Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jor

Editorial

Navigation in TKA surgery – Evolutionary technique or blind alley?

1. Introduction

Navigation as part of CAS (Computer Assisted Surgery) has been introduced into TKA more than 10 years ago. After the first experiences and its proven superiority in reconstituting mechanical leg axis it has lost its popularity over the last years. This was mainly because CAS adds time and definitely cost to surgery. Furthermore a lot of studies failed to show an improved clinical outcome of navigated knees. In the last years, some gap-balanced studies were able to demonstrate such an improvement when CAS was applied. This demonstrates that information about gap size in different knee flexion angles is of importance to the procedure of CAS.

Two different evolutionary directions can be observed in the technique of CAS over the last years. On the one hand, a trend to a simpler and faster technique for those surgeons that are focussed on information about their bone cuts solely. For those CAS can be pin-free or applied with a more modern tool, like the I-Pad.

Another direction of CAS is applicable for the surgeons using a tibia-first, gap-balancing technique. For those the more recent software is able to monitor the influence of specific surgical steps on gap-size throughout the entire surgery. With a dynamic analysis under ligament stress a more realistic simulation of the daily loads on soft tissue has been implemented. This information can be used for sequential release and so the effect of every release-step on the gaps can be quantified. It can also be used for specific surgical techniques, such as the sliding osteotomy of lateral or medial epicondyles in fixed valgus or varus deformities.

Another field of CAS is revision TKA. Like in primary TKA, it can be used to place the components more precisely than with conventional instruments. The same pin-free, faster techniques of TKA can be applied in revisions, too. This can help to overcome the problem of pin fixation in the presence of long stems.

This article wants to give an overview on the different options of computer assisted surgery in TKA and R-TKA. By summarizing the results of the literature, its benefits and its limitations are demonstrated. By showing new applications and improvements of standard CAS techniques, this article

wants to show the evolution of this technique. If those newer techniques will help to improve the clinical outcome and increase its daily feasibility and by that help to increase the acceptance of CAS in daily practice cannot be shown today.

2. First years of experience with CAS

At the beginning of this century Computer Assisted Surgery (CAS) was introduced in the operating theatres of Orthopaedic surgery. Very early on TKA became one of the major fields for CAS. While being a CT based technique in the first few years, a CT-free technique has been the standard for the last ten years.

At that time the main focus of CAS users was to obtain precise information regarding the precision of bone cuts. Based on this information, the positioning of the implant in all planes improved compared to conventional surgical techniques. Hetaimish et al (2012)¹ for example could show in their meta-analysis of 23 studies that with the help of CAS the risk of malalignment (more than 3°) could be significantly reduced from 30% to less than 10%. In another meta-analysis of Brin et al (2010)² the results were better for both techniques (18% outliers conventional technique compared to 3% with CAS), however, the significant difference between techniques remained the same.

Beside improved alignment and implant positioning, additional advantages like reduced blood loss were reported. In different studies the amount of blood loss reduction varied between 14% and 44%.^{3–6} The reason for this benefit was seen in the fact that an opening of the femoral medullary canal was not necessary.

Another advantage of navigation in daily practice is that it can be used with all different surgical techniques in TKA surgery, either measured resection or gap balanced.

However, small adaptations are needed, for example pins for placement of the reflectors need to be placed inside or outside the surgical approach. In rare cases those pins can be a potential source for infection or fracture, so that this can be stated as a disadvantage. Another disadvantage is the fact that those small alterations, like pin placement or palpation of anatomical landmarks add time to the surgical procedure,⁷ in particular at the beginning of the learning curve and with

older CAS machines. Due to this time effort a lot of surgeons used the technique not as their standard technique but for difficult cases only. And that made its application even more difficult. Speaking from our experience after more than 2000 CAS TKA's we can state that after a learning curve of around 3–4 months, or 50–80 cases, procedure time does not differ between CAS and the conventional surgical technique. Of course, time consuming steps like obtaining the anatomical landmarks, planning of the femoral component position are added. On the other hand, opening of the femoral canal and placement of the intramedullary rod is not needed and the positioning of all cutting blocks is less time consuming.

