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The use of image-free computer-assisted systems in total knee replacement surgeries
L'utilisation de systèmes pour chirurgies assistées par ordinateur dans les arthroplasties totales du genou

Report available at
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This report was prepared for the Joint Technology Assessment Unit (TAU)

of the McGill University Health Centre (MUHC) and of the Centre Hospitalier de l'Université de Montréal (CHUM)

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GLOSSARY

Varus - deformity in which the anatomical part is turned inwards.

Valgus - deformity in which the anatomical part is turned outwards.

L'utilisation de systèmes pour chirurgies assistés par ordinateur dans les arthroplasties totales du genou

RÉSUMÉ

L'arthroplastie totale du genou est indiquée pour soulager la douleur ainsi que pour l'amélioration fonctionnelle chez les patients ayant une dégénération grave de l'articulation du genou. Il s'agit d'une procédure habituelle, avec plus de 24,000 procédures primaires annuellement au Canada et 4,000 au Québec (données 2002-2003).

La procédure consiste en un remplacement des surfaces articulaires défaillantes du genou par une prothèse du genou (un implant articulaire interne) dont le positionnement a été normalement effectué à l'aide des guides intra-médullaires ou extra-médullaires. Plus récemment, des systèmes pour chirurgie assistée par ordinateur ont été développés pour améliorer le positionnement des composantes de la prothèse dans le but d'améliorer l'alignement prothétique postopératoire.

L'intervention conventionnelle connaît un haut degré de succès, avec seulement 10% de révisions nécessaires toutes les 10-15 ans. À l'exception des infections, ces chirurgies de révision sont nécessaires en cas de descellement, instabilité du genou ou usure du matériel de la prothèse. Ces complications peuvent être aggravées par un mal positionnement des composantes de la prothèse (fémorales ou tibiales). Malgré l'association entre le mal positionnement postopératoire des composantes de la prothèse et le descellement ou l'instabilité, la corrélation exacte entre l'ampleur du mal positionnement et la survie de la prothèse n'a pas été quantifiée. En fait, le degré de mal positionnement qui pourrait être considéré comme acceptable n'est pas bien spécifié dans la littérature, bien que la marge de ±3° soit souvent utilisée comme référence. Tandis que la preuve définitive d'une association entre un alignement amélioré et des résultats cliniques significatifs à long terme manque actuellement, sa probabilité semble intuitivement haute. Aussi, malgré l'absence de preuves, on suspecte qu'immédiatement après la chirurgie, la fonction du genou pourrait être affectée chez les patients avec un mal positionnement de la prothèse, ce qui pourrait interférer dans la réhabilitation de ces patients et dans leur retour aux activités quotidiennes.

Notre rapport a évalué l'effet de la chirurgie assistée par ordinateur sans image (image-free) dans la réduction du degré de mal positionnement post opératoire de la prothèse dans le cas des arthroplasties totales de genou. Une révision systématique de la littérature a été entreprise et les données ont été résumées. La piètre qualité méthodologique de la plupart des 19 articles trouvés, les incertitudes autour du point de référence pour qualifier le mal positionnement de la prothèse, et finalement l'absence d'une corrélation clinique entre cette mesure de mal positionnement de la prothèse et les résultats cliniques à court et à long termes limitent nos habilités à faire des recommandations définitives.

En général, les études identifiées ont démontré une petite différence moyenne d'environ 1° entre l'intervention conventionnelle comparativement à celle assistée par ordinateur dans le mal positionnement postopératoire de la prothèse quand on mesure l'alignement au niveau des composantes fémorales, tibiales ou de l'axis mécanique. Il y avait une variation (écart-type) de mal positionnement plus large chez les patients opérés avec la technique conventionnelle, menant à un plus grand nombre de patients n'atteignant pas la cible visée comparativement au groupe de patients opérés par la chirurgie assistée par ordinateur.

Nous avons estimé que, dépendamment du point de repère utilisé pour définir le mal positionnement, la chirurgie assistée par ordinateur permettra l'atteinte du résultat attendu pour 0 à 14 patients de plus par 100 opérations. Par exemple, aucun patient supplémentaire n'atteindra l'objectif visé avec la chirurgie assistée par ordinateur si on choisit une marge de mal positionnement de ±5° de la composante tibiale de la prothèse. Par contre, si on choisit une marge d'alignement de l'axis mécanique de ± 3°, 14 patients de plus atteindront l'objectif avec les systèmes informatiques par rapport à la technique conventionnelle.

Donc, ce dispositif peut améliorer le positionnement de la prothèse en évitant les cas extrêmes qui étaient plus fréquentes avec la technique conventionnelle par rapport à celle utilisant le système informatique.

En l'absence d'une corrélation démontrée entre le degré de mal positionnement post opératoire de la prothèse et les résultats cliniques, aucune évaluation du rapport coût-efficacité de cette technologie ne peut être entreprise.

Face à cette évidence limitée, nous avons décidé de réaliser un sondage auprès des chirurgiens orthopédistes pratiquant dans les centres académiques canadiens. Malgré un taux de réponse de seulement 45% (10 sur 22), il y avait un consensus que cette technologie devrait être disponible dans les institutions académiques comme le CUSM (Centre Universitaire de Santé McGill) et le CHUM (Centre Hospitalier de l'Université de Montréal).

Bien que l'impact de ces systèmes informatiques sur les résultats cliniques soit incertain, cette technique est disponible et il est donc important que les futurs chirurgiens orthopédistes soient préparés à l'utiliser. En outre, certains patients chez qui le positionnement de la prothèse par la technique conventionnelle serait probablement difficile, pourraient être identifiés avant l'opération. Il n'y a pas d'unanimité dans la proportion de ces patients, mais le taux médian observé dans notre sondage effectué auprès des experts, était de 20%. Établir une limite précise est difficile. Néanmoins, étant donné qu'environ 200 arthroplasties de genou sont réalisées chaque année au CUSM et supposant que les experts cliniques pourraient prédire que 20% des patients ont un risque élevé de mal positionnement, un budget annuel pour 40 cas serait requis. Le coût annuel estimé pour utiliser cette technologie chez environ 40 patients par année est d'environ $72,000.

RECOMMANDATIONS

Il n'y a pas d'évidences convaincantes qui démontrent l'amélioration des résultats cliniques suite à l'utilisation des systèmes informatiques de navigation assistés (computer assisted navigation systems) en arthroplastie totale du genou. Cependant, selon les experts, cette technologie pourrait résulter en une diminution des cas de mal positionnement chez certains patients. Par conséquent, il est recommandé qu'une enveloppe budgétaire soit approuvée et consacrée à un nombre limité de patients (Max. 40) présentant un risque élevé de mal positionnement à des fins d'utilisation de cette technique, ce qui permettra aussi au CUSM et au CHUM d'accomplir son rôle d'institution académique.

Ce rapport et ses recommandations seront mis à jour dès que de nouvelles évidences deviennent disponibles dans la littérature scientifique évaluée par les pairs.

The use of the image-free computer-assisted systems in total knee replacement surgeries

EXECUTIVE SUMMARY

Total knee replacement is indicated for pain relief and functional improvement in patients with severe knee joint degeneration and is a common procedure, with more than 24,000 primary procedures per year in Canada and 4,000 in Québec (2002-2003 data).

The procedure consists of the replacement of the joint articular surface with a knee prosthesis whose positioning has been conventionally performed with the use of intramedullary or extramedullary alignment. More recently, computer-assisted systems have been developed to improve the positioning of the prosthesis components with the goal of improving the postoperative prosthesis alignment.

The operation with the conventional technique achieves a high rate of success with only 10% revisions required by 10-15 years. Excluding infections, revisions may occur due to polyethylene wear, prosthesis loosening, knee instability, which may be aggravated by malalignment of implant components (tibial or femoral). Although postoperative malalignment of tibial and femoral components is associated with loosening and instability, the exact correlation between the extent of postoperative malalignment and prosthesis survival has not been well quantified. In fact, the extent of malalignment that is considered acceptable is not clear in the literature, although a margin of ±3° is the commonly used reference. While definitive proof of an association between improved alignment and long-term meaningful clinical outcomes is presently lacking, its likelihood intuitively seems reasonably high. Also suspected but unproven, is the possibility that patients with malalignment may also experience poorer function immediately after surgery, which may interfere with their ability to rehabilitate and return to normal daily activities.

This report evaluated the use of image-free computer-assisted systems in total knee replacement surgeries to reduce postoperative malalignment. A systematic review of the literature was performed and the data summarized. The poor methodological quality of the majority of the 19 identified studies, the uncertainty concerning which malalignment parameter should dominate, the lack of an established threshold to determine

malalignment and finally the absence of a clinical correlation between this surrogate outcome measure and both short and long-term patient outcomes greatly limits our ability to make definitive recommendations.

Overall, the identified studies showed a small average difference of about 1° between conventional and computer-assisted positioning techniques when measuring postoperative alignment achieved in the femoral or tibial components or in the mechanical axis alignment. There was a wider variation (standard deviation) of malalignment with the conventional techniques, leading to a larger number of patients not reaching the target goal compared with the computer-assisted group. Depending on the standards chosen to determine malalignment, we estimated that the computer-assisted surgery will result in anywhere from 0 to 14 additional patients / 100 operated reaching their target goal. For example, computer-assisted surgery will result in no extra patients reaching target if the goal is ≤ 5° (tibial component) but 14 if ≤ 3° of mechanical leg malalignment is the standard.

Therefore, this device may improve alignment by the avoidance of the occurrence of outliers as these are observed more frequently with the conventional technique than with the computer-assisted device. Due to the lack of proven correlation between postoperative malalignment of this magnitude and clinical outcomes, no cost-effectiveness analysis was undertaken.

The limited published evidence base prompted a survey of leading Canadian academic orthopedic surgeons. Although the response rate was only 45% (10 out of 22), there was a consensus to the effect that this technology should be available in a teaching institution such as the MUHC (McGill University Health Centre) and the CHUM (Centre Hospitalier de l'Université de Montréal).

Although the impact on patient outcomes remains uncertain, this is a clinically available technique and it is important that future orthopedic surgeons should be acquainted with it. Furthermore, the patients in whom alignment by traditional techniques is most likely to be difficult can be identified preoperatively. There is no unanimity as to the percentage of such patients, but the median estimate of the expert opinion consulted was 20%. Establishing a precise limit is difficult. However, given that approximately 200 knee

replacement surgeries are performed annually at the MUHC and assuming that clinical expertise may predict the 20% at highest risk of malalignment, a budget for 40 cases per year might be required. The estimated annual cost of using the device in 40 patients / year is approximately $72,000.

RECOMMENDATIONS

There is no convincing evidence that demonstrates improved clinical outcomes with the computer assisted navigation systems in total knee replacement surgery. However, expert opinion believes that this technology is likely to decrease malalignment in some patients. For this reason it is recommended that funding for a limited number of cases (Max. 40) annually should be approved for use in patients at the highest risk of malalignment. This will also allow the MUHC and the CHUM to fulfill their role as educational institutions.

This report and its recommendation will be updated in the future as new evidence on these devices becomes available in the peer-reviewed literature.

FOREWORD

In July 2006 the administrative director of the MUHC, Mr. Gary Stoopler requested an evaluation of the Navitrack® computer assisted system in total knee replacement surgeries by the TAU.

