29

Computer Assisted Total Knee Arthroplasty – The Learning Curve

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1. Introduction

Over the last decades, orthopedic surgery has encountered a growing development that remains unfailing today.
Particularly in the field of total joint replacement, it is indeed a functional surgery aimed at a rather elderly population whose functional demand is increasing.
It is undeniable that a senior aged 60 in 2011 is very different from the senior suffering physical or psychological constraints caused by the ageing of his body about thirty years ago.
Nowadays, many seniors are willing to have an active lifestyle or even practice sport on a regular basis.
In the field of total joint replacement, that demand generates steady progress, which can come up to that expectation.
Among all orthopedic interventions that marked the twentieth century, total hip and knee arthroplasties are the most important.
Total hip replacement has even been labeled "intervention of the century."
Many forms specifically aiming to improve the quality of life have been incorporated into the various protocols for total prostheses monitoring (SF 16, HSS).
They accurately reflect the increasing demand of patients, which currently consists of simply forgetting the presence of the prosthetic joint.
This growing demand requires the constant search for improved joint replacement outcomes. That improvement is necessary to gradually reduce the rate of complications or imperfect results found in the literature.
Although few interventions have so much improved the quality of life for patients, much progress is still needed in order to increase the percentage of patients satisfied with their prosthesis.
The goal of arthroplasty is to obtain a joint which will be and remain mobile and painless as long as possible.
However, some studies [1-3] estimate that more than ten percent of the number of total knee prostheses do not fully come up to the patients' expectations, particularly in terms of residual pain.
The ideal thing would be to replace in due course the osteoarthritic joint (joint whose cartilage is worn) with the prosthesis and to obtain a prosthesis which would be functional all throughout the patient's life.

In other words, total joint replacement would be performed once and for all, and its sufficient longevity would prevent all prosthetic revision imposed by the failure or wear of the implant.
However, it is clear that the current average lifespan [4-5] of prostheses does not allow to avoid that revision among relatively young patients, that is to say patients who are younger than 50 years old.
Considering the gradual increase in the population's life expectancy and the more intensive use of the prosthesis among younger patients, one or two prosthetic changes are frequently required in such cases.
At the beginning of the twenty-first century, improving prosthetic longevity is still an absolute necessity.
This improvement in the lifespan of the implant must be combined with an improvement in the functional outcomes of arthroplasty, making some daily life activities easier to carry out thanks to the increase in prosthetic knee flexion, the opportunity to squat or kneel, to drive or practice some more demanding sport activities.
But how can that prosthetic function be improved as well as the prosthetic longevity of the implant?
First by working on the prosthetic design in order to increase its functional capabilities.
Much progress has been made in prosthetic design (design of the total hip prosthesis femoral stem, femoral offset, metaphyseal filling, anti-rotation wings,etc., radii of curvature of the total knee prosthesis femoral condyles, femoral offset, posterior slope of the tibial component, trochlear design, etc.).
Therefore we are currently moving towards an almost uniform design, gradually tending towards an almost unanimous prosthetic shape.
Progress will probably be made in that field in the coming years but the major part seems to have been done.
Similarly, many studies have been conducted to improve prosthetic anchorage (cemented prosthesis or not, press-fit effect, screwed prostheses, etc.) and many others will still have to be conducted in the future.
It is in the field of tribology, that is to say the science of the materials used in friction couples, that discussions are still lively, especially between the advocates of "hard-hard" and those of "hard-soft".
After decades of "hard-soft" corresponding to the first years of total joint replacement, roughly to the polyethylene-metal friction couple, the hard-hard friction couple appeared in the 1980s and 1990s (mainly alumina ceramic/alumina ceramic, metal/metal), those friction couples permitting to reduce the volume of wear debris, which are responsible for the so-called "aseptic" loosening.
Indeed the regular production of wear particles (cement, polyethylene, metal) will initiate a macrophage reaction of resorption, which when increasing, will compromise the prosthetic anchoring.
A certain number of complications of 'hard/hard' couples (breakage of ceramics, dissemination of metal ions in the body) has made the debate a little more lively but it is still not resolved. Some operators prefer so-called "hybrid" couples (alumina ceramic/ polyethylene).
Improving the manufacturing techniques of various materials used is certainly an argument in the debate (maximum purity of ceramics limiting the risk of breakage, cross-linked polyethylene for superior mechanical resistance, etc.).