In the beginning of CAS, no overall improvement of the functional outcome of TKA was reported.¹⁰ This was caused by the fact that most of the early users applied the technique for alignment only^{7–9} and most of the data for these studies was obtained at the beginning of the learning process. In most of those studies CAS was used only for the bone cuts and not for soft tissue balancing. So the finding of non-superiority was not surprising, since alignment is only a small factor on the long way to a good clinical and functional result in TKA. Some more recent papers, all with gap-balanced technique, show significant improvement in functional knee score and a reduced number of outliers.^{11–14,17} Schnurr et al (2012)¹⁵ describe a reduced revision rate as another positive effect of CAS. However, until now no clear evidence regarding a clinical superiority of CAS compared to conventional technique can be stated.

A major problem of CAS is costs. In addition to hard ware costs daily costs for reflectors have to be mentioned. In Germany those reflectors cost at least 30–70 € per procedure. In some countries these additional costs can be transferred to the patient, in others not. And further costs for software updates have to be taken into account.

3. New developments of the last years

3.1. Alignment

Since a great number of surgeons perform their surgeries bone referenced (measured resection), their main focus is on correct bone cuts. For this group of surgeons the information on gaps, that the CAS machine can provide, isn't necessary, pinning and palpation of anatomical landmarks superfluous and time consuming. Based on the demand of measured resection a pin-free navigation technique was developed and recently introduced. With this technique the number of additional steps is minimized and the additional time effort reduced to around 15 s for the tibia and 20–30 s for the femur. Information on the varus/valgus angle, the tibial slope, the femoral flexion angle and the resection height is visualized (Fig. 1).

This technique can be used for standard bicondylar TKA as well as for Uni's and in TKA revisions. In addition to control of the correct cutting block position, a verification of the performed bone cuts can be done. This is a big advantage compared to other surgical techniques like patient specific instrumentation (PSI), in which the difference between planned cut and performed cut cannot be verified. The first publications concerning this technique^{16,17} demonstrate that it provides correct implant position and reduces surgical time. Chen et al therefore recommend using this technique also in conventional surgery as an additional tool to increase precision.

Similar developments of newer CAS systems for bone cuts are the IPod navigation and the iAssist system. Both techniques provide information regarding the varus/valgus angle, the tibial slope, the femoral flexion angle and the resection height. Again, no information regarding the gaps is provided.

Fig. 1 – Monitor screen after obtaining 4 anatomical points in pin-free navigation.

Until now there are no publications regarding results, advantages or disadvantages of these techniques.

3.2. New techniques for ligament balancing

For the group of ‘gap-balanced surgeons’ navigation gives a lot of additional information, such as the width of medial and lateral gap throughout the range of motion and implant position compared to the jointline. In gap-balanced techniques the femoral implant position is based on the difference of the medial and lateral gap in flexion. To measure those gaps in navigation the ligaments are put under tension with different systems of mechanical tensioners. The amount of tension is influenced by the contracture of soft tissue and osteophytes, therefore a release of the soft tissue and removal of the osteophytes needs to be performed before gap measurement is done. Another factor which has a major impact on the width of the flexion gaps (medial and lateral) is the weight of the femur. Since the springs of those tensioners often have only limited forces the weight of the femur can be higher than the maximum force and in consequence untruly small gaps are displayed. Different tensioner systems show different results although the ratio between the medial and lateral gap in flexion is not altered between most of the systems. However, the surgeon needs to know the limits of the tensioners he uses. In newer software versions this problem is solved by introducing a tibia trial and the smallest trial insert. In this approach the rigid implant cannot be compressed and thereby no untruly small values can be shown.

A big advantage of newer CAS systems is that gap information is not only provided during passive motion but also under ligament tension obtained by varus/valgus stress testing. Based on those stress tests the situation of ligaments during daily activities is more realistically simulated. This testing needs to be performed at the beginning of surgery to understand the type of deformity (varus/valgus; FFD/hyperextension) and the amount of release that is needed to correct the imbalance. Every step of release can be monitored objectively by stress testings (Fig. 2). By that an overrelease can be avoided.

After balancing the knee in extension the information on medial and lateral gap-width in extension and flexion is visualized and a suggestion for femoral component size and position is made by the computer. However, careful deliberation on this suggestion is necessary. For example a slight flexion of 3° around the anterior cortex point should be made. This recommendation is based on the difference between the sagittal femoral axis of CAS and the intramedullary position of non-navigated knees. By flexing the femoral component 3° this difference is almost equalled. However, it needs to be kept in mind that a distal cut in more flexion leads to a decrease of the flexion gap. Recent studies have shown that 1° of flexion is around 1–1.5 mm decrease of flexion gap.^{18,19} This correlation is shown in Fig. 3.

