In June 2001 the senior author (JMS) was approached by representatives of the Stryker organisation with the request that he introduce and evaluate their computer navigation technology (Stryker Corp, Leibinger, Kalamazoo, Michigan), version 1.1, for total knee replacement. After a visit to Professor Martin Sparmann’s unit in Berlin, and extensive discussions with a representative of the design team, the first computer-assisted total knee replacement (CATKR) of this series was carried out in September 2001. Since then, computer assistance has been used exclusively in the senior author’s practice, with the exception of two cases in which it could not be used for anatomical reasons.

The initial request from the Stryker organisation was to introduce the technology into Australia and to evaluate and modify the process. The representatives of the company were aware that the process of evaluation would need to be scientifically rigorous and thus potentially expensive. They were willing to support the research that was required, financially and organisationally. Between June 2001 and September 2001 a programme of clinical research was formulated which has since resulted in a series of publications.

The clinical introduction of CATKR required familiarisation with the software and considerable modifications in surgical technique. The greatest intellectual challenge was to design studies which would test the claims of the system. It became rapidly evident that what was required was an objective, quantitative, means of assessing the position of the arthroplasty in all the degrees of freedom that the system was able to control. It was also necessary to establish a comprehensive relational database which would store all the relevant data affecting the short-term alignment, functional outcome and longevity of the implant. The first requirement was met by development of the Perth CT protocol which, in conjunction with the Perth alignment index (PAI), provided an accurate indicator for alignment of the components. The second need took longer to establish and required the support of another company (Smith & Nephew Inc, Memphis, Tennessee), but has resulted in an Internet-based database with multiple-surgeon input.

In June 2003, the senior author (JMS) was approached by Smith & Nephew to assess the BrainLAB Vector Viscon system, using one of their prostheses. This system differed considerably from that of Stryker and has provided a second learning experience resulting in major modifications of the surgical technique, software and hardware. This article describes the major lessons which have been learned in the process of using these two systems in a total of 192 patients having 232 primary total knee replacements (TKR). Some of the errors and problems which were encountered initially are not discussed because they have been dealt with and are unlikely to recur. However, there are still major challenges and pitfalls in the undertaking of these procedures.

### Patients and Methods

The first study using the Perth CT protocol evaluated the Stryker system in cadavers and showed that the technology was ready for clinical evaluation. Two parallel clinical series were then initiated. One, a randomised, controlled study which was undertaken by a single surgeon in the final stages of training, has been published. The second was a series (CA1) of 122 knees without a control group using version 1.1 of the Stryker software and the Duracon monogram prosthesis (Stryker Corp). There was then a small study (CA2) of seven knees operated on using version 2.0 of the Stryker software. The latter did not require an iliac-crest beacon, and included additional operative options. A third group (CA3) consisted of 103 knees operated on using BrainLAB software, which went through five versions (β1, β2, β3, β4 and 1.5), and used the Genesis II prosthesis (Smith & Nephew Inc.). The senior author was the sole surgeon in
cohorts CA1 to CA3. There was no selection of patients and both primary and revision operations were performed, although only the primary procedures are presented here.

Assessment by the Perth CT protocol became routine halfway through the CA1 cohort. Information was gathered on standardised questionnaires and stored in the CAS_WA database concerning the details of the patients, the history, physical examination, diagnosis, operative details, progress in hospital after operation and outcome immediately after operation, at six and 12 months and then at yearly intervals.

At the same time as cohort CA3 was initiated a prospective series of jig-based TKRs was scanned by CT. This constituted jig-based series JB1. The patients were those of six other surgeons working in the same hospital as the authors and were scanned after operation before discharge. No selection criterion was used other than consent by the patient. Recruitment of patients was discontinued once a surgeon had contributed 30 to 40. A variety of prostheses was used. Finally, a retrospective survey of the patients of the senior author was carried out. They had been operated on in the two years before the start of computer-assisted TKR (1999 to 2000) and had jig-based Genesis II TKRs. They were approached solely because they lived in the Perth metropolitan area. Their clinical status and satisfaction with the procedure varied. They were willing to undergo assessment by CT of their TKR. They constituted series JB2. The characteristics of all the groups are summarised in Table I. The auditing of the CT outcomes of the non-computer-assisted TKRs was undertaken to justify persistence of soft-tissue balance they were not structured to act as an open ended system.

The systems use infrared sources which produce divergent beams subject to secondary reflections and cameras which possess chromatic aberrations. The position of the objects on which they are focused requires detection software and averaging algorithms. None of these processes was presumed to be perfect. In most cases the resultant accuracy of point detection was either not known or not openly stated.