As it can be noted, contrary to the field of prosthetic design, significant progress is still desirable in the field of tribology.
The improvement in the technical realization of total joint replacement remains a key-issue.
This improvement in the insertion technique is a major factor to lengthen prosthetic longevity.
In the field of total knee arthroplasty, improving the accuracy of bone cuts is bound to have consequences on prosthetic stability (ligament balancing) and overall alignment of the lower limb on which prosthetic longevity depends [6-7].
Improving the arthroplasty's accuracy means improving the equipment used for the implantation of the prosthesis, which is called "ancillary equipment".
Over the last decade, new ancillaries have emerged, which allow to carry out knee arthroplasty minimizing the damage to soft tissues and exposure of bone ends, in a view to simplify the postoperative course. These techniques are known as "minimally invasive" [8-9].
The length of surgical incisions was significantly reduced, limiting the aggression of the surrounding soft tissues (skin, subcutaneous cellular tissue, muscles and tendons). Some operators limit their incision to a few centimeters (approximately half a conventional incision).
Clinical improvement was described in the immediate aftermath of these minimally invasive techniques. Studies are currently being carried out to confirm such progress.
Computer-assisted surgery is the second line of research to improve the ancillary equipment.
The computer appeared in operating rooms in the early 1990s under the leadership of neurosurgeons. The precursor surgical intervention was the computer-assisted transpedicular spine surgery, then, in the mid-1990s, it was followed by the computer-navigated total knee arthroplasty performed in France by the Grenoble university surgical team [10].
From the beginning, two systems were used, one using pre-operative imaging (CT), the other one using "bone-morphing" TM.
At the time, the computer created practical difficulties because of its volume and the numerous cables required by a complex connection.
An immediate preoperative tedious calibration of the ancillary equipment considerably lengthens operating time.
For simplicity, concerning total knee arthroplasty, computer-assisted surgery must be regarded as a tool aiming to bring improved accuracy in the realization of bone cuts, leading to a better ligament balancing of the prosthetic knee and a global alignment of the lower limb being more frequently close to the vertical (the ideal range of the angle between the femoral mechanical axis and the tibial mechanical axis extending from 3 degrees of varus to 3 degrees of valgus).
The so-called femoral mechanical axis is the line joining the center of the femoral head and the center of the knee; the tibial mechanical axis connects the middle of the tibial plateaus and the center of the ankle joint.
Thanks to that regularity in the alignment, the unexplained outliers of the overall mechanical axis of the lower limb are scarce.
With the help of a stereoscopic infrared camera, the rays being reflected by optically reflective balls, it is possible to obtain a virtual anatomical reconstruction of the operated knee. The software, using an extensive database, then guides the various bone cuts via a

graphical user interface (screen) and benchmarks for instant viewing of the various cutting blocks.
This is seen as an aid to surgery and not a robot automation of the surgical gesture. The surgeon remains the master of the surgical gesture, following on the screen the computer's visual indications to guide and set the different cutting blocks.
As mentioned above, this improvement in cutting accuracy induces a better ligament balancing and an alignment of the lower limb more consistently correct, which should increase prosthetic longevity.
However no study has so far clinically demonstrated any lengthening of the lifespan of a so-called "navigated" total knee prosthesis.
The follow-up is too short, which explains this gap. Indeed, computer navigation is still, in terms of its regular practice, in its infancy.
Therefore the success is less massive than expected with the improvements achieved during surgery. Among the reasons for this limited development, the cost of materials [11] is mentioned, given its limited distribution. Longer operative time with the addition of specific technical steps required by the computer, leading to an increased septic risk, and finally difficulty of learning the technique, even for a trained operator. Given his experience and the excellent results of the so-called conventional prosthetic surgery, the operator is not always convinced that new technique is really useful.
It seemed interesting to mention our personal experience of learning computer-assisted surgery in the field of total knee replacement.
Indeed, the obstacles seemed to be overcome without great difficulty. Using more user friendly and easier systems, we were even able to modify our practice as our experience grew.
A comparison of operating times enabled us to demonstrate the permanent aspect of learning by making our adaption to a totally new and unknown computer system easier and easier.