INTRODUCTION

Total knee replacement surgery is indicated for pain relief and functional improvement[1] in patients with severe knee joint degeneration and deformity[2] mainly from rheumatoid or osteoarthritis[3]. The procedure involves the replacement of the joint articular surface with a knee prosthesis[2]. Total knee replacement is a common procedure, i.e., in Canada, more than 24,000 primary procedures (4,000 in Québec) in 2002-2003 and represents a 10% increase from the previous year[4].

Revisions are infrequent (<10%) [1 5 6] and may occur due to polyethylene wear, prosthesis loosening, knee instability, which may be exacerbated by malalignment of implant components (tibial or femoral), and infection[7 8 9]. Although it normally takes 10-15 years for patients to experience failure [1 5 6], early prosthesis failures also occur, predominantly due to infection but some are also due to instability or loosening[1 5].

The goals of total knee replacement surgeries include adequate alignment of the prosthesis components and the limb, stability of the knee, and attainment of sufficient range of motion which permits adequate movement to attain improved quality of life[10].

The mechanical axis of the leg is defined by a line drawn from the center of the hip, knee and ankle [11]. Although there is little doubt that severe postoperative malalignment of tibial and femoral components is associated with loosening[7 12 13] and instability [7], and consequently prosthesis survival[14], the exact correlation between the extent of postoperative malalignment and prosthesis survival has not been quantified[15]. In fact, the threshold for malalignment below which good clinical results are expected is not clear in the literature[16 17]. Some authors believe that a malalignment greater than 3° (varus or valgus) increases the risk of poorer clinical outcomes [18 19 20 21 22 23], but higher thresholds have been used [17 24 25 26 27]. Moreover the validity of the 3° cut point has not

been reliably established [10 13 18 20 24 25 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 40,43 44] . Other variables associated with surgery failure include diagnosis, age, weight, gender, prosthetic design, ligament balancing, amount of bone resection[35 32], and preoperative alignment[17].

The conventional technique of knee replacement may be guided by intramedullary or extramedullary alignment guides [45] that are invasive techniques[46].

More recently, computer-assisted systems for knee replacement surgery have been developed in order to guide the positioning of the prosthesis components thus improving the alignment[45]. Computer-assisted systems are active (surgical robots) or passive i.e., systems that do not perform any part of the surgery but assist in the positioning of the surgical instruments[45]. Passive systems can be further subdivided into image-based, which uses computed tomography (CT) or image-free systems, which uses infrared cameras to provide the positioning information[45].

When using an image-free system, first the mechanical axis of the limb in the frontal and sagittal planes needs to be defined, this is done by identifying the centers of the femoral head, knee and ankle[45]. Rigid metal body markers that reflect infrared light from cameras positioned around the patient are fixed to the bones (femur, tibia, and pelvis), the light is then captured by a detector thus providing information on the position of the prosthesis components [47 48]. Rigid markers are also fixed to surgical instruments and cutting blocks in order to provide their position during the surgery [48].

Accuracy of computer-assisted devices in general is estimated to be of 1-2° [48 49], but it also depends on the care used in fixing the rigid markers and in using the equipment as the detector does not differentiate the bone from the rigid markers, i.e., any movement of the marker will be seen by the computer as movement of the bone[48]. Stulberg et al. who evaluated the use of image-free software in 35 patients raised concerns about the registration accuracy of the earlier generation image-free software due to preoperative deformity and instability of the knee, computer hardware and software inaccuracy[19]. Evaluations of more recent generations do not appear to have been reported.

Similarly to other surgical procedures, experience is needed in order to achieve a reliable registration technique with computer-assisted devices for knee replacement surgeries, some authors have estimated a learning curve of approximately 10 patients [21] [50].

The specific goals of this evaluation are:

- To assess the improvement in accuracy of prosthesis positioning with image-free computer assisted devices for total knee replacement compared to the conventional (not computer assisted) technique.
- To determine the long-term clinical and economic impact of performing computer assisted total knee replacement compared to the conventional technique.

TECHNOLOGY

Navitrack® is an image-free system that uses a computer workstation with an optical tracking system to provide real time information about instrument positioning during the surgery[21] and is the focus of our report. It has received approval by Health Canada in April 2004[51] and by the FDA in August 2002[52]. There are other image-free systems to assist total knee replacement surgery, Orthopilot® (Aesculap), Stryker® (Stryker Leibinger) Vector Vision®.

Throughout the report, when we refer to computer-assisted surgery we refer to image-free systems, unless otherwise specified. When referring to conventional technique for total knee replacement we include those with or without intramedullary or extramedullary alignment guides.

METHODS

Systematic Literature Review

A systematic literature search was performed using the Medline, Embase, and International Network of Agencies for Health Technology Assessment (INAHTA) databases. Articles published in English or French, that evaluated either clinical (revision rates, safety etc.) or postoperative alignment as outcome measures with image-free computer-assisted devices compared to conventional total knee replacement surgery

were selected. Technology assessment reports, economic analyses, systematic reviews and meta-analyses were also included in our report. Studies not performed in live patients, simulation studies, in unicompartmental knee arthroplasty, and those that did not provide the actual postoperative alignment angle were excluded.

Search terms used: (computer-assisted OR computer-aided OR navigation) AND (total knee replacement OR total knee arthroplasty).

Since a technology assessment report was published in February 2004 and included in our report, we have only selected studies published after January 1st 2004. Last search: August 2006.

Statistics

The results of the studies identified were pooled together in order to estimate the reduction in the risk of postoperative malalignment with computer-assisted devices. The pooled analyses included the studies that reported the endpoints evaluated and identified through our or previous systematic literature searches. The pooled analyses were done using the RevMan software (the Cochrane Collaboration, Oxford, England, version 4.2 for windows). The measure of association used was the absolute risk difference between the two groups calculated using a random effects model.

RESULTS

We have identified 17 studies published since January 1st 2004 and that met our inclusion criteria[20 21 22 23 53 54 55 56 57 58 49 59 60 61 62 63 64]. The manufacturer of the device provided information on the results of two unpublished studies comparing the Navitrack® computer-assisted system and the conventional technique in total knee replacement surgery [65 66]. One technology assessment report published in February 2004[67] the report recommendations[68], one systematic literature review [69] and one economic analysis were also identified[70].

The studies consisted of randomized [23 53 54 59 61 65 66], matched-pair[55 56], non-randomized prospective [20 22,49,58 60 62 63 64] and retrospective[21 57] comparisons between image-free computer-assisted systems for total knee replacement surgeries and surgeries performed without the aid of such devices. In some cases, computer-assisted

surgeries were compared to historic controls using the conventional technique[20 49 60 62 63 64]. The main endpoints used in these 19 studies consisted of the postoperative alignment of the femoral and tibial components and of the mechanical leg axis, as measured in most studies by weight-bearing long-leg X-rays.

Among the 19 studies identified, four used the Navitrack® system, which is the object of our report[21 53 65 66]. None of the studies identified were designed to compare different computer-assisted systems.

Postoperative alignment

In general, the difference in mean postoperative alignment achieved in the femoral or tibial components or in the mechanical axis alignment between the groups was small, in the order of 1° or less (Appendix 1). In all studies the mean postoperative alignment of tibial and femoral components and mechanical leg axis was within 0-3° varus or valgus for both groups (Appendix 1).

However the range of malalignment (standard deviation) was slightly wider in the conventional technique group, i.e., the standard deviation was 1-2° higher in the conventional group compared to the computer-assisted group (Appendix 1).

In order to estimate the proportion of patients in each group with a postoperative malalignment greater than 3°, 4° or 5° in varus or valgus, we have pooled the results of the studies identified in our and previous systematic literature searches. Appendix 2 shows the pooled analyses results on the absolute difference in risk of postoperative malalignment between the two groups calculated using different criteria.

The pooled analysis including all comparative studies showed a non-statistically significant difference in postoperative tibial alignment within ±3° between the two techniques, i.e., 5% more cases operated with the computer-assisted technique compared to the conventional technique (absolute difference:5%, 95% confidence interval, CI: 0 , 9%). Using a ±5° cutoff no difference was seen between the two groups (absolute difference:0, 95% CI: -2% , +2%). For the postoperative femoral alignment, the absolute risk difference between the two groups was statistically significant using a ±3°

range (absolute difference: 12%, 95% CI: 3% , 21%) but the difference was not statistically significant using ±4°, or ±5° alignment ranges. For the mechanical leg axis, there was an 18% (95% CI: 15% , 22%) absolute difference in patients having an adequate alignment adopting a ±3° cutoff. The difference was not statistically significant (absolute difference: 3%, 95% CI: 0 , +6%) with a cutoff of ±5°. Appendix 2 also shows the results of the pooled analysis using only RCTs.

Two factors hinder the interpretation of the clinical significance of these findings:

- The absence of an established criterion to define acceptable component alignment, i.e., within ±3°, within ±4°, or ±5°.
- The absence of an established correlation between the small differences in the mean postoperative components' alignment seen (approximately 1°) and both short and long-term outcomes.

Functional and quality of life measures

We have identified two studies that evaluated the functional or quality of life impact of the use of image-free computer-assisted devices, as described below.

A randomized study compared the early (8 days) postoperative rehabilitation in patients who underwent total knee replacement using an image-free computer-assisted device (n=39) and conventional technique (n=31) [71]. There was a non-statistically significant trend to a faster rehabilitation with the conventional compared to computer-assisted surgeries as measured by quadriceps dysfunction, the difference was statistically significant when the conventional technique was compared to computer-assisted surgery using the medial parapatellar approach (outcome evaluated in a blinded fashion)[71]. The authors believe that this was caused by an additional dissection that needs to be done in order to place the femoral tracking array for the computer-assisted technique[71].

Unpublished data provided by Orthosoft from a randomized study showed no statistically significant difference between computer-assisted and conventional technique at six months on knee score (84 vs. 79, respectively p=0.12) and knee function (84 vs. 85 respectively) despite a statistically significantly higher proportion of patients in the

computer-assisted group with a mechanical axis and femoral component alignment within ±3° (79% and 96% respectively) compared to the conventional technique (67% and 83% respectively)[65]. Preoperative knee scores and knee function were identical for both groups[65]. The same study compared the SF-36 general and individual categories scores between the two groups 6 months after the operation[65]. Patients in the computer-assisted group showed a better global SF-36 score than patients in the conventional technique group (p=0.002) [65]. Patients in the computer-assisted group also showed better scores on most individual categories of the SF-36 questionnaire compared to the conventional technique group although the statistically significance of these results was not reported[65]. It is not clear if the preoperative SF-36 scores were different between the two groups as this information was not provided, which renders the interpretation of these results difficult. Moreover the changes in score from baseline in each group were not provided in the report. The authors report that patients were lost to follow-up at the 6-month evaluation, but the precise number of losses to follow-up in each group was not provided. It was also unclear if the postoperative alignment measures were done in a blinded fashion.

General conclusions - Results

Methodological issues in these studies further complicates the interpretation of their results. Most studies were not randomized and some consisted of comparisons between patients who received the procedure at different periods, which may affect the results since possible improvements in prosthesis design, surgical techniques and physicians' experience may render such comparisons inadequate. Accuracy and inter-rater reliability of the X-ray measurements of postoperative alignment may also undermine the interpretation of the results.

