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Robotics and navigation in total knee arthroplasty

Robotyka i nawigacja w endoprotezoplastyce całkowitej stawu kolanowego

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Abstract

In the last two decades we could realize a lot of technical support to perform total knee arthroplasties, starting with the robotic systems in the nineties of the last century. Following those methods the navigation systems were introduced first in a computed tomogram based version second in image free versions. Now we are discussing about the advantages of patient specific instruments or custom made protheses built by “rapid recovery” technology in special laboratories and still there is unknown, which is the goal of total knee arthroplasty: Restoration of leg axis within the Miculicz’ line or kinematic alignment with slide varus or valgus deformity depending on the preoperative situation. Even the robotic systems in TKA have a renaissance. In this review the historical development is summed up and a critical estimation is done comparing the visible results of these attempts to get better results in TKA.

Key words: robotic, navigation, patient specific instruments, total knee

Streszczenie


Słowa kluczowe: robotyka, nawigacja, endoprotezoplastyka stawu kolanowego
The development of technical support in surgery started 1906, when Clarke and Horsley introduced the stereotactic apparatus to be used in neurosurgery [1]. Since then the strong believe in technological development exists in surgeons worldwide and additional information in viewable situations like three-D-reconstructions for example got used in joint arthroplasties as well as in abdominal and neurosurgery.

At the end of the eighties first attempts for 3-dimensional movement analyses where done using ultrasound detectors (Fig. 1). Even in this attempts a frame with 3 ultrasound emitting diodes was fixed on a body to judge the movement in the space [2]. In addition to these developments the robotic was introduced into total knee arthroplasty. But these systems got on the market too fast so that the use of those very expensive equipment was reduced (Caspar and Fig. 2) [3]. The second disadvantage was the huge soft tissue trauma thought extended approach to the knee joint. The third problem was use of a robotics only with the leg fixed in a frame so that the computer guided arm could work on the bone. The surgeon himself was only standing beside without influence onto the ongoing process. After the patients with complications after robotics surgery (especially in Germany) sued the hospitals for the reason of treatments faults in there TKAs, the use of those robotic systems ended up.

At the end of the nineties the first navigation systems where introduced. The reason for that was the conclusion that a TKA implanted within +3° into the Miculicz’line should result in a better longevity of the implant than those implanted outside of this range [4]. Better clinical results have been estimated as well.

The first navigation systems have been Ct-based sytems (Navitrack, Surgigate e. g.). Those systems needed a 3-dimensional reconstruction of the bony surface of the operated knee. In a first step using the navigation system the acquisition of several surface points was necessary (surface matching). In a second step at the beginning of surgery the surface points had to be collected on the real bony surface (pairpoint matching) again (Fig. 3)[5].

Now infrared light emitting diodes where used together with infrared light collecting cameras. Disadvantages in these procedures at that time where the bad experience with the robotic systems and the introduction to the market to early before the systems got some more technical features. Likewise the radiation using a computer tomogram was identified as a disadvantage. But the advantage was a very exact position of the TKA shown in several publications at that time [6-8].
Nearly at the same time so called image free navigation systems where introduced to the market. Those systems where based on huge dates collected in 3-dimensional CT-reconstructions of several knees which were used like a fiducial registration. Those image free CAS-systems used as there preoperative plan, concepts of limb and implant alignment that are currently used with manual instrumentation (e.g. restoration of mechanical axis). In order to accomplish this plan, anatomic and kinematic information about a patient must be transmitted to the software on the computer and geometrically transformed using registration algorithms. Because bones are rigid and assumed unlikely to deform during the procedure, the algorithms used are called rigid. These algorithms require that the trackers attached to the bone do not move during the procedure. Fiducial registration requires that at least three sets of markers be implanted into each bone or attached to each tool to determine the object’s position and orientation. Therefore each tracker must have at least 3 LED’s or reflecting spheres. Some CAS knee systems measured the shape of the bone surface intra operatively and match the acquired shape to a surface model created from medical images and stored in the computer like a bibliography. One of the most important objectives of software development in CAS knee surgery is to depict procedure sequencethat are familiar to surgeons and with which they have become comfortable using manual instrumentation. This objective ended up with the development of a very handsome CAS system based on an apple I pod-screen attached directly in front of the surgeon to the bone (Brainlab) [9].

The cutting blocks for the proximal and distal as well as the chamfer cuts can be attached in the estimated best position guided by the navigation system. The preoperative leg axis was defined by the center of the hip (using a pivoting algorithm referenced by investigations by Ritschel et al. [10], center of the knee and center of the ankle joint in 2 planes.

Using these systems several publications could show the exact reconstruction of the leg axis within the miculicz’ line and the exact reconstruction of the tibial slope if necessary [11-15].