2. Materials and methods

In February 2003 we achieved our first computer-assisted total knee arthroplasty.
Two implantations were performed during the same operating session in the Val de Sambre clinic in Maubeuge.
At the time, concerning the primary knee arthroplasty, the author exclusively used the Natural Knee II TM sliding prosthesis (Zimmer, Warsaw, Indiana, USA).
The provision on a trial basis of the Navitrack Navigation System TM (Orthosoft, Zimmer) allowed those first two projects.
It is an imageless system requiring the calibration of computer tools (pointer, and cutting blocks) (Fig. 1) during the operation and not involving the bone morphing TM.
It was actually a simplified bone morphing including deposition of "computer chips" on the screen allowing to adjust cutting thickness (Fig. 2).
The graphical user interface not being interactive, the use of keyboards and pedals in the immediate vicinity or in direct contact with the operative field was a source of congestion and increased the risk of lack of asepsis.
After those two trials which were considered conclusive, the decision to purchase the equipment was made and, from September 2003, all primary knee arthroplasties were performed by the author using that system.

Fig. 1.

Fig. 2.

Computer-assisted surgery has been exclusively used whereas conventional surgery was only used for revision arthroplasty surgery.
Thus more than 200 total knee prostheses were implanted with a system that may now seem outdated, but which, at that time, gave entire satisfaction from September 2003 to July 2006.
The duration of the intervention and more specifically the time of tourniquet were studied [12] at the beginning and end of the user experience (Fig. 3) of this system.
In July 2006, we decided to use a more user-friendly system including a touch screen covered with a sterile drape allowing us to avoid cumbersome cables and pedals. It is also

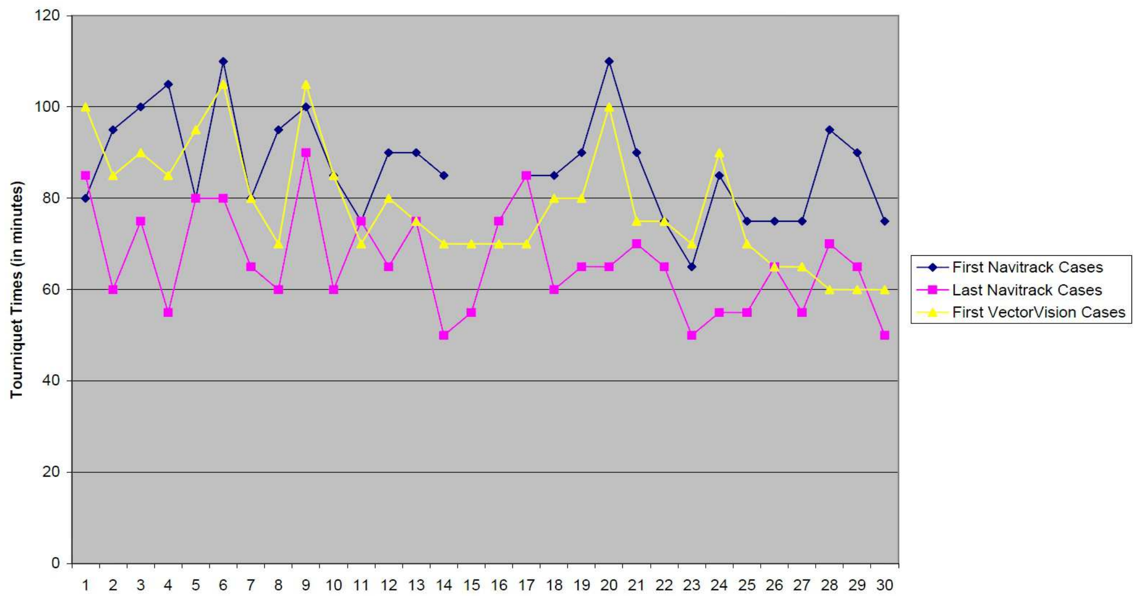

Fig. 3. Tourniquet Time

Fig. 4.

