State of the art in computer-assisted orthopaedic THR and TKR

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Computer assisted orthopaedic surgery (CAOS) was developed to improve the accuracy of surgical procedures, and it has dramatically improved in the last years from an experimental laboratory procedure to a routine procedure theoretically available for every orthopaedic surgeon. Besides robotic application, surgical navigation has been widely developed for joint arthroplasties, mostly for total knee replacement (TKR) and total hip replacement (THR). The first navigated joint replacement (a TKR) was performed in January 1997 by Saragaglia et al (1), using a non-image based system with intra-operative kinematic and anatomic analysis of the knee joint. Following these pioneers, other systems have been developed and validated. However, this appealing technology has not been adopted on a broad scale, and some surgeons complain of several relevant inconveniencies of using it on a routine basis. What have we already learnt, and what are the remaining questions?

1) Tracking technology

Navigation systems mainly use two different tracking technologies: infrared or electromagnetic devices. Infrared technology is the oldest and still the most used technology (1). Trackers may be active (sending infrared beam to the camera): this technology is the most precise and accurate, but these trackers need cables or batteries to get power. They are progressively replaced by passive trackers (reflecting beads which only reflect the infrared beam sent by the camera): there is no cable or battery, but these trackers are very sensitive to water, blood or dust, and must be carefully cleaned during the procedure.

A new technology is being developed currently, using electromagnetic sensors (2). These sensors are much less invasive and bulky than infrared trackers. However, the operative field must be free of any metallic device, which is not easy to obtain. This technology might be promising, but must only be considered as experimental today.

2) Data registration

Navigation systems may be based on pre-operative imaging ("image-based systems") or on purely intra-operatively acquired data ("non image based systems").

Most systems currently available for TKR are non-image based, and rely on data registered during the surgical procedure (1,3–6). Data may be a kinematic analysis of the joint (especially for hip joint), an anatomic analysis of the bone surfaces by point registration or mapping, or a combination of both techniques.

On the other hand, most systems used for THR are image based. Some rely on a pre-operative imaging, mainly a CT-scan, which allows a pre-operative planning of the procedure (7). A matching is performed intra-operatively between CT- and anatomic data. Other systems rely on an intra-operative fluoroscopic imaging (8).

Non image based procedures involve less costs, as CT-scan is not a routine pre-operative examination before THR or TKR. There is no evidence that image-based systems would be more precise or accurate.

3) Accuracy

Accuracy of navigation systems is dependant on the elementary accuracy of each step of the whole procedure. In experimental setting, accuracy has been evaluated to less than 1 mm for distance measurement, and less than 1° for angular measurements (9). In clinical setting, accuracy is difficult to evaluate properly, as the exact anatomic reference cannot be obtained, and thus accuracy might be decreased. It may be evaluated by the reproducibility of navigated intra-operative measurements. Several clinical studies have showed encouraging results. Reproducibility of the pelvic position registration during THR has been proved (10). Reproducibility of the whole registration process for TKR has been proved as well (11). Although indirect, these information show that accuracy of navigation systems is probably good enough for clinical purpose.

4) Precision

As for accuracy, precision of navigation systems is dependant on the elementary precision of each step of the whole procedure. In experimental setting, precision has been evaluated to less than 1 mm for distance measurement, and less than 1° for angular measurements (9). Again, in clinical setting, precision is difficult to evaluate properly, as the exact anatomic reference cannot be obtained, and might be decreased. Precision may be evaluated by the variation of the prosthetic orientation around the expected goal. Several clinical studies have showed encouraging results. Positioning of the cup during THR may be improved in comparison to conventional technique (12,13). Limb axis correction during TKR may also be improved, as well as individual component positioning of TKR (4–8,14). Although few studies report no improvement in comparison to conventional techniques (15), it is generally admitted that navigation systems significantly improve the precision of the prosthesis placement in comparison to conventional, visually oriented techniques.