Two of the studies identified in the systematic review and two unpublished studies used the device that is proposed for use at the MUHC, it is not clear if it is appropriate to generalize the results from different devices even if they were of the same type (image-free computer-assisted devices).

Technology assessment reports, systematic reviews, and economic analyses

The Ontario Health Technology Assessment Committee published in March 2004 concluded that there was not enough evidence regarding the long-term outcomes and safety of computer-assisted arthroplasty using navigation systems to support its recommendation[67,68].

In a systematic review published in March 2006 that included 6 randomized and prospective studies, Luring et al.[69] conclude that computer-assisted devices improve the postoperative leg alignment and component orientation compared to conventional techniques. However, the authors also point out that there is a lack of studies that evaluate short- or mid-term outcomes such as early rehabilitation, patient satisfaction, and ligamentous stability, and especially it hasn't been demonstrated if this improvement in leg alignment will result in long-term prosthesis survival [69]. Nevertheless, Luring et al. advocate the use of computer-assisted devices in patients with severe preoperative leg-axis deformities[69].

A published economic analysis using Markov modeling to compare computer-assisted to conventional surgery used the rate of postoperative malalignment reduction as surrogate endpoint to estimate the long-term effectiveness of computer-assisted devices[70]. The analysis showed that computer-assisted surgery has a slight 10-year cost-saving of £583 and a small gain of 0.0148 QALYs over 10 years[70]. Given the lack of quantifiable correlation between postoperative malalignment and long-term outcomes in total knee replacement surgeries, we believe that it is too early to make such an inference.

Safety

The intraoperative complications reported in the studies identified seemed to be generally similar in both groups (Appendix 1).

Possible complications specific to the use of computer-assisted devices are fracture of the tibia or femur due to the fixation of the reference arrays and increased risk of deep infections due to longer operation time[69]. However, these complications have not been reported in the studies identified.

One randomized study including 60 patients reported a reduction in blood and hemoglobin loss with computer-assisted total knee replacement compared to conventional technique using intramedullary alignment jigs[72].

Kalairajah et al. [73] reported a reduction in the mean number of microemboli detected (transcranial Doppler) with computer-assisted devices (mean: 0.64±0.74) compared to conventional technique using intramedullary alignment guides (mean: 10.7±13.5) (p=0.0003). The investigators could not confirm the nature (air, platelets, bone or fat) or the size of the emboli[73]. The investigators believe that the use of intramedullary rods may contribute to the formation of emboli[73]. The distribution of baseline risk factors such as cardiovascular disease in each group was not provided in the publication.

One randomized study involving 70 patients comparing an image-free computer-assisted device to the conventional technique observed a higher rate of acute postoperative confusional state with conventional technique (29%) compared to 1 (3%) in the computer-assisted group[23]. Additional information on other complications can be found in Appendix 1.

EXPERIENCE AT THE MUHC

Approximately 200 total knee replacements are performed annually at the MUHC (Mr. Gary Stoopler, Director, Administration), and so far the Navitrack® total knee replacement system has been used in approximately 15 patients with satisfactory results (information provided by Dr. Lenczner, Orthopedic Surgery, MUHC).

According to the experience at the MUHC, a proper prosthesis alignment results in both short- and long-term benefits such as improved patient function and increased longevity of the prosthesis respectively (information provided by Dr. Lenczner, orthopaedic surgery, MUHC). However, these outcomes have not yet been published in the peer-reviewed literature and long-term results will not be available for another 5-10 years.

Some patients are at a higher risk of prosthesis malalignment and are therefore more likely to benefit from the use of the computer –assisted technique such as those with previous knee surgeries, those in preoperative valgus malalignment or with other complexities (information provided by Dr. Lenczner, orthopaedic surgery, MUHC).

Estimation of the benefit with image-free computer-assisted devices

There is a lack of consensus on the degree of postoperative deviation of femoral or tibial components or mechanical axis from neutral alignment that is considered acceptable, however, the occurrence of postoperative prosthesis malalignment seems to be one of the factors that influence poorer medium and long-term outcomes such as patient function and prosthesis survival.

The benefit of computer-assisted devices probably lies in reducing the outliers defined by the postoperative malalignment greater than ±3°, ±4° or ±5° in tibial or femoral components or mechanical leg axis.

It is not clear which one of these alignment criteria is the most relevant with regards to prediction of long-term outcomes, therefore we have studied different scenarios in order to estimate the benefit of using the computer-assisted device.

In order to estimate the possible benefits of using image-free computer assisted devices in total knee replacement, we have assumed that the acceptable range of postoperative alignment to be within ±3° of the neutral mechanical leg axis, although this hasn't been demonstrated in the literature. Only results of RCTs were used in order to avoid bias associated with non-randomized comparisons. Pooling the results of the RCTs available (Appendix 2) we estimated that computer-assisted devices would result in a 14% absolute decrease in mechanical leg axis malalignment > ±3° compared to the conventional technique. This would be the equivalent of 14 less outliers for 100 operations conducted with the device (95% confidence interval (CI): 10 , 19). Using an acceptable range of postoperative mechanical axis alignment within ±5° of neutral would result in 2 less outliers with the device (95% CI: 0 , 5). If we consider the postoperative alignment of the tibial component within ±3° of neutral as the criterion, the expected benefit with the device would be 8 less outliers (95% CI: -2 , 17), or 26 (95% CI: 19 , 33) less outliers if we use the femoral component alignment within ±3° instead.

Due to the yet unproven correlation between an improvement in postoperative malalignment and clinical benefits, especially in the magnitude observed with the computer-assisted device compared to conventional technique, the cost-effectiveness of the device could not be calculated.

COST ANALYSIS AT THE MUHC

There are different options for renting or purchasing the device (Costs in Canadian dollars). Information from Mr. Gary Stoopler (Administration, MUHC).

1. Rent-purchase of the device

The costs involved are:

- Annual cost of rent-purchase of the equipment estimated at $57,972 ($4,831 monthly) for three years. The equipment includes the Sesamoid CAS system, navigation software, software service contract, OSH knee 2.0 universal STD kit, and drill guide NKII.
- Surgical disposable material: $350 per surgery ($14,000 for 40 surgeries).

If the device is used in 40 surgeries per year the total cost to the MUHC including the device and disposable surgical material would be: $71,972 ($57,972 (equipment) + $14,000 (40 x $350 for disposables).

2. Renting the device on a per surgery basis

- Rent of the device per surgery: $650 ($26,000 for 40 surgeries)
- Surgical disposable material: $350 per surgery ($14,000 for 40 surgeries)

If the device is used in 40 surgeries per year the total cost to the MUHC including the device and disposable surgical material would be: $40,000 ($26,000 for equipment + $14,000 for disposables).

3. Purchasing the equipment

- The cost of purchasing is $122,288 for 1 set of equipment
- Surgical disposable material: $297.50 per surgery with 15% discount ($11,900 for 40 surgeries)

We have assumed that there would be no other differences in costs between the two groups other than the equipment and materials required for the computer-assisted device, i.e., no difference in complications.

EXPERIENCE WITH IMAGE-FREE COMPUTER-ASSISTED DEVICES IN QUÉBEC AND CANADA

In order to have information on the experience of other Canadian centers with image-free computer assisted systems in total knee arthroplasty we have consulted the directors of orthopedic surgery of university hospitals in Canada. Out of 22 orthopedic surgeons contacted, 10 (45%) responded, of which, one does not perform total knee replacement, and in one case the device was not available at the hospital, therefore 8 contributed with information on their experience with the device. All responders considered the device to be a valuable technology that should be available for use at least in part of the total knee replacement surgeries, i.e., median of approximately 20% of the cases (range: <5% to >50%). Most responders (n=5, 63%) believe that the indications for its use are not yet very clear. Some suggested indications include inability to use intramedullary guides during surgery due to deformities or existing implants or devices, previous hip or knee surgeries etc., and revision surgeries. To maintain expertise it was suggested that surgeons should perform at least 5-24 procedures with the device per year.

We acknowledge that there is a possibility of selection bias in responding and that there are limitations of “expert opinion” as a measure of evidence based medicine, notwithstanding, these results are consistent with a small dedicated application of the technology.

DISCUSSION

The studies identified showed a small mean benefit in postoperative alignment of prosthesis components in total knee replacement with a computer-assisted technique compared to the conventional technique. Nevertheless, more outliers (14/100 patients, /95% CI: 10, 18) were observed in patients operated on with the conventional technique compared to the computer-assisted system.

Although currently unproven, patients with even the degree of malalignment observed in the studies identified may experience poorer function after the operation, which may interfere with the patients daily activities and may also result in a higher risk of revision surgery. Depending on the standards chosen to determine malalignment, we estimated that the computer-assisted surgery will result in anywhere from 0 to 14 additional

patients / 100 operated reaching their target goal. For example, computer-assisted surgery will result in no extra patients reaching target if the goal is ≤ 5° but 15 if ≤ 3° of mechanical leg malalignment is the standard.

The adoption of this device, even if for a limited number of cases will allow the performance of further research on the topic and will permit the research collaboration with other institutions.

Survey information from leading academic orthopedic surgeons across the country suggests that the technology is valuable at least in more complicated total knee replacement surgeries. However, important outcomes for patients such as function, satisfaction and survival have not been evaluated in the studies published so far[45]. Unpublished data from the manufacturer did not show a statistically significant benefit in functional outcomes with the computer-assisted device compared to the conventional technique within 6 months of the operation despite improved prosthesis alignment with the former[65]. It is therefore important that functional and clinical outcomes be collected on a regular basis in order to elucidate the role of this device in total knee replacement surgeries.

Given the lack of long-term evidence for improved outcomes, it is difficult to determine the clinical importance of the benefits observed with the use of the device. Unfortunately this may require at least ten years of follow-up[45 69]. As has been pointed out by some authors, it is also important to note that high prosthesis survival rates at 15-20 years have been observed with conventional techniques[45 74].

Establishing a restricted limit is a difficult and imprecise task. However, given that approximately 200 knee replacements surgeries are performed annually and assuming that clinical expertise may predict the 20% at highest risk of malalignment, a budget for 40 cases might be considered. The estimated annual cost of using the device in 40 patients / year is approximately $72,000.

RECOMMENDATIONS

There is no convincing evidence that demonstrates improved clinical outcomes with the computer assisted navigation systems in total knee replacement surgery. However, expert opinion believes that this technology is likely to decrease malalignment in some patients. For this reason it is recommended that funding for a limited number of cases (Max. 40) annually should be approved for use in patients at the highest risk of malalignment. This will also allow the MUHC and the CHUM to fulfill their role as educational institutions.

This report and its recommendation will be updated in the future as new evidence on these devices becomes available in the peer-reviewed literature.