an imageless system based on a standardized bone morphing carried out using a pointer fitted with reflective balls and not requiring time-consuming instrumental calibration (VectorVision, Brainlab, Munich, Germany) (Fig. 4).
A "coloring" of the reference bone surfaces using a computer pointer (stylus provided with reflective balls) permits to transmit essential anatomical data to the computer. The data allows the operator to choose a knee anatomical model being as close as possible to the operated knee in a huge database.
More than 300 arthroplasties have been carried out so far using that system, which is still used in the service now.

3. Results

When using the computer system, an average lengthening of time tourniquet of 18 minutes has been noticed (range 0-45 minutes), which is likely to increase the septic risk. That average lengthening refers to the average tourniquet time of "conventional" total knee arthroplasties performed by the author during the previous five years.
The more detailed analysis of the curves indirectly shows the technical difficulties experienced by the operator since, for an average tourniquet time of 87 minutes during the very first use of navigation (first 30 implantations with the Navitrack system), we observe that in 4 out of the first 10 cases, 100 minutes are reached or exceeded.
This period of 100 minutes is critical because it jeopardizes the achievement of the entire knee arthroplasty under pneumatic tourniquet, because the latter cannot be maintained more than 120 minutes or it can cause complications. The tourniquet release before the setting of cement may compromise the prosthetic anchorage, although for some operators the procedure is performed without any tourniquet.
When examining the curves, we can notice a progressive decrease in the time of tourniquet as the operator's experience and mastery of the technique develops.
Last but not least, a comparison of tourniquet time in the series performed using the second system has identified a more rapid decrease in additional operative time induced by the use of the computer ancillary, which supports the working hypothesis of the study, namely the maintenance of the operator's knowledge.
That situation could be compared to driving : the successive adaptation to a different vehicle is done gradually with less difficulty as the driving technique improves.
Over the last eight years, no specific complication to navigation has been deplored, except, at the beginning of our practice, some cases of transitory inflammation or suppuration of the holes of the tibial antenna fixation pins.
These were probably caused by the excessive overheating of the drilling, which caused neighboring bone necrosis. The problem was solved by the use of tibial fixation rods with a 3.5 mm diameter.
We observed no supracondylar fracture on way to the fixing pin of the femoral rigid body and a single non-displaced tibial fracture, which rapidly consolidated.
Particular care is brought to the precise location of the fixing rods to reduce the risk of fracture [13].
Similarly, the average rate of postoperative prosthetic sepsis (less than one percent in the literature and personal experience) has not been modified by the lengthening of operating time.

The functional results and the possible and expected lengthening of computer-assisted arthroplasty longevity will be clinically studied as soon as the mean perspective of the series will be sufficient to be scientifically exploited.

