TKR.

A power calculation was performed, based on a 3° difference in alignment between groups. An operative intent of 1° and a standard deviation (sd) of 2.5° was used with an assumed error of 0.5° when using CAS. To achieve an alpha of 0.8 and p-value of < 0.05 required 50 knees in each group.

All patients scheduled for an elective primary TKR by three participating surgeons (including PFMC and JDS) between June 2005 and July 2006 were eligible for enrolment. All patients attended a routine pre-admission clinic when they were invited to participate. From the 120 patients approached, 26 patients were excluded from final analysis. Five declined to participate in the trial and three were lost to follow-up. Of these three, one patient died from an unrelated myocardial infarction, one withdrew from the trial and one was subsequently admitted to a nursing home following a fracture of the femoral neck and was unavailable for review. Eighteen patients were deemed not to have adequate radiographs to allow precise measurement of the joint line; this included poorly exposed films, inadequate films not showing all landmarks and films which did not meet the strict standardised protocol set for this trial (Fig. 1).

Pre-operative data collection included standing long-leg anteroposterior (AP) radiographs, functional assessment using the IKSS, and quality-of-life assessment using the SF-12 questionnaire. Patient demographics, medical history, body mass index (BMI) and blood indices were also recorded. Functional and quality-of-life measures were recorded at three, six, 12 and 24 months post-operatively. Standing AP radiographs were also taken six weeks post-operatively. The study was approved by the hospital's Human Research and Ethics committee (HREC-A 027/05).

All patients received a modular, total condylar TKR (PFC; DePuy, Warsaw, Indiana) with all components cemented.

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Fig. 1
Flowchart of study patients.
with CMW1 cement, (Johnson & Johnson, Warsaw, Indiana) and with the patella replaced in all cases. Eleven patients (12%) received a posterior stabilised (PS) implant while the rest had cruciate retaining (CR) implants. The criteria for the use of a PS implant were an obviously deficient PCL or pre-operative malalignment greater than 15°.

We used an imageless computerised navigation system (Ci System; Depuy) which used a proximal tibial and a distal femoral reference array, comprising of three reflector spheres. These arrays were inserted via two bi-cortical Steinmann pins into the distal femur, through the initial incision and in the proximal tibial shaft through a separate stab incision. The bone cuts were then navigated (all except the patella cut), and the size, orientation, and alignment of the prosthesis were then determined by the navigation system. Fine tuning and alteration of the computer’s recommendation were possible at any stage. With the conventional group a standard system of intra- and extramedullary guides (Sigma SP2 instruments, Depuy) were used to align the femoral and tibial components respectively.

In both the CAS and conventional group, the surgical aim was to achieve a neutral coronal alignment, that is, a 0° mechanical axis, femoral rotation aligned with the epicondylar axis and checked using Whiteside’s line.21 The tibia was cut with a 3° posterior slope. Soft-tissue balancing was standardised using the same sequence in both groups as previously described by Whiteside.22 A tourniquet was used in all cases.

The joint lines were measured using weight-bearing long-leg AP radiographs (Fig. 2a), which were standardised using a custom-made perspex stand, ensuring that the malleoli were 10 cm apart with the tibial tubercle facing forward.23 The joint line was measured in two ways, from the tibial side and from the femoral side. From the tibial side a straight line was drawn passing between the mid-point of the tibial spine and the midpoint between the inner edges of the malleoli. A line perpendicular to this line was drawn from the proximal tip of the fibula. The joint line was measured as the distance from this line, to the midpoint of a straight line connecting the femoral condyles.
From the tibial side, negative values indicated depression of the joint line, and from the femoral side they indicated an elevation of the line. Magnification was accounted for in two ways, with the length of the keel of the tibial tray determining the differences in magnification between patients and the distance in between the malleoli determining magnification between pre- and post-operative films. Rotational profile was checked using the width of the tibia at the level of the joint line. Measurement of the joint line from the tibial side was based on the Snider and Macdonald method, which itself was based on Kawamura and Bourne’s work, but has been expanded to determine the tibial axis more accurately by performing the measurements on standardised long-leg radiographs and taking magnification into account. The Snider and Macdonald method of measuring the joint line has been validated using the tibial tubercle on a lateral radiograph, which is the other commonly used method of determining the joint line. The tip of the fibula was an easier landmark to use than the tibial tubercle as the precise location of the tubercle on radiographs is often hard to determine. All radiographs where measured three times by a single researcher (SB). Measurement of the joint line from the tibial side was more reproducible with a mean correlation coefficient of 0.8, whilst measuring from the femoral side was less accurate, resulting in a correlation coefficient mean of 0.6.