The detection of the centre of rotation of the femoral head was fundamental to defining the mechanical axis. This depended on the presence of a concentric centre of rotation with a relatively stable pelvis. An accuracy read-out was produced, but the exact implication of having an accuracy varying between 0 mm and 4 mm was not clear.

The process of registration defined the individual anatomical characteristics of the patient. The surgeon needed to be familiar with the anatomy which was being defined, such as the characteristics and variations of the medial epicondyle. Care needed to be taken to a variable degree. In the BrainLAB system some of the steps involved gathering data for the cosmetic appearance of the images and these were not involved in the alignment of the prosthesis, while others were critical for the positioning of the implant.

All software packages share assumptions, use reference axes and reference planes, and have defaults. Those discussed here were based on the assumption that a TKR should be accurately aligned at right angles to the axis of mechanical neutrality. Surgeons who believe that the primary philosophy of a TKR should be soft-tissue balance or optimal kinematics should not use this generation of CATKR. While the packages did contain various displays of soft-tissue balance they were not structured to act as an adequate basis for surgery. In the coronal plane, the axis of mechanical neutrality was also the mechanical axis of the limb, which was a line connecting the centre of the femoral head to the centre of the talus. In the sagittal plane a compromise situation was reached because the replaced knee did not always achieve full extension. The axis of mechanical neutrality was taken separately as the mechanical axis of the femur and the anatomical axis of the tibia.

There was considerable divergence of opinion as to which reference axes should be used in the axial plane, the rotational axis. For femoral alignment the user was offered a number of choices; the transepicondylar axis, the anteroposterior axis, the posterior condylar axis or an arbitrary mean of the transepicondylar axis and anteroposterior axis. However, the transepicondylar axis is probably the most reliable. If the wrong choice was made the accuracy of the system was downgraded. For the tibia the problem was greater since no tibial landmarks seemed to have the consis-

### Table I. Details of the patients in the various groups

<table>
<thead>
<tr>
<th>Group*</th>
<th>Number of patients</th>
<th>Bilateral TKR†</th>
<th>Knees</th>
<th>Male (%)</th>
<th>Mean age (yrs; sd)</th>
<th>CA‡ system</th>
<th>Nature of survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>102</td>
<td>20</td>
<td>122</td>
<td>65</td>
<td>74.2 (8.8)</td>
<td>Stryker v. 1.1</td>
<td>Prospective</td>
</tr>
<tr>
<td>CA2</td>
<td>7</td>
<td>0</td>
<td>7</td>
<td>86</td>
<td>72.5 (7.6)</td>
<td>Stryker v. 2.0</td>
<td>Prospective</td>
</tr>
<tr>
<td>CA3</td>
<td>83</td>
<td>0</td>
<td>103</td>
<td>52</td>
<td>73.70 (9.4)</td>
<td>BrainLAB</td>
<td>Prospective</td>
</tr>
<tr>
<td>JB1</td>
<td>130</td>
<td>10</td>
<td>140</td>
<td>41</td>
<td>68.95 (16.9)</td>
<td>None</td>
<td>Prospective</td>
</tr>
<tr>
<td>JB2</td>
<td>41</td>
<td>0</td>
<td>41</td>
<td>60</td>
<td>74.65 (8.0)</td>
<td>None</td>
<td>Retrospective</td>
</tr>
</tbody>
</table>

* see text for explanation of groups
† TKR, total knee replacement
‡ CA, computer-assisted
tency to provide alignment of the required accuracy. Hence, there was a tendency to prefer making the rotational alignment of the tibial component match the femoral component irrespective of tibial landmarks.9

The anteroposterior positioning of the femoral component could be determined mechanically (Stryker Corp.) or by software (BrainLAB). The latter offered a choice between using the anterior cortex of the femoral shaft or the posterior surface of the condyles as a point of reference. Choosing the posterior option involved a considerable risk of overstuffing of the patellofemoral joint or of notching the femur. Anterior referencing was the safer option. It allowed the surgeon to downsize easily when a mistake was made in sizing the component.

The depth of the cut or the amount of bone to be removed from the femur and the tibia could be assessed by referencing to the surface of either minimal or maximal wear, the high or low points. Neither was totally satisfactory. Use of the point of minimal wear allowed the cut to be judged to approximate the thickness of the implant if the surface had no wear. If there was wear over the entire bony surface then a compromise was needed. In practice, it was rarely possible both to minimise the amount resected and to remove sufficient bone with a single cut. Our preference was to use the high reference and to take further cuts of 2 to 4 mm as necessary. For the femur it could be argued that the reference should be to the transepicondylar line10 rather than to articular surfaces which are variably worn.