APPENDIX 1 – RESULTS OF THE STUDIES IDENTIFIED THROUGH THE SYSTEMATIC LITERATURE REVIEW

Study / Interventions	Interventions / Study methodology	Patient characteristics	Alignment	Surgery time	Complications
Bolognesi and Hofmann[21] (2005) Navitrack® (N=50) conventional surgery (N=48) Measurements at 6 weeks	Retrospective study Procedures performed by one surgeon Postoperative alignment measured radiographically (long-standing) by the same observer Not blinded No losses to follow-up	Gender distribution similar – other variables not given (author mentions that age was similar) Varus knees preoperatively: CA: 34 (68%) / Conv.: 41 (82%) – No information on magnitude of malalignment Different surgical approaches were used*, differ between groups. *medial patellar, subvastus, midvastus exposure	Femoral component (mean ±SD): CA: 90°±1.0° / Conv.: 90°±2° Tibial component Varus group CA: 91°±1.4° /Conv: 92°±2.2° Valgus group CA: 90°±1.2°/ Conv: 91°±1.3° goal=90° Hip-knee angle alignment not provided	Mean tourniquet time CA: 68 min. Conv: 57 min. P=0.004	0(at 6 weeks)
Macule-Beneyto et al.[53] (2006) Navitrack® (n=20), Stryker® (n=66), Orthopilot® (n=16) Conventional (N=84) Measurements in the first few days postoperatively	Prospective randomized study including 5 hospitals 3 hospitals used the Stryker system, different hospitals used the Navitrack and Orthopilot systems Postoperative alignment measured radiographically (standing) Not blinded Postoperative assessment not possible in 7 (6.4%) for CA and 9 (9.7%) for Conv.	Mean age: CA.: 71.6 (69.5 – 73.8) / Conv. 72.3 (70.9 – 73.8) Mean BMI: CA.: 30.4 (29.5 – 31.3) / Conv.: 31.4 (30.4 – 32.4) Varus preoperative alignment: CA: 87 85% / Conv.: 84% No information on magnitude of malalignment	Conventional group had a 1.19° in axis deviation greater deviation compared to CA (p<0.001) Goal: 180° No differences in the final angle of the extremity with the different navigation systems (evaluated in different hospitals, no demographic information for each system)	Mean operation time: CA.: 93.6 min. Conv.: 76.9 min p< 0.001	-
Decking et al. [54] (2005) Orthopilot® (n=27) Conventional (n=25) Measurements at 3 months	Prospective randomized study Postoperative alignment measured radiographically (full leg, weight-bearing, standing) Not blinded No information on losses to follow-up	Age: CA: 64.7 (±9.4) / Conv.: 67.3 (±6.3) BMI: CA: 27.9 (±3.5) / Conv.: 30.2 (±4.95) Primary osteoarthritis: CA: 18 (67%) / Conv.: 21 (84%) Rheumatoid arthritis: CA: 3 (11%) / Conv.: 2 (8%) Postraumatic arthr.: CA: 6(22%) / Conv.: 2 (8%) Varus preoperatively: CA: 19 (70%) / Conv.: 19 (76%) No information on magnitude of malalignment	Mean leg mechanical axis alignment (3 months) CA: 1.5°±2.1° / Conv: 2.3°±3.5° Goal: 0° No statistically significant difference in femoral or tibial mechanical axis (alignment not shown)		Postoperative wound infections with skin necrosis CA: 2 (7.4%) / Conv.: 2 (8%) Revised sugery: CA: 2 (4%) pts with infection Conv.: 0 No infections were present at 3 months

Appendix 1 cont.

Study / Interventions	Interventions / Study methodology	Patient characteristics	Alignment	Surgery time	Complications
Haaker et al. [55] (2005) Orhopilot® (n=100) Conventional (n=100)	Matched-pair study (body weight, age, gender, reason for surgery, preoperative deformities of the mechanical leg axis Two types of implants distributed evenly between groups Postoperative alignment measured radiographically by an independent doctor (long-leg, standing) Blinded No losses to follow-up (200 patients with available X-rays were used)	Mean age (range): CA: 68 (51-89) / Conv.: 69 (51-88) Mean BMI (range): CA: 27.6 (20.2 – 44.5 / Conv.:26.9 (21.3-40.9) 1. diagnosis for treatment: CA: primary arthritis (85%) Conv.: arthritis (87.4%) Mechanical axis (varus), mean (SD):CA: 6.3° (±9.7) / Conv.: 3.73± (9.7)	Coronal tibial axis CA: 90.17°±1.14° (range: 86-94°) / Conv: 89.33°±1.56° (range: 84-92°) Coronal-femoral axis CA: 89.43°±1.29 (range 86-94°) / Conv: 90.49°±2.54° (range 86-100°) Mechanical axis (deviation from normal axis) CA: 0.77°±1.91 / Conv.:1.81°±3.01	Operating times CA: 111 min. (range 80-190) Conv.: 101 min. (range059-155)	
Matsumoto et al. [56] (2004) Vector Vision ® (n=30) Conventional (n=30)	Prospective study Matched pair comparison between surgeries done by the same physician during the same period Postoperative alignment measured radiographically (long-leg, weight-bearing) Blinded	Osteoarthritis Exclusion: Valgus deformity, bony defects, rheumatoid arthritis Preoperative alignment not given	Mechanical axis angle CA: 179.4±1.9 / Conv.: 179.2±2.6° (NS) Coronal tibial angle CA: 90.6°±1.6° / Conv. 91°±1.9° (NS) Coronal femoral angle CA: 90°±1.6° / Conv: 90.2°±2.1° (NS)	-	
Confalonieri et al. [57] (2005) Orthopilot® (n=38) Conventional: intramedullary alignmet guide (n=40), extramedullary (n=37) Measurements at 12 months	Retrospective study All operations performed by one surgeon. Three different types of prostheses used Same postoperative rehabilitation program for all patients Postoperative alignment measured radiographically at 12 months by an independent radiologist (standing, long-leg, anteroposterior) Blinded	Age: CA: 72 (56-84), intram.: 67 (47-81), extram.: 70 (39-86) Mean HKA (preop.): CA: 175°±6.7 / intram.: 174.1°±7.6 / extram.: 176.1°±6.3 Mean flexion deformity (preop) CA: 2.3°±2.6 / intram.: 2.1°±2.1 / extram.: 2.2°±2.2	Frontal femoral component angle CA: 90.5°±1.6 (range: 87-94°) / intram.: 91.05°±2.17 (range: 85-95°)/ extram.: 91.19°±2.68 (range: 85-96°) (NS) Frontal tibial component angle CA: 89.97°±1.5 (range: 83-97°)/ intram.: 90.6° ±2.1 (range: 87-95°) / extram.: 90.8°±2.5 (range: 86-95°) (NS) Goal: 90° Hip-knee angle (goal: 180°): CA: 179.18±1.8 / intram.: 178.6°±2.6 / extram.: 177.8°±3.3	Operation time: CA: 109.2 min. (89-133) Intram.: 91.2min (74-112) Extram.: 82.2 min (65-106)	0 (intraoperative)

Appendix 1 cont.

Study / Interventions	Interventions / Study methodology	Patient characteristics	Alignment	Surgery time	Complications
Bathis et al.[22] (2004) Vector-Vision® (n=50) Conventional with extramedullary control (n=50)	Prospective study Treatment assignment not clear One type of prosthesis used Postoperative alignment measured radiographically Blinding: NA Losses to follow-up: NA	Knee ostheoarthritis Age (years): CA: 69.7±8.4 / 71.6±7.9 Preop. leg axis: CA: 7.8°±4.8° / Conv.: 9.1°±4°	Deviation from the neutral position Mechanical leg axis CA: 1.3°±1.1 (range: -5 – +4°) / Conv.: 2.2°±2.2 (range: -4 - +10°) p=0.0117 Femoral component CA: 1.6°±1.1 / Conv: 2°±1.6 (NS) Tibial component: CA: 1.1°±0.9 / Conv.: 1.5°±1.2 (NS)	-	-
Bathis et al.[58] (2004) Vector Vision® (n=80) Conventional (n=80) (extram.)	Prospective study Treatment allocation according to week day All operations by same team One type of prosthesis used Postoperative alignment measured radiographically obtained by 2 different observers 3 times on different days (full-length, weight-bearing) Blinded No losses to follow-up	Age (years): CA:68.7±9.3 / Conv.: 70.9±9.1 Preop. axis deviation: CA: 8.4°±5.1° / Conv.: 8.6°±4.3°	Deviation from the neutral axis Femoral component: CA: 1.5° (95%CI: 1.2 , 1.7) Conv: 2.1°(95%CI 1.7 , 2.4) (p<0.01) Tibial component: CA: 1.2°±(95%CI 1 , 1.5) / Conv.: 1.5° (95%CI 1.2 , 1.7) (NS) Mechanical axis of the leg CA : 1.4° (95% CI: 1.2 , 1.7) / Conv.: 2.4° (95%CI: 2 , 2.8)	Operation time CA : 78.2±12 Min / Conv. : 64±11 min (p<0.01)	-
Zorman et al.[49] (2005) VectorVision® (n=62) Conventional (n=72)	Prospective data collection for CA surgeries. Comparison with previous case series Postoperative alignment measured radiographically (conv.) and provided by the computer (CA) Blinded Losses to follow-up: NA	-	Tibial component deviation CA: 0.4°±0.3° ge : 0 – 1.4°) / Conv.: 1.8°±1.7 (range: 0 – 8°) (p<0.0001) Femoral component deviation CA: 0.6°±0.4° (range: 0-1.8°)/ Conv.: 2.2°±1.9 (range: 0-8°)(p<0.0001) Mechanical axial deviations (HKA) CA: 1°±0.6° (range: 0-2°) / Conv.2.7°±2.2° (range: 0-9°) (p<0.0001)	-	-
Chin et al. [59] (2005) N=90 VectorVisio® Conventional, intramedullary., extramedullary instrumentation	Randomized study All implants had patella resurfacing Postoperative alignment measured radiographically evaluated by a blinded observer (long-leg, weight-bearing)	No exclusion criteria Age(years): CA: 67.3 (48-80) / intram.: 66.9 (52-78) / extram: 65.6 (52-77)	Tibial component mechanical axis angle CA: 90.1 (range 86-94°) / intram.: 91.9° (range 85-101.5) / extram: 90.3° (86-94) Femoral component-mechanical axis angle CA: 90.6° (range 89-94) / intram.: 91.7°(range 86-102.5) / extram.: 91.3° (88-97)	-	-

Appendix 1 cont.

Study / Interventions	Interventions / Study methodology	Patient characteristics	Alignment	Surgery time	Complications
Daubresse et al.[60] (2005) Orthopilot® (n=50) Conventional, extramedullary control (n=50)	CA surgeries done between 2000-2001 and conventional between 1996-1997 Postoperative alignment measured radiographically	-	HKA: CA: 180°±1° / Conv: 180°±3 (NS) Anteroposterior alignment (tibial) CA: 90°±1° (range:88-92°) / Conv: 90°±2 (range: 87-93°) (p<0.001) Anteroposterior alignment (femoral): CA: 90°±1° (range: 87-92°) / Conv.: 89°±2° (range:86-93°) (p<0.05)	-	-
Stockl et al. [61] (2004) Stryker® (n=32) Conventional (n=32)	Randomized study Postoperative alignment measured by CT scans and verified radiographically – all measurements done by 3 observers	Age (years): CA: 68.2±7.6 / Conv: 72.4±8.7	Mechanical axis deviation CA: 0.3°±2.35° (-5 - -3°)/ Conv: 0±3.19° (-11 - -8°) Goal: 0°	-	-
Jenny et al.[62] (2005) Orthopilot® (n=235) Conventional (extramedullary instrumentation) (n=235) Endpoints measured between 6th -12th week	Prospective in CA group (1999-2001) Compares to historical matched controls (1995-1999). Matched on BMI and preop. coronal mechanical femorotibial angle Same prosthesis used in CA and control group 5 participating hospitals Alignment measured on long-leg stance X-ray	Age (years): 70 (24-95) BMI: 30±4.3 (not separated by group)	Coronal orientation of femoral component (goal:90°) CA: 90.3°±1.6° / Conv.: 90.4°±2.2° (p=0.51) Deviation from expected angle: CA: 1.1°±1.3° (range:0 , -7°) / Conv.: 1.6°±1.6° (range: (0 , -9°) (p<0.01) Coronal orientation of the tibial component CA: 89.7°±1.6° / Conv.: 89.6°±1.8° (p=0.35) Deviation from expected angle: CA: 1.0°±1.3° (range:0 - -6°) / Conv: 1.3°±1.4° (range: 0 - -6°) p=0.03 Mechanical femorotibial angle CA: 0°±2 / Conv.: 0.6°±3.4 p=0.02	Operation time CA: 108±22 min / Conv.: 99±22 p<0.01	Phlebitis: CA: 4 (1.7%) / Conv: 10 (4.3%) Pulmonary embolism: CA: 2 (0.9%) / Conv.: 1 (0.4%) Hematoma: CA: 2 (0.9%) / Conv: 9 (3.8%) Skin necrosis: CA: 0 / Conv.: 4 (1.7%) Infection: CA: 1 (0.4%) / Conv.: 2 (0.9%) Delayed rehabilitation: CA: 4 (1.7%) / Conv.: 6 (2.6%)

Appendix 1 cont.