Randomisation was performed using a computer generated number with the surgeon informed of the results on the day prior to surgery. Patients and the researcher were kept blinded, and the patient was blinded to the type of operation until all review data at the 24 month visit had been collected. The researcher (SB), who performed all radiological analyses, was blinded via de-identification and randomisation of radiographs. This helped maintain blindness when further radiological data was required.

**Statistical analysis.** This was carried out using SigmaStat version 3.5 (SPSS Inc., Chicago, Illinois). Continuous parametric data was analysed using one-way analysis of variance (ANOVA), while non-parametric data were tested using Mann-Whitney non-parametric rank-sum test. Linear regression modelling was used to determine correlation coefficients.

**Results**

In total 94 patients had sufficient radiographs and results for comparison of the changes in the measurements from the tibial side, whose mean change was elevation by 1 mm (9 mm of elevation to 7 mm of depression). Only two (2.1%) patients had a change of joint line of > 8 mm. When measuring from the femoral side, only 90 patients had suitable radiographs and results for comparison. The mean change was depression by 1 mm (5 mm of elevation to 8 mm of depression). Only one (1.1%) patient had change of joint line position of > 8 mm.

**CAS vs conventional TKR.** No pre-operative values were significantly different between the two groups (Table I).

In terms of the post-operative level of the joint line, both from the tibial (Fig. 3a) and the femoral side (Fig. 3b) there was no significant difference when CAS was compared to conventional surgery (fromibia p = 0.157, from femur p = 0.557). With conventional surgery, the mean change of the joint line was 1 mm (range 7 mm depression to 9 mm elevation, SD 4 mm) of elevation from the tibial side and 2 mm (range 7 mm depression to 5 mm elevation, SD 3 mm) of depression from the femoral side, while with CAS the joint line was well maintained with a mean of 0 mm elevation (range 6 mm depression to 8 mm elevation, SD 4 mm) from the tibial side but slight depression from the femoral side (mean 1 mm depression, range 8 mm depression to 5 mm elevation, SD 3 mm). Of those two patients with > 8 mm change in joint line from the tibial side, both were from the conventional group, while from the femoral side only one patient was outside of the 8 mm range, having undergone CAS.

Outliers were defined as being more than 1.5 SD from the mean. Analysis of outliers using a chi-squared test revealed no significant difference between groups. From the tibial side, nine of the outliers belonged to the conventional group and six to the CAS group (p = 0.457). From the femoral side six of the outliers belonged to the CAS group and four to the conventional group (p = 0.852).

**Tibial vs femoral joint line change.** A significant linear relationship was found between the change in joint line as measured from the tibial side compared to the change as measured from the femoral side (p = 0.022). This relationship showed that as the joint line was lowered from
It was also lowered from the femoral side (Fig. 4).

**Functional scores vs joint line.** The joint-line was defined as being maintained if it was within 2 mm of the pre-operative level and elevated or depressed if it lay outside of this boundary. Two millimetres was chosen as the cut-off as it most evenly splits the patient cohort. The level of the joint line was then compared with the IKSS. No correlation was found between IKSS scores and the joint line, although those knees with a maintained joint-line from the tibial side had a better mean total IKSS at all time-intervals (Fig. 5). This was not significant either when measured from the tibial side or the femoral side ($p = 0.623$ and $p = 0.407$, respectively).

The level of the joint line was also compared to the change in IKSS. When measured from the tibial side this proved to be significant, especially in the medium-term (24 months), where there was not only a significant difference between a change in the total IKSS and joint level ($p = 0.003$, Fig. 6) but also a significant difference in the individual components of the score (Table II). Those knees with a depressed joint-line post-operatively had the least improvement in IKSS compared with pre-operative scores, with their mean improvement being 28 points less than the maintained group, and 29 points less than the elevated group. When measured from the femoral side, no significant difference was noted ($p = 0.770$).