5) Complications

Operative time is increased in comparison to conventional technique. This increase is due to the additional steps of the navigated procedure, mainly fixation of the trackers, and registration of intra-operative data. An additional operative time of 10 minutes is generally advocated for TKR (14). Some authors did not observe such increase, probably because the need for additional or corrective resection is decreased with navigation.

Navigation system involves fixation of the trackers on the bone by means of screws or pins, thus creating a hole with weaker bone resistance. A higher incidence of femoral fractures has been reported after navigated implantation of a TKR (16,17). Attention must be paid to the site of implantation of the femoral screw, avoiding the anterior femoral cortex. Multiple pin fixation might be safer (18).

Computer breakdown may occur as for each electric or electronic device. However, the rate of this complication has been reported to be very low. Manual instruments must be provided to be able to complete the implantation in a conventional way.

Array loosening may occur, especially in osteoporotic bones, leading to premature end of the navigated procedure. Fixation of the arrays at the beginning of the procedure is a critical step (18), and attention must be paid to avoid any impingement with instruments or surgeon's hand or arm during surgery.

6) Learning curve

Navigation is considered to be a demanding procedure, with a significant learning curve. Some authors advocate such systems to be used only by high volume experienced surgeons. This point has been evaluated in the literature. No learning curve was observed when the radiological quality of implantation was analyzed (19). There was an early additional increase of the operative time for beginning surgeons in comparison to experienced teams, but this additional increase disappeared after 20 navigated implantations, and the operative time was similar for both beginning and experienced surgeons after that point.

7) Navigation as a teaching tool

Navigation has proved to be a very effective teaching tool. Trainees in contact with navigation showed a better understanding of the principles of TKR (20). Even experienced surgeons were able to improve their skills during conventional implantation of a TKR after gaining experience with navigation (21). The learning curve of THR (22) and hip resurfacing (23) was significantly decreased with the help of a navigation system.

8) Cost / cost-effectiveness

Navigation is a sophisticated procedure with high level software and hardware. Purchasing of the system itself and its maintenance is costly. There is an additional cost for specific instruments during each procedure. The additional operative time must also be considered. The question of cost-effectiveness has been addressed in a virtual cost simulation (24). Provided that the use of navigation will decrease the revision rate, cost-savings would be achieved if the added cost of computer-assisted surgery is $629 or less per operation. However, the cost-effectiveness is sensitive to variability in the costs of computer navigation systems, the accuracy of alignment achieved with computer navigation, and the probability of revision total knee arthroplasty with malalignment.

9) Future trends?

Navigation systems for THR and TKR have been adapted for other applications in hip or knee arthroplasty: hip resurfacing (23), unicompartmental knee replacement (UKR) (25). The clinical experience seems to be promising for these two new applications.

Direct navigation of the sawblade instead of the resection guides has been proposed to go away from the costly conventional instruments (26). Early results are interesting, but still experimental. Following the same philosophy, individual templating of the resection guides has been proposed, but this technology is not widely used (27).

Navigation may be a tool to decrease the invasiveness of the procedure. Skin incision and joint opening might be decreased, as a relevant part of them is necessary for visual orientation only (28). Extra-articular tool fixation might also help for a less invasive surgery (29).

The usefulness of robots is still under discussion. Industrial robot adapted to the operating room were effective but very demanding and involved even much higher costs than navigation alone; only few teams are still using them (30,31). Active constraint robot proved to be highly effective for UKR, but again cost is a limiting factor (32). The alternative might be the development of minirobots (33).

Navigation remains a “hot topic”, and some surgeons are fully in opposition with its use. However, there is no example in the field of medicine where an improvement in the accuracy and in the reproductibility of a technical procedure was not followed by an increased quality of care. However, long term results of navigated THR or TKR are still lacking. But navigation will improve in the future. Navigation systems must become easier, quicker, more user-friendly, and also cheaper to be adopted and used on a routine basis.

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