Defaults are the manufacturers’ settings, which can be obligatory or optional. There is a tendency for the more complex systems to produce an increasing range of default options. It is necessary to be aware which default settings are present, how to change them and how to check that they have not been changed by accident. At times we encountered defaults which were bizarre and have been difficult or impossible to change.

For navigating on targeted or open co-ordinates, the Stryker system provided the surgeon with the absolute co-ordinates. Thus in aligning the distal femoral cut the display showed a simple stylised outline of the femur and the position of the beacon mounted on the cutting block. The co-ordinates of the beacon were shown as the depth of cut, femoral varus/valgus and femoral flexion/extension. The BrainLAB system provided the same option. It also gave the opportunity to set a plan after which the display showed numbers which related to the plan and not to the initial reference axes. If a complex or erroneous plan was entered then the process of navigation could be very confusing. We have refused to use the targeted approach.

There was no calibration process and no information was provided on the impact of variations of the physical organisation of the equipment, such as the distance of the camera from the patient, or the accuracy of registration on the outcome. We did not know if there was any drift in the system. Operative data were gathered by both systems. Version 1.1 of the Stryker system had a reasonable paper printout which defined the pre-operative deformity, intra-operative bone cuts and the final outcome. In version 2.0 this was slightly downgraded. The BrainLAB system was very poor in this regard until version 1.5. This provided some information, the usefulness of which has not yet been evaluated.

Major deformity presented a number of theoretical challenges. The optimal alignment of a TKR is when the prosthesis is aligned along an axis of mechanical neutrality. This goes through the centre of the tibial plateau in the coronal plane and just anterior to the centre in the sagittal plane. However, gross coronal deformity of either femoral or tibial shafts made this impossible. The prosthesis could lie parallel to the axis of mechanical neutrality with it falling to either the medial or lateral side of the centre of the prosthesis (Fig. 1). This presumably produces an unequal distribution of pressure in the polyethylene which could be as damaging as any other form of malalignment.

Rotatory deformity, as may occur after a fracture of the femoral shaft (Fig. 2a) or a femoral osteotomy (Fig. 2b), may produce a similar problem. The transepicondylar line may then not be an appropriate guide to the plane of tracking of the patella. Perhaps in such cases soft-tissue balance becomes a better guide to alignment than bony landmarks.
Radiographs showing a three-dimensional deformity resulting a) from a fracture of the femoral shaft and b) from a lower femoral osteotomy.

Photographs of a) a Stryker screw-array housing with stabilising teeth which produce an 'apple-corer' effect in soft bone, b) a BrainLAB screw housing in the metaphysis of a femur and c) a BrainLAB two-pin-array housing in the tibial shaft.
Clinical introduction

Concentric rotation of the hip and pelvic stability were important in the registration. This technique was impossible in patients who had undergone arthrodesis of the hip and was downgraded and tedious in those with subluxing hips. In the current versions which do not have a pin in the iliac crest, it helped to clamp the pelvis rigidly before draping.

The beacon or reflector arrays could be mounted on a variety of anchoring devices, the choice being greater with the BrainLAB system. The Stryker system has a single screw, with a toothed stabilising ring which bites into bone (Fig. 3a). It had to be used in the diaphysis or proximal metaphysis. The teeth produced an ‘apple-corer’ effect and one fracture of the shaft of the femur was associated with its use. BrainLAB hardware had a single screw which could be used in the metaphyseal flare (Fig. 3b) and did not produce the same stress-riser effect. This positioning was very useful in revision surgery since a stem could be introduced past the array. All single-screw mounts were liable to displacement in soft bone. There were also two pin-mounting arrays which were stable even in osteoporotic bone and used wires of small diameter (Fig. 3c). This was preferred in elderly patients but these arrays had to be positioned so that skin and muscle did not tension the wires, thus changing the position of the arrays.

The registration process in both systems was software-guided, easy and took less than ten minutes after the first few cases. The Stryker system used battery-powered beacons, which were compact, while the BrainLAB system used reflectors on a mount which was easy to use but mechanically complex and employed reflecting balls which were expensive disposable items. They were more bulky, but could be removed when not being used.