Study / Interventions	Interventions / Study methodology	Patient characteristics	Alignment	Surgery time	Complications
Anderson et al. [20] (2005) Stryker® (n=142) Conventional, intramedullary guide (n=61)	CA surgeries performed in 2002-2003 Conv. surgeries performed in 2001. Patients were matched Surgeries performed by 1 surgeon Postoperative alignment measured radiographically (full length, weight-bearing) by an independent observer Blinded	Mean age (years): CA: 68 (41-84) / Conv.: 67 (41-89) Severity of disease: CA: 3.3 / Conv.: 2.9) Mean preoperative mechanical axis (° varus): CA: 3.2 / Conv.: 3.6	Tibial component CA: 0° (-4 – +3) / Conv.: 0.5° varus (-3 – +3) (p<0.05) Femoral component CA: 0.5° varus (-4 - +6)/ Conv.: 0.8° valgus (-5 - +5) (p<0.001) Mechanical axis CA: 0.3° varus / Conv.: 0.3° varus	-	-
Chauhan et al. [23] (2004) N=70 (35 in each group?) Stryker® / Conventional CT scans at hospital discharge, X-rays at 6 weeks	Blocked randomization All surgeries performed by the same surgeon Postoperative alignment evaluated by CT scans performed by the same radiologist (verified by a second radiologist). X-rays were performed at 6 weeks by a radiologist (blinded)	Groups were similar in age, BMI, preoperative deformity (p> 0.05). Specific baseline values not provided.	Statistically significant improvement with CA compared to Conv. in postoperative femoral and tibial alignment and rotation. Mean values not provided	Surgery time, mean (range): CA: 80 min. (60-120) Conv.: 67 (55-90) p=0.001	% assuming 35 patients/group Pulmonary embolus: CA: 0 / Conv.: 1 (3%) Transient ischemia: CA: 0 / Conv.: 1 (3%) Deep vein thrombosis: CA: 1 (3%) / Conv.: 2 (5.7%) Superficial infection: CA: 1 (3%) / Conv.: 2 (5.7%) Stiff knee requiring manipulation under anesthesia: CA: 1 (3%) / Conv.: 0 Acute postoperative confusional state: CA: 1 (3%) / Conv.: 10 (29%) All patients recovered with no long-term morbidity
Kim et al. [63] (2005) Stryker® (n=69) Conventional (intramedullary /extramedullary control) (n=78) Evaluation at 4 months or 1 year (when possible) (CA) / Conv.: not standardized historic controls	Prospective for CA compared to historic controls with Conv. with available radiographs. All procedures by the same surgeon Postoperative alignment measured by full leg, weight bearing radiographs Not blinded	Mean age (years): CA: 68 / Conv.: 70 Different components used between the two groups resulting from a difference in preference by the surgeon over time	Final N in each group cannot be determined as some radiographs were excluded due to inadequacy (CA: 24% / Conv.: 34%), but number of patients with no valid radiograph not provided Mechanical axis: Within ±3°: CA: 94% / Conv.: 73% P=0.001 Within ±5°: CA: 100% / Conv.: 100%	-	-

Appendix 1 cont.

Study / Interventions	Interventions / Study methodology	Patient characteristics	Alignment	Surgery time	Complications
Clemens et al. [64] Orthopillot (n=30) (using a new and an older system) Conventional (n=30?)	Prospective for CA compared to historic controls with Conv. Two surgeons performed the procedures.	Not provided	A wider spread of the results was seen with the conventional technique compared to the computer-assisted surgeries (newer software) in: mechanical, femoral, and tibial axis Specific values not provided	-	Deep vein thrombosis: CA: 3 (5% if n=60), 1 with the new version. / Conv.: 1 (3.3% if n=30) Breakage of the drill for fixation of the rigid body at the iliac crest: CA: 1 (old system) / Conv.: 0
Information provided by Orthosoft[65] N=295 (Navitrack® / conventional technique) Evaluations performed at 6 weeks and 6 months Number of patients in each arm and number of losses to follow-up not specified	Randomized Postoperative alignment measured by standing radiographs Blinded (unclear)	No differences in demographics between the two groups reported (values not shown) Preoperative mechanical axis: CA: 174.7° ±7.9° / Conv.: 174.8° ±7.4° (not statistically significant) Preoperative knee score: 42 (both groups) Knee function: 54 (both groups)	Evaluation at 6 months (number of patients available ?) Mechanical axis CA: 179.5° ±2.5° / Conv.:179° ±3° p=0.04 for variability Femoral component alignment within ±3°: CA: 96% / Conv.: 83% P=0.0006 Tibial component alignment within ±3°: CA: 84% / Conv.: 80% Knee score: CA: 84 / Conv.: 79 (p=0.12) Knee function: CA: 84 / Conv.: 84 (not statistically significant) SF-36 – preoperative values not shown SF-36 Global score: superior for CA (p=0.002) SF-36 scores were higher for CA compared to Conv. across most categories (statistically significant?)	-	-
Information provided by Orthosoft[66] Navitrack® (n=40) / Conventional (n=51) Evaluation performed at 6 weeks	Randomized Postoperative alignment measured by long-leg standing radiographs Performed by independent observer Blinded	Mechanical axis: Subvastus approach: CA: 174.7° ±7.2°/ Conv.: 176.7° ±9.3° Patella eversion approach: CA: 175.5° ±8.1° / Conv.: 173.9° ± 5.9° No demographic information provided	Mechanical axis Subvastus approach: CA: 178.7° ±2.6 / Conv: 179.3° 0±3.3 (p=0.004 F-test) Patella eversion approach: CA: 180.1° ±2.2 / Conv: 179.4° ±2.8	-	-

BMI : body mass index / CT=computer tomography / min.= minutes / SD=standard deviation

* One case where the position fell outside the 3° range – the investigators believe that it was due to either the anatomic registration was not performed accurately or that one of the trackers moved

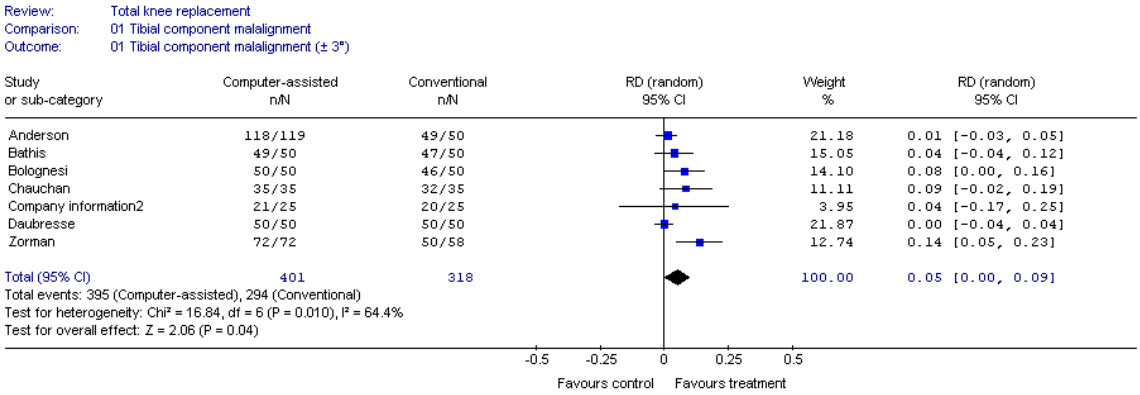
CA= computer-assisted / CI= confidence interval / Conv=conventional / intram.=intramedullary / extram.= extramedullary / HKA= hip knee angle / NA= not available / NS=not statistically significant / RA=rheumatoid arthritis

APPENDIX 2 – POOLED ANALYSES OF POSTOPERATIVE ALIGNMENT

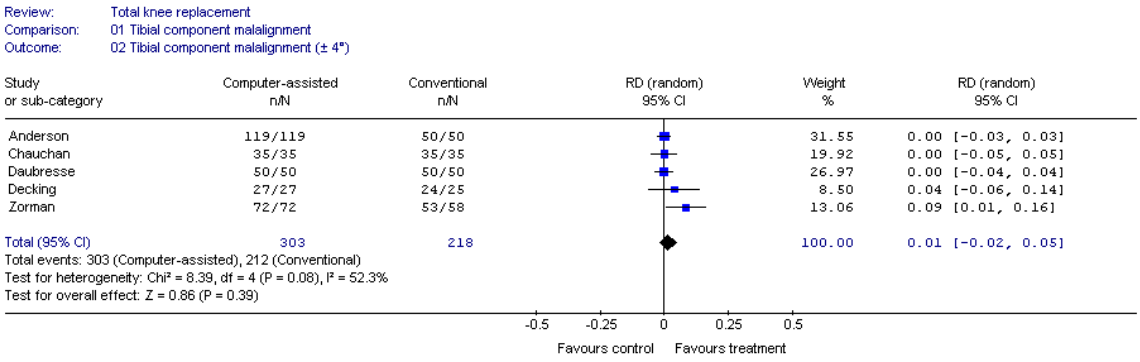
Some of the numbers used in the pooled analyses constitute an approximation of the actual number as the information sometimes had to be derived from graphs.