**Quality of life vs joint line.** When a comparison was made between the joint line, as measured from either the tibial or femoral side, and the SF-12 no significant correlation could be found. There was no significant correlation between the joint line level and change in the SF-12 either (Table II).

**Range of movement vs joint line.** The levels of the joint-line as measured from the tibial and femoral side were compared firstly to flexion levels at 24 months and secondly to the change in flexion from pre-operative values. Both comparisons were found to be insignificant (Table II).
Axial alignment vs joint line. The overall mechanical alignment of the leg was compared to the level of the joint line. Negative values indicated a varus deviation while positive values indicated a valgus deviation. A significant correlation was found to exist between the level of pre-operative knee alignment and post-operative joint line as measured from the tibial side. This was significant when using negative values for varus alignment and also when simply comparing degrees from neutral (all positive values). No significance was found when the joint line was measured from the femoral side (Table II).

When compared to change in alignment a correlation was evident but the association did not reach significance.

To find the driving force affecting the IKSS, a multiple linear regression analysis was used. We compared the dependant constant of the IKSS with possible independent values affecting it (Tables III, IV and V).

Reviewing these sets of multiple linear regressions, it can be seen that change in alignment, not change in joint line, seems to be the driving force behind the change in function as measured by the IKSS ($p = 0.036$).

A limitation of this study is the inclusion of two different types of TKR, being cruciate-retaining ($n = 83$) and posterior stabilised ($n = 11$). To counter this limitation, all data were re-analysed with the PS patients excluded. All correlations between the IKSS and the level of the joint line remained significant ($p = 0.006$). However, the difference between the mean change of IKSS in those where the joint line was depressed versus maintained increased by one point to 28 points ($p = 0.05$). A limitation of their study was the use of retrospective films, which were only available in 45% of the cohort. In some patients, where no pre-operative radiograph was available, radiographs of the contralateral knee were used. The pre-operative alignment or change in alignment of these knees was not measured or compared.

Snider and Macdonald also looked at the IKSS and its correlation to joint line level. They used a cohort of 200 randomly selected primary TKRs from a database and reviewed their radiographs retrospectively. No mention was made regarding correction for magnification. They recorded a post-operative joint line elevation of 2.7 mm to 4.4 mm depending on the type of prosthesis and found that joint line change was weakly correlated with pre-operative knee scores, change in IKSS and change in flexion. No significant correlation was found between those patients with

Discussion

This study showed that although a correlation may exist between depressing the joint line and the change in clinical outcomes as measured by the IKSS, this correlation was partly a result of the level of pre-operative malalignment and the ability to correct that deformity. It is well known that correcting alignment results in superior functional outcome and in terms of the IKSS, with alignment being a significant component of the score, this makes sense.

Partington et al looked at the effects of the joint line on the IKSS. Their retrospective study was mainly concerned with revision surgery, although they did look at the change in joint line after primary TKR. They noted that on average the post-operative joint line was elevated by 1 mm and that after revision surgery, those knees with less than 8 mm of joint line elevation had an IKSS clinical score a mean of 16 points better than those with elevation greater than 8 mm ($p = 0.05$). A limitation of their study was the use of retrospective films, which were only available in 45% of the cohort. In some patients, where no pre-operative radiograph was available, radiographs of the contralateral knee were used. The pre-operative alignment or change in alignment of these knees was not measured or compared.

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elevated joint lines and those that were depressed (n = 22). Alignment was not measured in this study.

Although these studies used 8 mm as the cut-off to determine maintenance of joint line, in our study only 2.1% of patients had a joint line level outside of this cut-off. In Snider and Macdonald's\textsuperscript{7} cohort this number was far greater with 17% of patients falling in this category. To be able to maintain any power in this study, it was decided to reduce the cut-off at which the joint line was considered to be maintained.

Our method of measuring the level of the joint line expanded on Snider and Macdonald's\textsuperscript{7} method. By using standardised weight-bearing films and accounting for magnification we believe our method to be more accurate. The joint line is difficult to measure on a two-dimensional radiograph, and this can be considered a limitation of this study.