Computer assistance could be used either as an adjunct to jigs or without any devices for mechanical alignment. While the former could provide the novice user with a feeling of security it was an unsatisfactory hybrid and was abandoned after ten operations. The ‘freehand technique’ was found to be simpler, quicker and reduced the range of instruments needed for the operation. Initially, the cutting blocks were fixed by two drill bits. These were found to be unstable and we finally resorted to using four smooth pins, two parallel initially and two drilled obliquely. The cutting blocks have been simplified because they did not need jig attachments.

The accuracy of the system was totally dependent on the stability of the beacon or reflector arrays. Any movement downgraded the results. Small movements were difficult to detect and once movement of the arrays was recognised clinically the TKR was likely to be grossly malaligned. In both systems there are processes for detecting displacement of the array, but their sensitivity was uncertain and their use was not a mandatory part of the procedure.

Intra-operative checks. Once registration and the preparatory surgery were complete the procedure was relatively simple. The jig was set and the cut made and checked. However, aligning the cutting blocks perfectly according to the established landmarks did not inevitably produce perfect bone cuts. It was possible to compare the angle at which the cutting block was set and the resulting bone cut. The minimal variation was zero in all cases. The left-hand column in each block is the lower 95% confidence limit. The second column from the left is the mean variation. The third column is the upper 95% confidence limit and the right-hand column is the maximum deviation (FF, femoral flexion/extension; FV, femoral varus/valgus; FIR, femoral internal rotation; TV, tibial varus/valgus; TPS, tibial posterior slope).

The variation between the angle at which the cutting block was set and the resulting bone cut. The minimal variation was zero in all cases. The left-hand column in each block is the lower 95% confidence limit. The second column from the left is the mean variation. The third column is the upper 95% confidence limit and the right-hand column is the maximum deviation (FF, femoral flexion/extension; FV, femoral varus/valgus; FIR, femoral internal rotation; TV, tibial varus/valgus; TPS, tibial posterior slope).

Positioning the components on to the cut bone was an additional potential source of error, especially when the bone was very soft. Using uncemented prostheses, asymmetrical blows from the mallet could cause malposition. With cement an uneven mantle could have the same effect. When positioning a cemented tibial plateau it was possible to control the position and avoid major malalignment. However, this was not possible with the femoral component since the curved surface made it impossible to assess alignment without special tools.

The additional time taken for computer-assisted surgery varied both with experience and with the degree of obsession demonstrated by the surgeon. The iliac-crest array made draping somewhat tedious, but this has since been
not having to assemble jigs. There was a learning curve associated with setting up the cutting blocks. It was necessary to watch three changing co-ordinates on a computer screen while holding a cutting block and pin driver, but those trained in arthroscopic surgery should rapidly acquire this skill. Time was spent on correcting variations in bone cuts. Because errors were occasionally detected they could be corrected. When using jigs errors were often not detected and thus no time was spent on their rectification.

Changes in software
Each new software ‘upgrade’ has presented major surprises and challenges. The removal of the iliac-crest pin and moving from Stryker version 1.1 to version 2.0 made the registration more tedious, seemingly less accurate and resulted in an increase in the need for a number of lateral patellar releases. The CT assessment of a very small number suggested that there was a tendency to rotate the femoral cut internally. BrainLAB versions \( \beta_1 \) to \( \beta_3 \) had idiosyncratic default settings which were corrected in version \( \beta_4 \).

Outcomes
CT assessment. In the Stryker series CA1, it was possible to compare the final bone cuts as measured during surgery and

The variation between the angle of the bone as shown by the computer-assisted system and the resulting alignment of the prosthesis as shown by the CT scans. The left-hand column in each block is the lower 95% confidence limit. The black column is the mean variation. The middle white column is the percentage of matching alignments. The right-hand column in each block is the upper 95% confidence limit (FF, femoral flexion/extension; FV, femoral varus/valgus; FIR, femoral internal rotation; TV, tibial varus/valgus; TPS, tibial posterior slope).