In a second generation of these systems the soft tissue balancing was introduced as a huge advantage to check the result of e.g. femoral rotation in its influence on the soft tissues [16, 17]. Even in revision surgery of the TKA the navigation systems could be helpful and in this situation also time saving in comparison to the conventional procedure with special features to restore the joint line more comfortable [18, 19].

But critics found the time consuming procedure was to expensive for treatment and the proof, that the longevity of the TKAs was better than in conventional treated cases as well as better clinical results in the cases treated with navigational help are not issue of dispute [20]. Since then in a short time a publications showing better results with navigated TKA after 10 years are available [21].

Especially in USA, the time consuming procedure of navigation in TKAs was a disadvantage because theatre time is rented by the surgeon. So Fitz at al. introduced a procedure to do all the preoperative planning even based on a 3-dimensional model of the knee using ct-scans in a laboratory and create individual cutting blocks to be fixed in defined positions on the bony surface during procedure to get exact results. In those systems called Conformis a patient individual implant is built on the database as well [22].

Other trade marks use patient individual cutting blocs to implant a serial prothesis (Biomed, medacta). Those cutting blocks a created using rapid recovery technology [23-25].

The advantage for the surgeon is the time saving procedure in the theatre. Disadvantage may be some difficulties with the soft tissue balancing, so that several onlay hights have to be available.

Even the X-ray exposure which was a big critical issue at the beginning of CT based navigation now days is not a feature that is mentioned as a disadvantage. Less known fact is that even in the nineties the use of patient individual cutting blocs was tried using CAD technology by Radermacher et al. (Helmholtz In situt, Aachen,Germany) [26]. But at that time the realization of this procedure was not necessary judged by several surgeons because the hype of navigation in real time was going on. For ten years this way was not followed.

Some trademarks are able to base the collected data of the treated knee on MRI-scans, so that the radiation conflict is not that high. Especially in Germany where the DRG (diagnosis related groups)-system does not allow to reimburse more funds for the hospital using modern technology, the patient individual cutting blocs used for serial prothesis are only used in small amounts. The patient individual protheses (Conformis) are used in a more bigger amount because they subventioned more by the government. If the long term results are better than the conventional procedures has to be shown.

Even in the last five years there is to realize a renaissance of the robotic systems. Especially the Mako-system is available in Europe by now. With this system a combination of navigation and robotic guidance by the surgeons hand is introduced to perform unilateral TKAs as well as bilateral TKAs [27]. In the earlier times the Acrobat system by Cobb was introduced even to implant the unicondylar knee arthroplasty (UKA) more exactly [28].
Fig. 4A-D. First trial of patient specific instruments by Radermacher, Germany. A – Ct-scan, B – implant simulation, C – planned osteotomies, D – patient specific cutting block for the tibial osteotomy.
Discussion

In the last twenty years there have been a lot of attempts to implant the unicompartimental as well as the bicondylar total knee replacement more precisely. Reason for that should have been some bad experiences with wear debris or early failure with these implant or like Sharkey pointed out at least 2002: Why are total knee arthroplasties failing today [29]?

But why are failing new CAS-procedures today? First of all the introduction of those new methods becomes faster and faster. If we look at the first attempts of robotics in TKA we realized pressure on the surgeons from the market - may be for advertising reasons, but those new devices machines were not sophisticated enough at that time and so most of them ended up in the museum after 2-3 years.

The same happened to the first generation of navigation systems which were ct based systems. They were dropped on the market without scientific real control and after the bad experience with the robotic systems the difficult to be used and radiation consuming systems did not enter the theatres for a long time. But allready 1997 in Grenoble there was created an image-free navigation system by Delp et al. This group waited till the time was right after the failure of the Ct based systems to get on the market [30].

In the following 8 to 10 years navigation was a good tool to learn something about the correct femoral rotation [31] soft tissue balancing and alignment of the leg axis into the Mikulicz´ line and at least in Germany 12.5% of TKAs were implanted by the help of navigation systems (mainly image free systems; BQS-Report 2005, [32]). Although at that time there have been published some very nice papers in well listed journals, which could show, that the alignment of the protheses was better than the conventional procedure but instead the interest on navigation systems went down after 2005 [11-15].

But astonishingly at the same time there could have be seen a renaissance of robotic systems surprisingly for a very small implant like a unicompartimental knee arthroplasty. I think this circumstance is to strange to be understood by a surgeon who never tried to place a tibial component of an Uni with a slope of 5-7° using a minimal invasive approach. We did some investigation in this special problem and could state that navigation is able to restore the slope of tibial component in 100 consecutive cases very precisely [15]. So what we have to consider is, that we need a tool for the restoration of an implant in a 3-dimensional space.
But sure, all this mentioned procedures are time consuming and especially in the modern health systems, in which the cases are paid (pauschal), time is money and the goal is to treat so much cases as possible. The second problem was the clinical outcome. The fact that for a long time a better clinical outcome was not proven and only some details like less blood loss could be shown by single investigators [33] the question: navigation - is d-day approaching by Bellemans was not so wrong to judge the situation of navigation at the end of the first decade [20].