Tibial component (all studies)

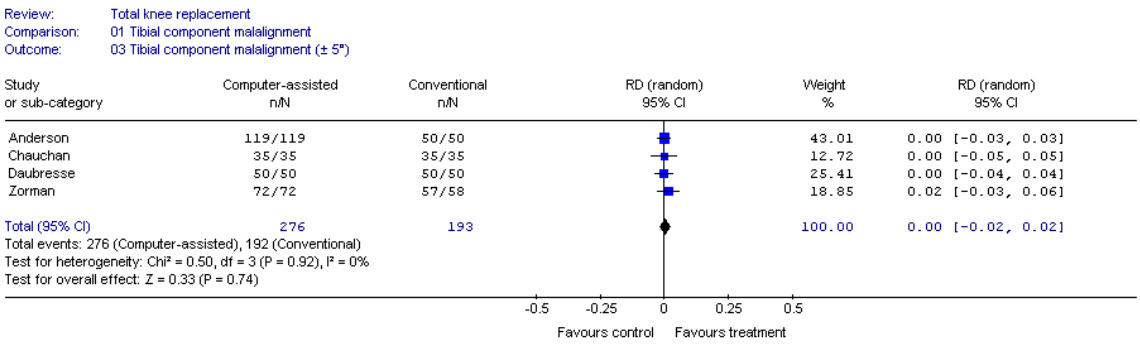
Within ±3°



Within ±4°

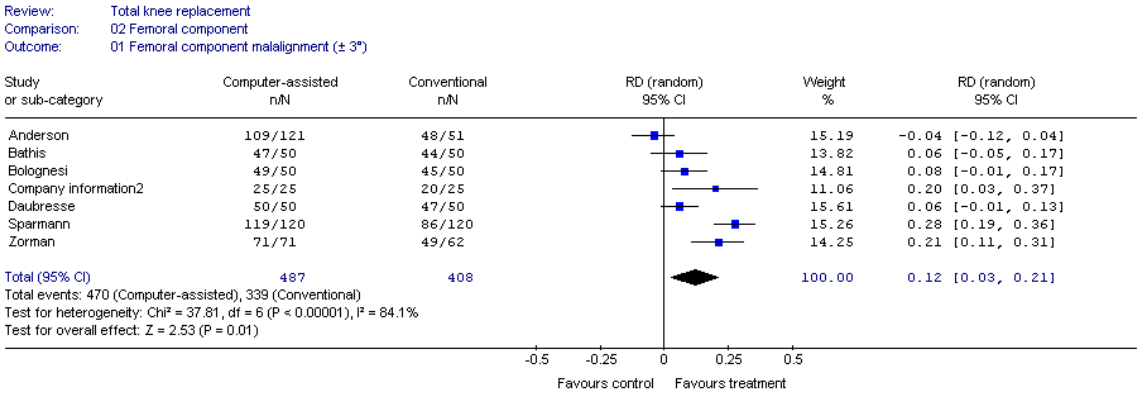


Within ±5°

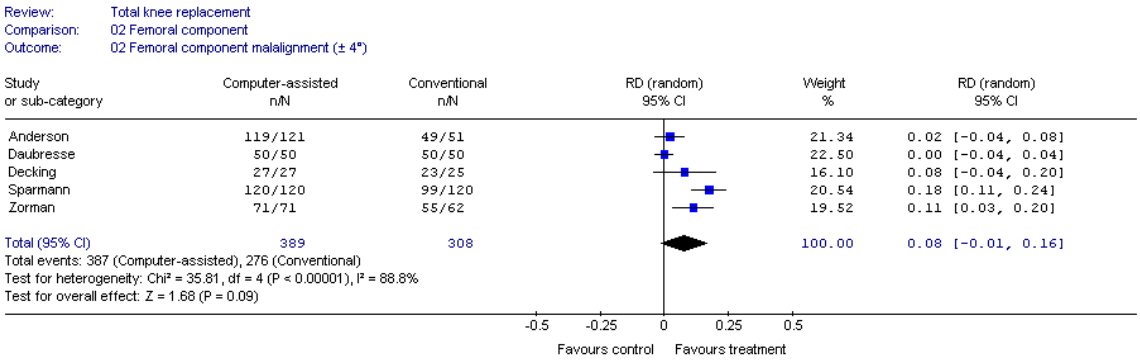


Femoral component (all studies)

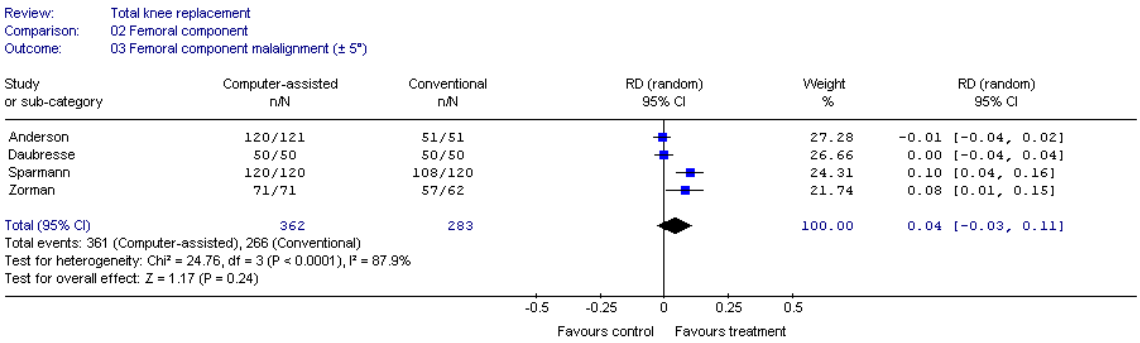
Within ±3°



Within ±4°

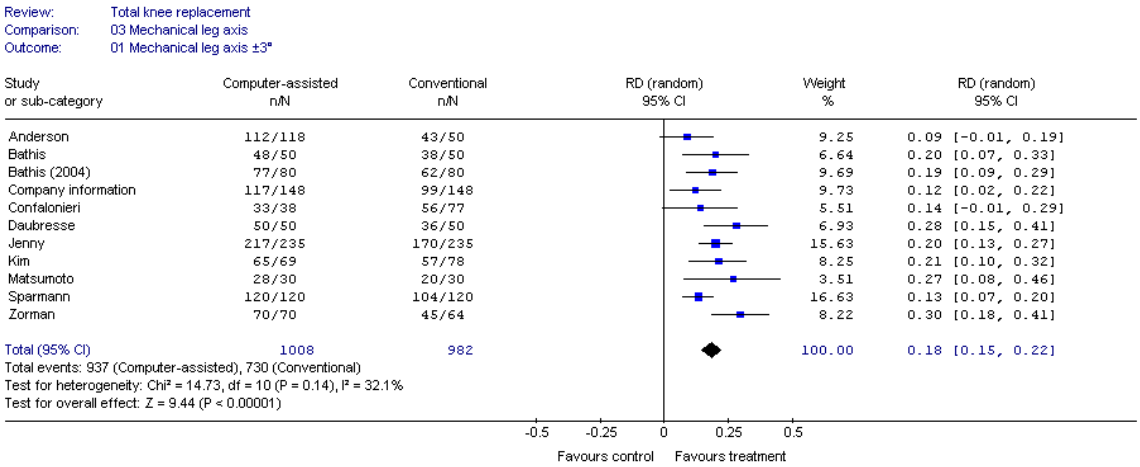


Within ±5°

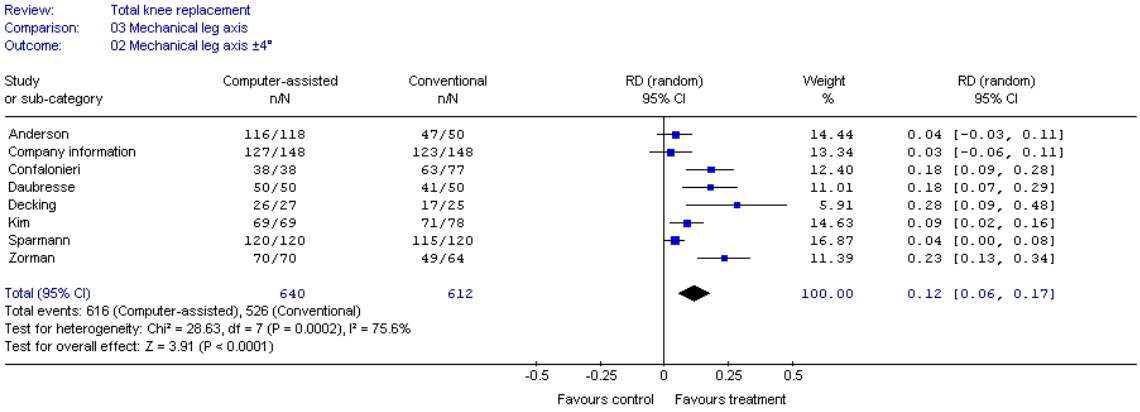


Mechanical leg axis alignment (all studies)

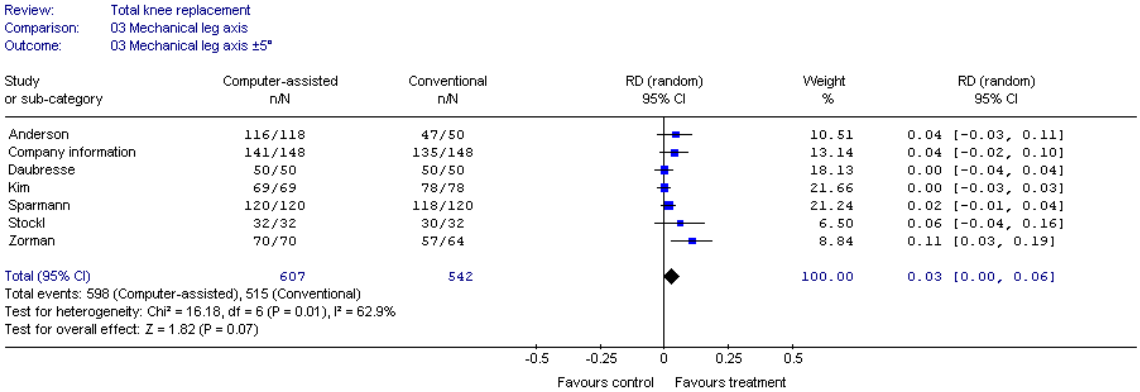
Within ±3°



Within ±4°

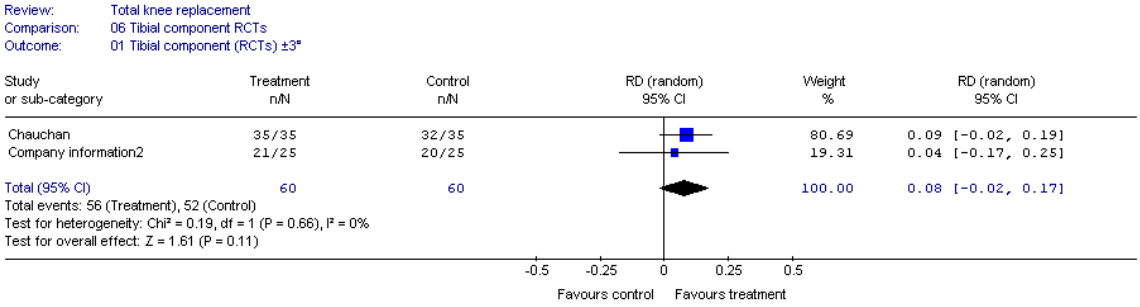


Within ±5°

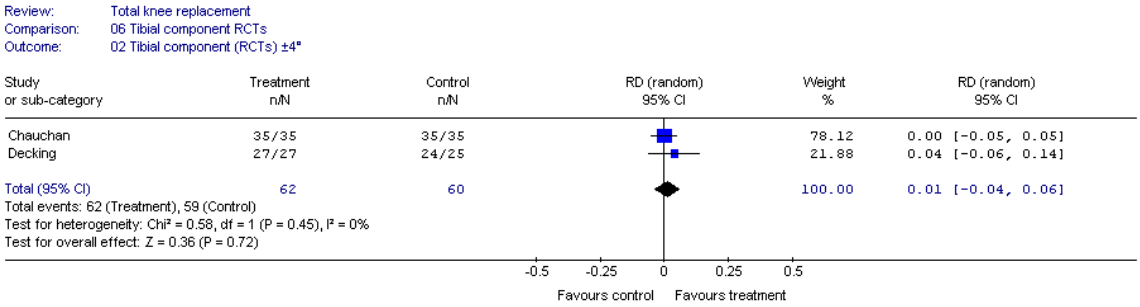


Tibial component (RCTs)