4. Discussion

As seen, after studying of the duration of the learning curve, we can consider this learning difficulty as easily surmountable.
The reluctance of some practitioners, experienced in the practice of orthopedic joint replacement, to perform computer-assisted surgery is mainly due to the supposed difficulty of learning an innovative technology, with all the constraints that it brings, and not to the duration of the learning curve itself.
In addition, the computer ancillary equipment itself, tends to annoy or frighten those trained operators who only consider that equipment as an additional constraint.
Actually the major obstacle now seems to be the cost of equipment and particularly in France since the supervisory bodies consider that the benefit induced by the technique is not sufficient to support the extra cost induced by the purchase and use of computer equipment.
That benefit will only be found and admitted through the rigorous exploitation of satisfactory scientific studies. To be useful, such studies must always have sufficient perspective (10-year-follow-up minimum), but computer-assisted surgery started being used on a regular basis about 12 years ago. In the coming years, exploitable series should appear.
Similarly, the proliferation of studies on the comparative functional results of conventional arthroplasties versus navigated arthroplasties should rapidly lead to interesting conclusions.
It is mainly in the private sector that the financial aspect has the greatest impact. Indeed, in a context of economic crisis, the health system severely suffers from the decline of its funding due to a reduction in social contributions, if only because of rising unemployment.
The financial investors involved in the management of the private health care system in France are increasingly careful with potential investments such as the purchase of a new ancillary equipment.
The need for learning computer-assisted surgery, considered by some operators as tedious, with the costs incurred by the purchase of computer equipment (hardware and software), is currently a major obstacle to the further development of that promising technique.
However, that development will itself lead to a consequent decrease in acquisition costs through the diffusion of technology.
Similarly, the different national science societies for computer-assisted surgery will have to continue their efforts of representation, for educational purposes, including in university education.

5. Conclusion

In our view, and especially in the field of total hip and knee arthroplasties, computer-assisted surgery represents a promising technique, able to bring significant progress in terms of function and prosthetic longevity.
These improvements will meet the needs of elderly patients, who are more and more numerous, more and more demanding about maintaining a good quality of life and sometimes wishing to practice sport on a regular basis.

Similarly, younger and younger patients will take advantage of that technical progress.
To allow further development of computer navigated surgery, a reduction of costs is necessary and will only be obtained thanks to the diffusion of the technique and the improved support of those costs by supervisory bodies, once they have been convinced of the reality of the benefit provided by the computer.
To achieve this goal, the proliferation of scientific studies is essential. Those studies must be very serious, have a sufficient perspective, and be rigorously statistically exploited.
In those conditions, the expected improvement in terms of longevity and prosthetic function will be clearly demonstrated and allow the financial support of supervisory bodies.
As for the supposed inconvenience of learning time, our study has shown that it is minimal. On the one hand, a limited number of implantations is necessary to that learning (about 30 cases) and on the other hand, the growing experience allows the operator to adapt more easily to any new computer ancillary.
Finally, the educational value of the material is undeniable. Young operators should not be trained to the exclusive practice of computer-aided prosthetic surgery but their introduction to that technique should enable them to have a more rigorous, thoughtful and interactive approach of the different stages of arthroplasty surgery, which could improve their reasoning.

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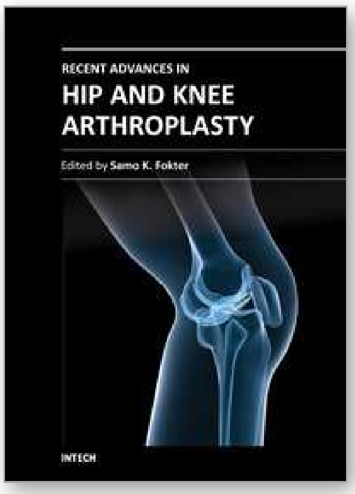

Recent Advances in Hip and Knee Arthroplasty

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The purpose of this book is to offer an exhaustive overview of the recent insights into the state-of-the-art in most performed arthroplasties of large joints of lower extremities. The treatment options in degenerative joint disease have evolved very quickly. Many surgical procedures are quite different today than they were only five years ago. In an effort to be comprehensive, this book addresses hip arthroplasty with special emphasis on evolving minimally invasive surgical techniques. Some challenging topics in hip arthroplasty are covered in an additional section. Particular attention is given to different designs of knee endoprostheses and soft tissue balance. Special situations in knee arthroplasty are covered in a special section. Recent advances in computer technology created the possibility for the routine use of navigation in knee arthroplasty and this remarkable success is covered in depth as well. Each chapter includes current philosophies, techniques, and an extensive review of the literature.

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