Discarded and the draping in the CA2 and CA3 cohorts was conventional. Placement of the fixed arrays and registration took about ten minutes in both systems. Time was saved by

Table II. Summary of the outcome as measured using the CT protocol and Perth alignment index for all groups

<table>
<thead>
<tr>
<th>Groups*</th>
<th>Mean error (˚)</th>
<th>Mean number of parameters malaligned</th>
<th>Number</th>
<th>Number with zero score</th>
<th>Percentage with zero score</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA1 and CA2</td>
<td>3.08</td>
<td>1.56</td>
<td>91</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>CA3</td>
<td>3.27</td>
<td>1.43</td>
<td>92</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>JB1 and JB2</td>
<td>5.83</td>
<td>2.18</td>
<td>184</td>
<td>16</td>
<td>9</td>
</tr>
</tbody>
</table>

* see text for explanation of groups

Table III. Summary of the angular measurements (˚) for the six parameters measured in the Stryker (CA1 and CA2), BrainLAB (CA3) and jig-assisted groups. The ideal outcome is zero for measurements except for the tibial sagittal parameter, which varies according to the design specifications of implant. The zero score takes into account the variable target alignment of the tibial slope as do the ‘perfection’ scores

<table>
<thead>
<tr>
<th>Group*</th>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>sd</th>
<th>Total</th>
<th>Zero score</th>
<th>% Perfect</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA1 and CA2</td>
<td>Femoral coronal</td>
<td>-3</td>
<td>3</td>
<td>-0.16</td>
<td>1.67</td>
<td>112</td>
<td>92</td>
<td>82.14</td>
</tr>
<tr>
<td>CA1 and CA2</td>
<td>Tibial coronal</td>
<td>-4</td>
<td>2</td>
<td>-0.54</td>
<td>1.34</td>
<td>112</td>
<td>101</td>
<td>90.18</td>
</tr>
<tr>
<td>CA1 and CA2</td>
<td>Femoral sagittal</td>
<td>-8</td>
<td>11</td>
<td>0.41</td>
<td>2.81</td>
<td>112</td>
<td>82</td>
<td>73.21</td>
</tr>
<tr>
<td>CA1 and CA2</td>
<td>Femoral axial</td>
<td>-8</td>
<td>6</td>
<td>-0.14</td>
<td>2.76</td>
<td>112</td>
<td>68</td>
<td>60.71</td>
</tr>
<tr>
<td>CA1 and CA2</td>
<td>Femorotibial mismatch</td>
<td>-10</td>
<td>12</td>
<td>0.41</td>
<td>3.01</td>
<td>112</td>
<td>75</td>
<td>66.96</td>
</tr>
<tr>
<td>CA3</td>
<td>Femoral coronal</td>
<td>-5</td>
<td>6</td>
<td>0.29</td>
<td>1.92</td>
<td>115</td>
<td>92</td>
<td>80.00</td>
</tr>
<tr>
<td>CA3</td>
<td>Tibial coronal</td>
<td>-3</td>
<td>3</td>
<td>-0.02</td>
<td>1.39</td>
<td>115</td>
<td>109</td>
<td>94.78</td>
</tr>
<tr>
<td>CA3</td>
<td>Femoral sagittal</td>
<td>-5</td>
<td>9</td>
<td>0.83</td>
<td>2.08</td>
<td>115</td>
<td>94</td>
<td>81.74</td>
</tr>
<tr>
<td>CA3</td>
<td>Tibial sagittal</td>
<td>-3</td>
<td>9</td>
<td>2.27</td>
<td>2.21</td>
<td>112</td>
<td>77</td>
<td>73.21</td>
</tr>
<tr>
<td>CA3</td>
<td>Femoral axial</td>
<td>-6</td>
<td>7</td>
<td>0.02</td>
<td>2.32</td>
<td>115</td>
<td>89</td>
<td>77.39</td>
</tr>
<tr>
<td>CA3</td>
<td>Femorotibial mismatch</td>
<td>-10</td>
<td>10</td>
<td>0.97</td>
<td>4.13</td>
<td>115</td>
<td>54</td>
<td>46.96</td>
</tr>
<tr>
<td>None</td>
<td>Femoral coronal</td>
<td>-3</td>
<td>6</td>
<td>0.99</td>
<td>1.93</td>
<td>181</td>
<td>138</td>
<td>76.24</td>
</tr>
<tr>
<td>None</td>
<td>Tibial coronal</td>
<td>-5</td>
<td>5</td>
<td>-0.37</td>
<td>1.73</td>
<td>180</td>
<td>156</td>
<td>86.67</td>
</tr>
<tr>
<td>None</td>
<td>Femoral sagittal</td>
<td>-5</td>
<td>11</td>
<td>1.03</td>
<td>2.50</td>
<td>182</td>
<td>130</td>
<td>71.43</td>
</tr>
<tr>
<td>None</td>
<td>Tibial sagittal</td>
<td>-6</td>
<td>16</td>
<td>4.87</td>
<td>3.70</td>
<td>182</td>
<td>70</td>
<td>38.46</td>
</tr>
<tr>
<td>None</td>
<td>Femoral axial</td>
<td>-10</td>
<td>9</td>
<td>0.50</td>
<td>2.98</td>
<td>181</td>
<td>117</td>
<td>64.64</td>
</tr>
<tr>
<td>None</td>
<td>Femorotibial mismatch</td>
<td>-14</td>
<td>13</td>
<td>-0.75</td>
<td>4.29</td>
<td>180</td>
<td>83</td>
<td>46.11</td>
</tr>
</tbody>
</table>