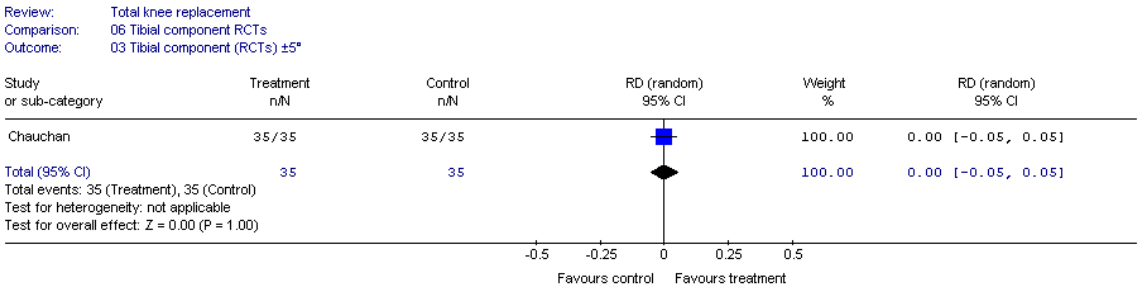
Within ±3°



Within ±4°

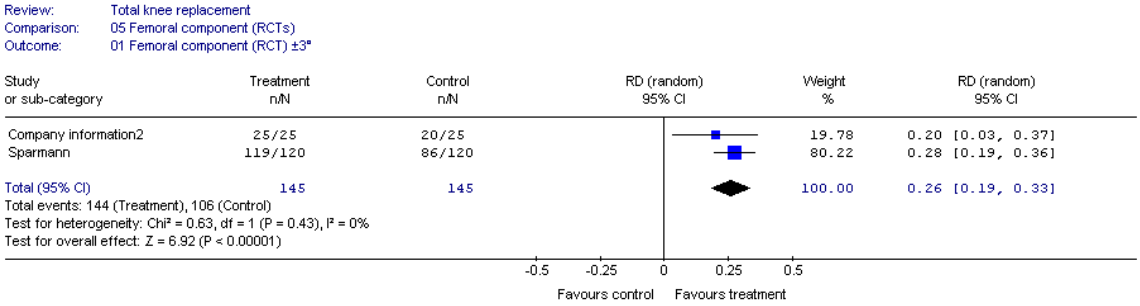


Within ±5°

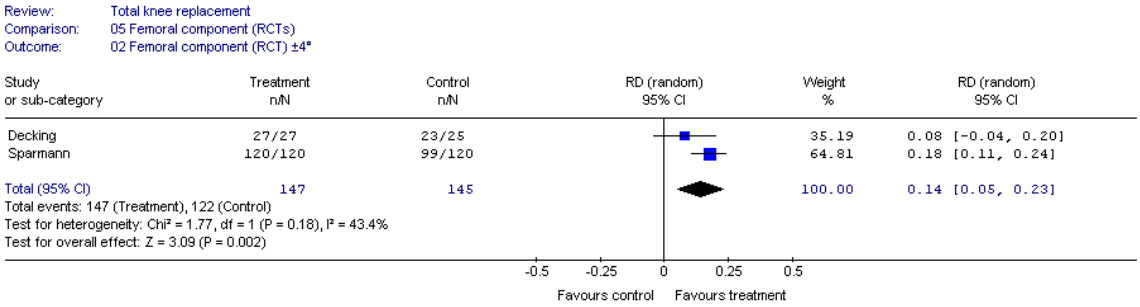


Femoral component (RCTs)

Within ±3°



Within ±4°

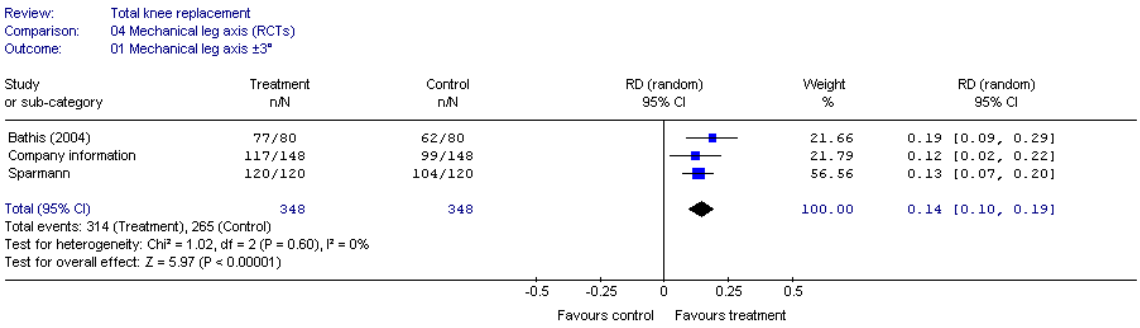


Within ±5°

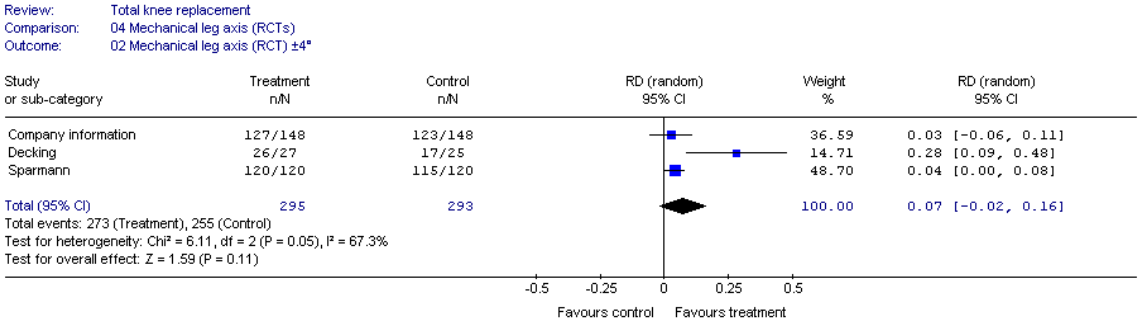
Not possible due to lack of RCTs reporting this outcome.

Mechanical leg axis alignment (RCTs)

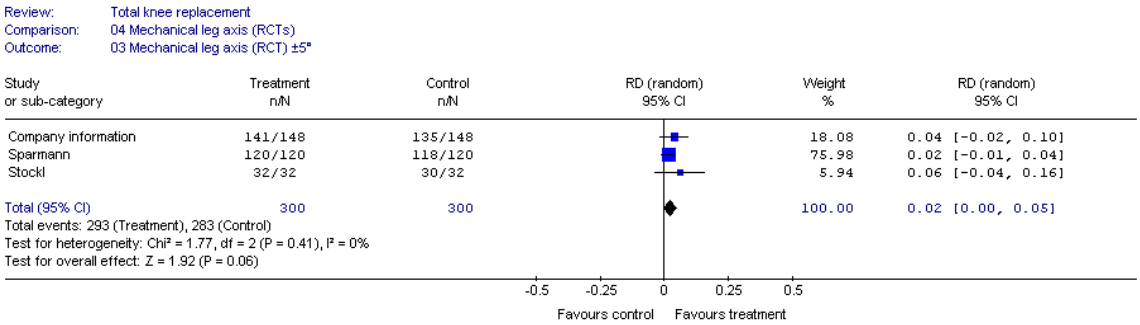
Within ±3°



Within ±4°



Within ±5°



REFERENCES

1. Sharkey PF, Hozack WJ, Rothman RH, Shastri S, Jacoby SM. Award paper. Why are total knee arthroplasties failing today? Clin Orthop Relat Res 2002; 7-13.

2. Foo L., Samuel M., Yeo SJ. Computer assisted knee arthroplasty for osteoarthritis and other non-traumatic diseases (Protocol). Cochrane Database of Systematic Reviews 2005; 4:Art. No.: CD005524. DOI: 10.1002/146512858.CD005524

3. Anonymous. NIH Consensus Statement on total knee replacement December 8-10, 2003. J Bone Joint Surg Am 2004; 86-A:1328-35.

4. Canadian Joint Replacement Registry (CJRR) - Canadian Institute for Health Information (CIHI). 2005 Report - Total hip and total knee replacements in Canada.

5. Fehring TK, Odum S, Griffin WL, Mason JB, Nadaud M. Early failures in total knee arthroplasty. Clin Orthop Relat Res 2001; 315-8.

6. Goldberg VM, Kraay M. The outcome of the cementless tibial component: a minimum 14-year clinical evaluation. Clin Orthop Relat Res 2004; 214-20.

7. Zihlmann MS, Stacoff A, Romero J, Quervain IK, Stussi E. Biomechanical background and clinical observations of rotational malalignment in TKA: literature review and consequences. Clin Biomech (Bristol, Avon) 2005; 20:661-8.

8. Graves SE, Davidson D, Ingerson L, Ryan P, Griffith EC, McDermott BF, et al. The Australian Orthopaedic Association National Joint Replacement Registry. Med J Aust 2004; 180:S31-4.

9. Werner FW, Ayers DC, Maletsky LP, Rullkoetter PJ. The effect of valgus/varus malalignment on load distribution in total knee replacements. J Biomech 2005; 38:349-55.

10. Dorr LD, Boiardo RA. Technical considerations in total knee arthroplasty. Clin Orthop Relat Res 1986; 5-11.

11. Insall JN, Binazzi R, Soudry M, Mestriner LA. Total knee arthroplasty. Clin Orthop Relat Res 1985; 13-22.

12. Bathis H, Perlick L, Tingart M, Luring C, Perlick C, Grifka J. Radiological results of image-based and non-image-based computer-assisted total knee arthroplasty. Int Orthop 2004; 28:87-90.

13. Jeffery RS, Morris RW, Denham RA. Coronal alignment after total knee replacement. J Bone Joint Surg Br 1991; 73:709-14.

14. Brady OH., Masri BA., Garbuz DS., Duncan CP. Rheumatology: 10. Joint replacement of the hip and knee - when to refer and what to expect.

15. Rinonapoli E, Mancini GB, Azzara A, Aglietti P. Long-term results and survivorship analysis of 89 total condylar knee prostheses. J Arthroplasty 1992; 7:241-6.

16. Perlick L, Bathis H, Perlick C, Luring C, Tingart M, Grifka J. Revision total knee arthroplasty: a comparison of postoperative leg alignment after computer-

assisted implantation versus the conventional technique. Knee Surg Sports Traumatol Arthrosc 2005; 13:167-73.

17. Ma HM, Lu YC, Ho FY, Huang CH. Long-term results of total condylar knee arthroplasty. J Arthroplasty 2005; 20:580-4.

18. Berend ME, Ritter MA, Meding JB, Faris PM, Keating EM, Redelman R, et al. Tibial component failure mechanisms in total knee arthroplasty. Clin Orthop Relat Res 2004; 26-34.