Before placing the 4 in 1 block, again the gaps are visualized and the influence of rotation on the ratio between medial and lateral gap-width is shown. By changing the block position the size of the flexion and extension gap on the medial and lateral flexion gap can be altered and finally equal gap size should be reached. Although the technique is gap-balanced it is recommended to control the position of the cutting block related to the anatomical landmarks like epicondylar axis, posterior condyles and Whiteside's line.²⁰

Finally the stress testing is performed again after all bone cuts are executed and the trial implant is positioned. At that point, normally, all gaps should show values between 1 and 3 mm. Until now it is unclear what the optimal gap size for an individual is and whether its value changes interindividually. Maybe in an older patient with a looser knee a larger gap size is more appropriate than in a tall strong man with very tight ligaments?

After performing all these steps a protocol is printed. In this protocol the pre- and post-OP axis as well as ROM and the post-OP stability is shown (Fig. 4). This protocol can serve as additional information for the patient and can be used later on as an official document that proves quality of the procedure.

Although Schnurr et al. 2012 have shown that with a gap-balanced, navigated technique the revision rate can be reduced and the clinical outcome can be improved, future studies are needed to prove the benefit of this new CAS technique.

Fig. 2 – Gap sizes (yellow lines) during entire range of motion under stress test. On the left side of the image the femoral component and its position is shown. Every change of implant position will influence the gaps.

Fig. 3 – Influence of femoral component flexion on flexion gap size. The left image shows 0° of flexion and a flexion gap of 18.5 and 15.5 mm. Flexion of 7.5° reduces the flexion gap to 13 and 10 mm. The difference between medial and lateral flexion gap is later corrected by the rotational position of the femoral component.

4. New applications of CAS

4.1. New surgical techniques

With the use of CAS the different releasing steps can be objectively quantified. Based on this fact, previously established surgical techniques, such as the sliding osteotomy of the medial or lateral condyle can be improved. The sliding osteotomy was introduced by Brihault et al (2002)²¹ with a

conventional lateral parapatellar approach. By sliding the lateral condyle distally the extension gap can be increased. This is used to balance fixed valgus deformities that have a valgus in extension only. In cases where an additional valgus in flexion is present an isolated slide in distal direction is not sufficient; an additional slide to posterior needs to be performed. The main problem of the non-navigated sliding osteotomy is that the sliding distance can only be determined after the osteotomy has been performed. However in small knees with a large deformity sometimes the sliding distance exceeds the anatomical limits (e.g. insertion of the LCL and M. popliteus). Therefore it would be beneficial to know the distance in advance.

In the navigated sliding osteotomy, on the other hand, the sliding distance can be calculated based on the stress tests of the ligaments and their difference. Thereby the distance is known prior to osteotomy. Another benefit of the technique is that no multiple sliding attempts are needed in order to find the perfect distance. Recently our group has published a study on the use of CAS for the sliding osteotomy in fixed valgus deformities.²²

The osteotomy is performed parallel to the lateral cortex of the femur. The piece of bone should be at least 0.5 cm thick. A release of all proximal structures is needed in order to slide the lateral condyle distally. By sliding the piece of bone only in distal direction and not in anterior/posterior direction only the extension gap is addressed, while gap size of the flexion gap remains unaltered. On the medial side the technique is quite similar, however, often a shift in both directions (distal and posterior) is needed because the severe fixed varus deformities are mostly fixed varus in extension and in flexion. Mulaji et al (2013)²³ have described their similar CAS based technique recently.

4.2. CAS in TKA revision

Although CAS has its main focus in primary TKA, since the early days it has also been used in Revision-Total Knee Arthroplasty (R-TKA).^{24,25} A more recent publication described the benefits of CAS in reconstruction of leg axis in the coronal

Fig. 4 – This figure shows a protocol after a TKAr. The leg alignment pre and post-Op, as well as range of motion pre and post-OP and the joint stability at the end of surgery are documented. Joint stability represents the active stress testing curve during entire range of motion.

and sagittal plane.²⁶ Its benefit on ligament balancing and by that on the functional outcome has only been described by Perlick et al so far.