* see text for explanation of groups
the final positions of the components as shown by CT (Fig. 5). There was some non-concordance. Using the available data on all the parameters provided 228 measurements. Of these, 115 (50%) of the two angles were within 1° of each other and 160 (70%) were within 2°. There was no statistical correlation between the cuts produced and the CT measurements for all parameters.

The CT analysis of the CA1 and CA2 series showed that the mean PAI was (3.08):(1.56) for the Stryker, (3.27):(1.43) for the BrainLAB and (5.83):(2.18) for the jig-based system (Table II). The prevalence of perfect alignments (PAI = 0:0) was 24%, 22% and 9%, respectively.

When the six basic parameters were looked at individually (Table III) several clear trends became apparent. In all groups the coronal measurements showed the best alignment both in terms of the prevalence of a perfect (within 2°) outcome and the range or scatter of results. In the sagittal plane the CATKRs had a perfect outcome for both components in about 70% of cases. In the JB1 and JB2 series the femoral sagittal alignment was of the same degree of accuracy. However, tibial sagittal alignment, the tibial slope, was downgraded to 39% of perfect. The range of error in tibial placement was 22° using jigs, compared with 11° and 12° using CA. The differences in tibial slope were highly significant (p < 0.001). The axial parameters showed minor differences between techniques with a slight advantage to the BrainLAB system over the others. The rate of error was still about 30% with all systems. Femorotibial matching was not controlled by the computer-assistance packages. The better outcomes of the Stryker system in this aspect reflected their superior, non-navigated, instrumentation.

When the CT assessment of the JB1 and JB2 series was examined in regard to the individual surgeons (Table IV) it was clear that there was a wide variation in outcome. The variation between surgeons was much greater than the mean differences between the jig-based and computer-assisted knees. The implication of this is that basic improvements in surgical technique probably had as much to offer as using computer assistance. Of interest also was that the result of the JMS retrospective series (JB2) which suggested that using computer assistance may have improved this surgeon’s results.

### Specific morbidity

The placement of pins and screws in bone is inevitably associated with some risk. When the iliac crest was being used in the CA1 series there were six (6%) injuries to the lateral cutaneous nerve of the thigh with some persistent numbness, three pin-track infections (3%) and two peri-prosthetic fractures, both of which were in elderly, osteoporotic patients and followed major falls. One was through the site of the screw for the array and the other through a medial femoral condyle well away from the site of the screw. In the CA3 patients the only specific complications have been four (4%) pin-track infections in the tibia, one of which was very troublesome and may have led to infection of the prosthesis. As a result we now avoid putting pins below the main wound in patients whose skin is of poor quality.

### Conclusions

The major achievement of computer-assisted TKR is that it has forced us to measure the alignment more extensively than we have in the past. The use of CT and the gathering of high-quality standardised data meant that we were able to relate outcome to alignment in a more sensitive manner. Routine use of the Perth CT protocol and the PAI has provided a powerful tool for audit which should present a stimulus to upgrade our surgical techniques irrespective of whether we go on to the routine use of computer assistance.

Computer assistance itself is an exciting technology which has already improved the alignment of TKR. It has enormous future potential and its role will progressively increase to include soft-tissue balance and replacement kinematics. With experience the risks, time expended and additional costs of the process are reduced to the point at which it is neither difficult nor especially time-consuming. By contrast, there is little future for mechanical jigs since they are unlikely to achieve much more than they already have. The speed of a jig-based TKR is, at least in part, caused by a false sense of security.

Part of the improvement generated by the computer technology is due to the excellent feedback provided during surgery. However, although beguiling, it has potential pitfalls in its present state. It is neither transparent nor fail-safe. It is a hostage to the whims and prejudices of programmers and company representatives, who often do not explain the changes which they make. Surgeons need to be aware of the assumptions, the default options and the settings which are in place before starting the operation. They need to be very wary about software upgrades and sceptical about style when it seems to triumph over substance. The fact that it looks good does not mean it will work. Targeted navigation is a good example. It is potentially dangerous and we advise against using it.

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