19. Stulberg SD, Loan P, Sarin V. Computer-assisted navigation in total knee replacement: results of an initial experience in thirty-five patients. J Bone Joint Surg Am 2002; 84-A Suppl 2:90-8.

20. Insall JN, Scuderi GR, Komistek RD, Math K, Dennis DA, Anderson DT. Correlation between condylar lift-off and femoral component alignment. Clin Orthop Relat Res 2002; 143-52.

21. Bolognesi M, Hofmann A. Computer navigation versus standard instrumentation for TKA: a single-surgeon experience. Clin Orthop Relat Res 2005; 440:162-9.

22. Bathis H, Perlick L, Tingart M, Luring C, Grifka J. CT-free computer-assisted total knee arthroplasty versus the conventional technique: radiographic results of 100 cases. Orthopedics 2004; 27:476-80.

23. Chauhan SK, Scott RG, Breidahl W, Beaver RJ. Computer-assisted knee arthroplasty versus a conventional jig-based technique. A randomised, prospective trial. J Bone Joint Surg Br 2004; 86:372-7.

24. Jonsson B, Astrom J. Alignment and long-term clinical results of a semiconstrained knee prosthesis. Clin Orthop Relat Res 1988; 124-8.

25. Bargren JH, Blaha JD, Freeman MA. Alignment in total knee arthroplasty. Correlated biomechanical and clinical observations. Clin Orthop Relat Res 1983; 178-83.

26. Ito J, Koshino T, Okamoto R, Saito T. 15-year follow-up study of total knee arthroplasty in patients with rheumatoid arthritis. J Arthroplasty 2003; 18:984-92.

27. Tew M, Waugh W. Tibiofemoral alignment and the results of knee replacement. J Bone Joint Surg Br 1985; 67:551-6.

28. Ritter MA, Faris PM, Keating EM, Meding JB. Postoperative alignment of total knee replacement. Its effect on survival. Clin Orthop Relat Res 1994; 153-6.

29. Rand JA, Coventry MB. Ten-year evaluation of geometric total knee arthroplasty. Clin Orthop Relat Res 1988; 168-73.

30. Laskin RS. Total condylar knee replacement in patients who have rheumatoid arthritis. A ten-year follow-up study. J Bone Joint Surg Am 1990; 72:529-35.

31. Ritter MA, Herbst SA, Keating EM, Faris PM. Radiolucency at the bone-cement interface in total knee replacement. The effects of bone-surface preparation and cement technique. J Bone Joint Surg Am 1994; 76:60-5.

32. Moreland JR. Mechanisms of failure in total knee arthroplasty. Clin Orthop Relat Res

1988; 49-64.

33. Stern SH, Insall JN. Posterior stabilized prosthesis. Results after follow-up of nine to twelve years. J Bone Joint Surg Am 1992; 74:980-6.

34. Piazza SJ, Delp SL, Stulberg SD, Stern SH. Posterior tilting of the tibial component decreases femoral rollback in posterior-substituting knee replacement: a computer simulation study. J Orthop Res 1998; 16:264-70.

35. Windsor RE, Scuderi GR, Moran MC, Insall JN. Mechanisms of failure of the femoral and tibial components in total knee arthroplasty. Clin Orthop Relat Res 1989; 15-9; discussion 19-20.

36. Wasielewski RC, Galante JO, Leighty RM, Natarajan RN, Rosenberg AG. Wear patterns on retrieved polyethylene tibial inserts and their relationship to technical considerations during total knee arthroplasty. Clin Orthop Relat Res 1994; 31-43.

37. Hungerford DS, Krackow KA. Total joint arthroplasty of the knee. Clin Orthop Relat Res 1985; 23-33.

38. Archibeck MJ, White RE Jr. What's new in adult reconstructive knee surgery. J Bone Joint Surg Am 2004; 86-A:1839-49.

39. Ecker ML, Lotke PA, Windsor RE, Cella JP. Long-term results after total condylar knee arthroplasty. Significance of radiolucent lines. Clin Orthop Relat Res 1987; 151-8.

40. Lotke PA, Ecker ML. Influence of positioning of prosthesis in total knee replacement. J Bone Joint Surg Am 1977; 59:77-9.

41. Nizard RS, Porcher R, Ravaud P, Vangaver E, Hannouche D, Bizot P, et al. Use of the Cusum technique for evaluation of a CT-based navigation system for total knee replacement. Clin Orthop Relat Res 2004; 180-8.

42. Garg A, Walker PS. Prediction of total knee motion using a three-dimensional computer-graphics model. J Biomech 1990; 23:45-58.

43. Feng EL, Stulberg SD, Wixson RL. Progressive subluxation and polyethylene wear in total knee replacements with flat articular surfaces. Clin Orthop Relat Res 1994; 60-71.

44. Hvid I, Nielsen S. Total condylar knee arthroplasty. Prosthetic component positioning and radiolucent lines. Acta Orthop Scand 1984; 55:160-5.

45. Nizard R. Computer assisted surgery for total knee arthroplasty. Acta Orthop Belg 2002; 68:215-30.

46. Mihalko WA., Krackow KA. Differences between extramedullary, intramedullary, and computer-aided surgery tibial alignment techniques for total knee arthroplasty. J. Knee Surg. 2006; 19:33-36.

47. Gidwani S, Fairbank A. The orthopaedic approach to managing osteoarthritis of the knee. BMJ 2004; 329:1220-4.

48. Krackow KA, Phillips MJ, Bayers-Thering M, Serpe L, Mihalko WM. Computer-assisted total knee arthroplasty: navigation in TKA. Orthopedics 2003; 26:1017-23.

49. Zorman D, Etuin P, Jennart H, Scipioni D, Devos S. Computer-assisted total knee arthroplasty: comparative results in a preliminary series of 72 cases. Acta Orthop Belg 2005; 71:696-702.

50. Stulberg BN, Zadzilka JD. Computer-assisted surgery: a wine before its time: in opposition. J Arthroplasty 2006; 21:29-32.

51. Health Canada - Medical Devices Licence Listing. NAVITRACK SYSTEM-TOTAL KNEE REPLACEMENT CT-LESS . http://cpe0013211b4c6d-cm0014e88ee7a4.cpe.net.cable.rogers.com/mdall/english/Device.cfm?ID=112526&DeviceName=NAVITRACK%20SYSTEM%20%2D%20TOTAL%20KNEE%20REPLACEMENT%20CT%2DLESS . Last access: October 23rd 2006

52. Food and Drug Administration (FDA). 510(K) - Summary of Safety and Effectiveness. Navitrack TM System. Optical TKR CT-Less. http://www.fda.gov/cdrh/pdf2/k021760.pdf 2002;

53. Macule-Beneyto F, Hernandez-Vaquero D, Segur-Vilalta JM, Colomina-Rodriguez R, Hinarejos-Gomez P, Garcia-Forcada I, et al. Navigation in total knee arthroplasty. A multicenter study. Int Orthop 2006;

54. Decking R, Markmann Y, Fuchs J, Puhl W, Scharf HP. Leg axis after computer-navigated total knee arthroplasty: a prospective randomized trial comparing computer-navigated and manual implantation. J Arthroplasty 2005; 20:282-8.

55. Haaker RG, Stockheim M, Kamp M, Proff G, Breitenfelder J, Ottersbach A. Computer-assisted navigation increases precision of component placement in total knee arthroplasty. Clin Orthop Relat Res 2005; 152-9.

56. Matsumoto T, Tsumura N, Kurosaka M, Muratsu H, Kuroda R, Ishimoto K, et al. Prosthetic alignment and sizing in computer-assisted total knee arthroplasty. Int Orthop 2004; 28:282-5.

57. Confalonieri N, Manzotti A, Pullen C, Ragone V. Computer-assisted technique versus intramedullary and extramedullary alignment systems in total knee replacement: a radiological comparison. Acta Orthop Belg 2005; 71:703-9.

58. Bathis H, Perlick L, Tingart M, Luring C, Zurakowski D, Grifka J. Alignment in total knee arthroplasty. A comparison of computer-assisted surgery with the conventional technique. J Bone Joint Surg Br 2004; 86:682-7.

59. Chin PL, Yang KY, Yeo SJ, Lo NN. Randomized control trial comparing radiographic total knee arthroplasty implant placement using computer navigation versus conventional technique. J Arthroplasty 2005; 20:618-26.

60. Daubresse F, Vajeu C, Loquet J. Total knee arthroplasty with conventional or navigated technique: comparison of the learning curves in a community hospital. Acta Orthop Belg 2005; 71:710-3.

61. Stockl B, Nogler M, Rosiek R, Fischer M, Krismer M, Kessler O. Navigation improves accuracy of rotational alignment in total knee arthroplasty. Clin Orthop Relat Res 2004; 180-6.

62. Jenny JY, Clemens U, Kohler S, Kiefer H, Konermann W, Miehlke RK. Consistency of implantation of a total knee arthroplasty with a non-image-based navigation system: a case-control study of 235 cases compared with 235 conventionally implanted prostheses. J Arthroplasty 2005; 20:832-9.

63. Kim SJ, MacDonald M, Hernandez J, Wixson RL. Computer assisted navigation in total knee arthroplasty: improved coronal alignment. J Arthroplasty 2005; 20:123-31.

64. Clemens U, Miehlke RK. Experience using the latest OrthoPilot TKA software: a comparative study. Surg Technol Int 2003; 11:265-73.

65. Information provided by Orthosoft (unpublished). TKA Navigation with the Navitrack Imageless System. A simple and efficient instrumento to optimize knee alignment.

66. Information provided by Orthosoft (unpublished). Combining knee navigation with 2 different subvastus surgical approaches: A Prospective, randomized and comparative study.

67. Medical Advisory Secretariat - Ontario Ministry of Health and Long-Term Care. Computer-assisted hip and knee arthroplasty: navigation and active robotic systems. February 2004

68. Ontario Health Technology Advisory Committee (OHTAC). OHTAC Recommendation: Computer assisted hip and knee arthroplasty: navigation and robotic systems. March 24th 2004

69. Luring C, Bathis H, Tingart M, Perlick L, Grifka J. Computer assistance in total knee replacement - a critical assessment of current health care technology. Comput Aided Surg 2006; 11:77-80.

70. Dong H, Buxton M. Early assessment of the likely cost-effectiveness of a new technology: A Markov model with probabilistic sensitivity analysis of computer-assisted total knee replacement. Int J Technol Assess Health Care 2006; 22:191-202.

71. Weinrauch P, Myers N, Wilkinson M, Dodsworth J, Fitzpatrick P, Whitehouse S. Comparison of early postoperative rehabilitation outcome following total knee arthroplasty using different surgical approaches and instrumentation. J Orthop Surg (Hong Kong) 2006; 14:47-52.

72. Kalairajah Y, Simpson D, Cossey AJ, Verrall GM, Spriggins AJ. Blood loss after total knee replacement: effects of computer-assisted surgery. J Bone Joint Surg Br 2005; 87:1480-2.

73. Kalairajah Y, Cossey AJ, Verrall GM, Ludbrook G, Spriggins AJ. Are systemic emboli reduced in computer-assisted knee surgery?: A prospective, randomised, clinical trial. J Bone Joint Surg Br 2006; 88:198-202.

74. Callaghan JJ, Liu SS, Warth LC. Computer-assisted surgery: a wine before its time: in the affirmative. J Arthroplasty 2006; 21:27-8.