When using CAS in revisions one has to keep in mind that the evaluation of the position of the primary implant and its potential malalignment needs to be analysed before and during revision surgery, otherwise there is a danger of copying the primary mistake. In revision standard CAS systems with pin fixation can be problematic because of the use of stems. Therefore a pin-free navigation just for performing correct bone cuts can be helpful, although no information regarding the gaps can be obtained.

5. Conclusion

CAS was introduced in the beginning of this century in TKA surgery. In the beginning the main focus was on correct and precise bone cuts. Due to increased time effort and costs and the non-superiority in clinical outcome the acceptance decreased over time. In recent years more focus was laid on the information of gap size. In a gap-balanced technique this information is used to balance the knee and position the femoral component in order to achieve equal gaps. Some recent reports have shown very positive effects of this navigation-based gap-balanced technique on clinical outcome. With new software updates dynamic stress tests of the ligaments can be performed throughout the entire range of motion. This next step can help to further improve the dynamic stability of TKA knees and by that hopefully the clinical results and patient satisfaction. However, this needs to be proven in the next years.

The information on gap size can further be used to improve standard surgical techniques. So every release step can be objectively quantified. A special aspect of CAS has been demonstrated in the sliding osteotomy of the lateral condyle. With CAS the information on gap size under stress can help to determine the sliding distance prior to osteotomy.

In conclusion modern CAS techniques are far more than just a help to restore mechanical leg axis. They give a lot of helpful information about the soft tissue envelope of the knee and can therefore be of help to balance the knee throughout the entire range of motion.

REFERENCES

1. Hetaimish BM, Khan MM, Simunovic N, Al-Harbi HH, Bhandari M, Zalzal PK. Meta-analysis of navigation vs conventional total knee arthroplasty. *J Arthroplasty*. 2012 Jun;27:1177–1182.
2. Brin YS, Livshetz I, Antoniou J, Greenberg-Dotan S, Zukor DJ. Precise landmarking in computer assisted total knee arthroplasty is critical to final alignment. *J Orthop Res*. 2010 Oct;28:1355–1359.
3. Conteduca F, Massai F, Iorio R, Zanzotto E, Luzon D, Ferretti A. Blood loss in computer-assisted mobile bearing total knee arthroplasty. A comparison of computer-assisted surgery with a conventional technique. *Int Orthop*. 2009 Dec;33:1609–1613.
4. Schnurr C, Csécsei G, Eysel P, König DP. The effect of computer navigation on blood loss and transfusion rate in TKA. *Orthopedics*. 2010 Jul 13;33:474.
5. Millar NL, Deakin AH, Millar LL, Kinnimonth AW, Picard F. Blood loss following total knee replacement in the morbidly obese: effects of computer navigation. *Knee*. 2011 Mar;18:108–112.
6. Khakha RS, Chowdhry M, Norris M, Kheiran A, Patel N, Chauhan SK. Five-year follow-up of minimally invasive computer assisted total knee arthroplasty (MICATKA) versus conventional computer assisted total knee arthroplasty (CATKA) – a population matched study. *Knee*. 2014 Oct;21:944–948.
7. MacDessi SJ, Jang B, Harris IA, Wheatley E, Bryant C, Chen DB. A comparison of alignment using patient specific guides, computer navigation and conventional instrumentation in total knee arthroplasty. *Knee*. 2014 Mar;21:406–409. <http://dx.doi.org/10.1016/j.knee.2013.11.004>. Epub 2013 Nov 14.
8. Mason JB, Fehring TK, Estok R, Banel D, Fehring K. Meta-analysis of alignment outcomes in computer-assisted total knee arthroplasty surgery. *J Arthroplasty*. 2007 Dec;22:1097–1106.
9. Barrett W, Hoeffel D, Dalury D, Mason JB, Murphy J, Himden S. In-vivo alignment comparing patient specific instrumentation with both conventional and computer assisted surgery (CAS) instrumentation in total knee arthroplasty. *J Arthroplasty*. 2014 Feb;29:343–347.
10. Cheng T, Pan XY, Mao X, Zhang GY, Zhang XL. Little clinical advantage of computer-assisted navigation over conventional instrumentation in primary total knee arthroplasty at early follow-up. *Knee*. 2012 Aug;19:237–245.
11. Blakeney WG, Khan RJ, Palmer JL. Functional outcomes following total knee arthroplasty: a randomised trial comparing computer-assisted surgery with conventional techniques. *Knee*. 2014 Mar;21:364–368.
12. Pang HN, Yeo SJ, Chong HC, Chin PL, Ong J, Lo NN. Computer-assisted gap balancing technique improves outcome in total knee arthroplasty, compared with conventional measured resection technique. *Knee Surg Sports Traumatol Arthrosc*. 2011 Sep;19:1496–1503.
13. Lehen K, Giesinger K, Warschkow R, Porter M, Koch E, Kuster MS. Clinical outcome using a ligament referencing technique in CAS versus conventional technique. *Knee Surg Sports Traumatol Arthrosc*. 2011 Jun;19:887–892.
14. Lützner J, Günther KP, Kirschner S. Functional outcome after computer-assisted versus conventional total knee arthroplasty: a randomized controlled study. *Knee Surg Sports Traumatol Arthrosc*. 2010 Oct;18:1339–1344.
15. Schnurr C, GÜdden I, Eysel P, König DP. Influence of computer navigation on TKA revision rates. *Int Orthop*. 2012 Nov;36:2255–2260.
16. Baier C, Maderbacher G, Springorum HR, et al. No difference in accuracy between pinless and conventional computer-assisted surgery in total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc*. 2014 Aug;22:1819–1826.
17. Chen JY, Chin PL, Tay DK, Chia SL, Lo NN, Yeo SJ. Less outliers in pinless navigation compared with conventional surgery in total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc*. 2014 Aug;22:1827–1832.
18. Matziolis G, Hube R, Perka C, Matziolis D. Increased flexion position of the femoral component reduces the flexion gap in total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc*. 2012 Jun;20:1092–1096.
19. Roßkopf J, Singh PK, Wolf P, Strauch M, Graichen H. Influence of intentional femoral component flexion in navigated TKA on gap balance and sagittal anatomy. *Knee Surg Sports Traumatol Arthrosc*. 2014 Mar;22:687–693.