We measured the joint line in two ways, from the femoral side and from the tibial side. These two methods proved to correlate with each other, demonstrating that Snider and Macdonald's\textsuperscript{7} method. By using standardised weight-bearing films and accounting for magnification we believe our method to be more accurate. The joint line is difficult to measure on a two-dimensional radiograph, and this can be considered a limitation of this study.

We measured the joint line in two ways, from the femoral side and from the tibial side. These two methods proved to correlate with each other, demonstrating that
joint line change was reciprocal between the two sides of the joint, that is, when raised from the tibial side, the joint line was also raised from the femoral side. This is reassuring as it prevents joint stuffing. However, when measured from the femoral side, joint line change did not seem to correlate significantly with functional outcomes or alignment. A few factors may explain this. Measuring the joint line from the femoral side proved to be less reproducible, with a lower correlation coefficient. This may question its accuracy. Also, in varus knees bony deformity is mainly tibial,27 and since the majority of our patients had a varus deformity, any joint line change associated with deformity is likely to be situated on the tibial side.

An elevated post-operative joint line is seen to be linked to a larger pre-operative malalignment. This could help explain some of the findings in the literature linking an elevated joint line with poor functional outcomes. In our cohort, pre-operative alignment did correlate significantly with change in overall IKSS. But more importantly, change in clinical outcome was also linked to change in alignment, as is expected with the IKSS, with alignment being a significant component of this assessment.

An explanation why a more severe deformity is likely to result in an elevated joint line could be that the release of contracted ligaments in a deformed knee leads to a larger joint gap, which is then filled with a thicker tibial insert to maintain balance. Also given that often the least worn part of the joint is used as a guide to determine bony resection, in knees with global bony loss, this may result in over resection, again requiring a larger tibial insert to balance the knee.

This study does have limitations. From the 115 patients consented, only 94 had adequate films and follow-up to allow an accurate measurement of the joint line from the tibial side and 90 from the femoral. This substantially reduced the power of the study. A major limitation was also the inclusion of 11 patients with a PS TKR. A decision was made to keep these patients, as amongst our cohort these had the most malaligned knees pre-operatively and we believed that it was important to consider the impact of significant malalignment on joint line. Another limitation is the difficulty in blinding the patients and the radiograph reviewer when Steinman pins were used in the CAS group. From experience the patients were not aware of the significance of the pin sites, and although the pin-track was visible on radiograph with a careful search, it was not sought and was only seen inadvertently in two cases. A final limitation is the use of radiographs to measure the joint-line. We spent much time and effort trying to maintain strict standardisation and measurement techniques, but we still believe that a radiograph is not the best method of measuring the joint-line. Future studies should consider a role for CT or MRI in determining the exact level of the joint line; however, this would result in non-weight-bearing imaging, itself a limitation. An assumption was also made that the pre-operative joint line was the natural joint line and hence it was against these values that we defined joint line maintenance. This assumption may be incorrect in patients with severe bony destruction.

Clearly there are many factors affecting the outcome of TKR, of which change in the joint line is just one. CAS was not found to be significantly better at maintaining the joint line when compared to conventional surgery. The surgeon

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<th>Table V. Multiple linear regressions comparing change in International Knee Society score (IKSS) with joint line level from the tibial side, pre-operative gross alignment, age, sex and body mass index (BMI)</th>
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<td>p-value</td>
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<td>Constant: change in IKSS total score 24 months post-operatively</td>
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<td>Joint line level</td>
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<th>Table VI. One way analysis of variance of results with posterior-stabilised patients removed</th>
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<td>Depressed (n = 22)</td>
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<td>Mean change in IKSS* total score (range)</td>
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<td>Mean change in IKSS knee score (range)</td>
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<td>Mean change in IKSS function score (range)</td>
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<td>Mean pre-operative alignment (range)</td>
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* IKSS, International Knee Society score
† indicates statistical significance
should be aware that the joint line may make a difference to the clinical outcome, but it is noted that current techniques, either computer assisted or conventional, are reliable in maintaining the joint line in primary TKR, with only two patients falling outside of the 8 mm mark. The level of the joint line is linked to alignment and may be altered by the correction of malalignment. This link with alignment reduces the reliability of the IKSS as a measure of functional outcome when studying the joint line, as alignment is a component of this score. Future studies will require larger cohorts and a more robust method of measuring the joint-line such as CT or MRI.

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References