Most of the studies, with a few isolated exceptions [34] as mentioned above, concur that significantly improved TKA longevity is related to an accurately aligned mTFA (medial tibiofemoral angle) [35-37].

The current author’s research showed that, to date, only 1 other study has been published on the subject of the loosening rate of conventional versus navigated TKAs that include a horizon of more than 10 years [38]. The Kim study [38] reported no significant difference in the survival rate, whether implanted conventionally or with navigation. From a comparison of the survival rates, it is apparent that the revision rates in both groups were very low (0.8% for conventional and 1.2% for navigated), also in respect of the comparative study itself.

Two different types of protheses were involved in the comparison (cruciate ligament retaining mobile, posterior stabilized fix). Each patient underwent a conventional and a navigated TKA. However, it is not possible to determine how many of the respective protheses were included in the 2 groups. A study focusing on a similar time period as the study of Baumbach et al. [21], with 8 years horizon, published a statistically insignificant failure rate of 18.9% for conventionally implanted protheses and 5.6% for navigation-assisted protheses (21 = 39). The study of Mofletta and Caldo (22 = 40), which covered a 5-year period, similarly showed no significant difference in the aseptic loosening rate associated with conventional and navigated TKAs. This must, however, be qualified by mentioning that the above study defined as an exclusion criterion a preoperative varus axis deviation of more than 15°. In the study of Baumbach et al. [21], the results for the navigated group were also similarly promising, with no signs of loosening in a total of 90.2% of the protheses. However, the conventional group within this study was found to have a higher loosening rate than that reported in the studies of Kim [38] and Mofletta et al. [40].

A study of Ewald at al.[41] published a total TKA failure rate of 6.5% after 10 years. The majority of the revisions were attributable to the design of the femoral prothesis plate, which caused an increased loosening rate of the retropatellar replacement and thus a requirement for revision.

There are some other studies reporting survival rates of 95% after 10 years and 87% after 13 years (24 = 42), or that of Wright with a loosening rate of just 2.8% after 10 years (25 = 43). This surprising result could be explained by the lower average BMI of the patients included in that study (BMI of 27.2) compared with the study of Baumbach et al. (BMI > 31; 21). In summary, the group of patients in the Baumbach study who underwent a navigated TKA had lower loosening rates after 10 years than reported by the long-term studies available involving patients treated conventionally. Even the study of Schnurr et al. 5-6 years after navigation [44] reports about promising results and I am sure that there will follow further investigations about the longterm effect of navigation in TKAs.

The last step in a couple of new developments was the patient specific instruments. First of all the cost effectiveness was proven and most of Trademarks for implants assumed, that the budget for instruments in the hospitals could be reduced as well as the costs of the hospitals for sterilization by this method [45]. Surprisingly the need for preoperative CTK or MRI-scans was no burden for health insurance and radiological regulations anymore compared with the situation 10 years before.

But at least the costs for the patient specific instruments for the implantation of serial protheses have been to high especially in Germany – so that only the combination with patient specific custom made protheses was more or less successful. But greater scientific experience has not resulted from that circumstance. But some question according the soft tissue balancing and the advices for the laboratory planning of those protheses are still open.

Drawing into account that at the moment there are some discussions about the right reconstruction of the leg axis like kinematic alignment with reconstruction in a mild varus in severe varus deformities and a mild valgus in severe valgus deformities there are some controversies for the use of all this technical instruments to perform TKAs [46, 47]. But at least even the best surgeon needs control and the question will be how far we can go to a varus/valgus reconstruction of the leg axis before we reduce the longevity of the prothesis or overuse the ligaments of the older patients. On the other hand there seems to be no difference in the results after TKA between experienced and surgeons in residency. So at least at the end of a 20 years period of development of different CAS-tools for the alignment in total knee arthroplasty there are still more questions than answers [48].

Still there are 20-30% of patients after TKAs not satisfied with the result. But this is not only a result of proper alignment or restoration of leg axis high mobility implants or custom made products. We have to realize, that we have to make the decision for the total knee arthroplasty more carefully without promising well outcomes and return to full sport ability for everything. The key for successful arthroplasties is the clinical indication and decision for the right implant type (Uni, CR, PS, CCK, hindge). And all these alternatives have to be available in the Orthopedic departments where the patient is treated at.

But it is a fact also, we learnt a lot about total knee arthroplasties in the last two decades which is also a result of the different available CAS tools. Before that time even experienced surgeons succeed in achieving optimal alignments in only
around 60% of conventional TKAs and there was no significant difference between experienced and inexperienced surgeons at all [49]. In my opinion all these alternative CAS tools have added some knowledge about the TKA -performing. The kind of CAS support is of second interest and depends on the experience and knowledge of the surgeon in these tools. And we have to wait for more long-term result even for those after kinematic alignment to make our decision [50].

References