20. Hube R, Mayr HO, Kalteis T, Matziolis G. Extension first technique for TKA implantation. *Oper Orthop Traumatol*. 2011 Jul;23:241–248.
21. Brilhault J, Lautman S, Favard L, Burdin P. Lateral femoral sliding osteotomy lateral release in total knee arthroplasty for a fixed valgus deformity. *J Bone Joint Surg Br*. 2002 Nov;84:1131–1137.
22. Strauch M, von Eisenhart Rothe R, Graichen H. A new navigation-based technique for lateral distalizing condylar osteotomy in patients undergoing total knee arthroplasty with fixed valgus deformity. *Knee Surg Sports Traumatol Arthrosc*. 2013 Oct;21:2263–2270.
23. Mullaji AB, Shetty GM. Surgical technique: computer-assisted sliding medial condylar osteotomy to achieve gap balance in varus knees during TKA. *Clin Orthop Relat Res*. 2013 May;471:1484–1491.
24. Perlick L, Lüring C, Tingart M, Grifka J, Bähis H. Revision prosthetic of the knee joint. The influence of a navigation system on the alignment and reconstruction of the joint line. *Orthopade*. 2006 Oct;35:1080–1086.
25. Thielemann FW, Clemens U, Hadjicostas PT. Computer-assisted surgery in revision total knee arthroplasty: early experience with 46 patients. *Orthopedics*. 2007 Oct;30(10 suppl):S132–S135.
26. Meijer MF, Stevens M, Boerboom AL, Bulstra SK, Reininga IH. The influence of computer-assisted surgery on rotational, coronal and sagittal alignment in revision total knee arthroplasty. *BMC Musculoskelet Disord*. 2014 Mar 19;15:94.

Heiko Graichen*

Department for Arthroplasty, Orthopaedic Hospital Lindenlohe,
92421 Schwandorf, Germany

*Asklepios Orthopädische Klinik Lindenlohe, Lindenlohe 18,
92421 Schwandorf, Germany.

E-mail address: h.graichen@asklepios.com

<http://dx.doi.org/10.1016/j.jor.2015.02.006>

0972-978X/Copyright © 2015, Professor P K Surendran Memorial Education
Foundation. Publishing Services by Reed Elsevier India Pvt. Ltd. All rights
reserved.