The role of newer technologies in knee arthroplasty

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Abstract

The success of a total or unicompartmental knee replacement depends primarily on restoring the mechanical axis of the lower limb. Traditionally, this is performed using intra- or extra-medullary alignment rods to help centralize and align the components along a universally agreed and anatomically derived mechanical line from the centre of the femoral head to the middle of the ankle. This can often lead to inaccurate placement, patient dissatisfaction and early failure. However this 'one-for-all' model may not be the best approach. In the twenty-first century, with younger and more active patients, modern technology is paving the way for more individual, accurate, reproducible and anatomically tailored methods of performing knee arthroplasty. This paper aims to introduce to the modern orthopaedic surgeon some of the technological non-biological advances available in managing knee osteoarthritis.

Keywords advances; knee arthroplasty; navigation; patient specific; robotics; technology

Introduction

The prevalence of activity-limiting osteoarthritis is rapidly increasing. By the year 2040, an estimated 78 million (26% of the projected total adult population) adults aged 18 years and older in the USA will have medically diagnosed osteoarthritis, compared with the 52.5 million adults in 2010–2012. Two-thirds of these will be women. During this time period, it is also estimated that 35 million adults (44% of adults with arthritis or 11% of all USA adults) will report arthritis-attributable activity limitations. Furthermore, with the current rise in obesity, these estimates are thought to be quite conservative. To add to the burden, not only is the prevalence increasing, but so are the functional demands of these patients, whilst the age of presentation is decreasing.[1] The modern, younger patient not only demands a pain free joint; they also want to exercise and continue taking part in sporting activities.

As a result, longevity and survival of the components of a knee replacement has never been more important. The commonest cause of failure of a knee replacement is aseptic loosening, and so it is key that efforts are made to ensure survivorship. Although implant design plays a key role, the success of knee arthroplasty depends largely on accurate component sizing, mechanical alignment and orientation, gap kinematics and soft tissue handling.[2] This is almost entirely facilitated by accurate component measuring and implantation.

With an ever younger and more active patient population, there may be an argument for performing unicompartmental knee replacement (UKR) in a single affected knee compartment rather than the entire tibiofemoral and patellofemoral joint. The underlying principles of a UKR, which differ to TKR, is to not overcorrect or overstuff the affected joint compartment, as this will overload the non-replaced compartment and potentially lead to dissatisfaction and progression of the osteoarthritic disease. Furthermore, smaller bone resections in such procedures may reduce subsidence of the components and, should the UKR need to be converted to a TKR in the future (for whatever reason), then it appears to be a relatively bone preserving procedure.[3] It is the senior author's belief that in such procedures, more so than during TKR, component alignment and orientation is even more crucial.[4]

Despite the unquestionable amount of care taken during knee replacement surgery, up to 30% of patients remain dissatisfied with their outcome.[5] While this dissatisfaction is likely to be multifactorial, malalignment of the prosthetic components is a major cause of post-operative complications. A neutral mechanical axis plus or minus 3° is felt to have a positive impact on the survivorship of the prosthesis by reducing the risks of abnormal wear, component loosening and premature implant failure.[6,7]

So, what measures can be taken to try and ensure that the prosthesis functions to a high level but can also stand the test of time? Technological advancements in the 21st century have been immense, and not only in the field of surgery. Making a phone call from one's mobile phone is now considered a secondary function; its primary service is now that of a small computer in your pocket. To that effect, could modern technology be beneficial to knee replacement surgery? This paper aims to introduce the non-biological technological advances currently being used as well as those being developed to aid knee replacement surgery.

Patient-specific instrumentation

Patient-specific instrumentation (PSI) uses the premise that every patient's knee is different and unique and thus a one-for-all design from 'off-the-shelf' does not fit everyone appropriately and is not the optimal treatment option. Using either CT or MRI imaging, computer software is used to create a detailed 3D image or model of the bony architecture of the patient's knee, including osteophytes. This then allows the surgeon to accurately plan their operation, including orientation of bone cuts, specifically for that patient. Once agreed and approved by the surgeon, tailored cutting blocks are created and supplied for the operation, taking into account the bony morphology and mechanical alignment of the joint. The presumed benefit of tailored made cutting blocks for the individual patient is that they will allow more accurate positioning of the implants, which in turn should lead to a better post-operative outcome. Furthermore, the patient-specific cutting blocks are supplied in a single sterilized

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Please cite this article in press as: Pastides P, Nathwani D, The role of newer technologies in knee arthroplasty, Orthopaedics and Trauma (2016), http://dx.doi.org/10.1016/j.mporth.2016.10.003

tray, which reduces the need for the conventional multiple instrumentation trays and so, in turn, reduces processing costs.

However, does the use of PSI actually meet these targets? A recent systematic review by Sassoon et al. set out to investigate the effect of PSI on mechanical alignment, surgical efficiency and also clinical outcomes.[8] They found that of the 16 studies included, the majority did not show an improvement in overall limb alignment when PSI was compared with standard instrumentation. Mixed results were seen across studies with regard to the prevalence of alignment outliers when PSI was compared with conventional cutting blocks, with some studies demonstrating no difference, some showing an improvement with PSI and a single study showing worse results with PSI. In terms of surgical efficiency, no significant decrease in operative times was noted and even though the instruments are provided in a single tray, most surgeons tended to have the standard instrumentation trays available in theatre as well, thus not actually reducing the number of intra-operative instrument trays used. More concerning was the fact that despite the tailored plan and cutting blocks generated by the PSI manufacturers, the accuracy of execution was found to be lacking during the actual operation, often with multiple intra-operative changes, thereby disrupting the flow of the operation and negatively impacting efficiency further.

Roh et al. have reported similar findings in a randomized controlled trial involving 50 patients in each treatment arm.[9] They evaluated post-operative hip-knee-ankle angles, femoral component rotation and coronal and sagittal alignments of each component, cross-checking those who underwent PSI procedures with conventional instruments. They found that outliers in the hip—knee—ankle angle were comparable, and sagittal alignment and femoral component rotation did not differ in terms of outliers between the two groups. Interestingly, PSI procedures were abandoned in eight knees (16%) during the surgery because of malrotation of the femoral components and decreased slope of the tibia. The same findings have been reported by other authors.[10,11]

The question though is why, since the blocks are moulded based on the actual joint geometry, do these inaccuracies occur? Stronach et al. showed that 77% of PSI femurs and 54% of tibias did not fit accurately and required intra-operative adjustment.[12] They speculated that due to the multiple steps involved in the production of these blocks, including imaging quality, model creation, planning and finally manufacturing, there are plenty of areas where small errors can be made and magnified throughout the production, which could culminate in inaccurate and imperfect cutting blocks. This would explain why most surgeons performing PSI procedures have the traditional instrumentation trays available, hence rebutting the argument that PSI procedures involve less trays. Some even use computer navigation in addition to the PSI to make intra-operative corrections (as in the case of the senior author).

Custom-made knees

Implanting patient-specific implants rather than generic off-the-shelf designs can also be performed to further individualize an operation. One such device is the *ConforMIS* knee system. The presumed advantage of such an approach is that there is individual fit that reduces sizing compromize compared to 'off-the-shelf' implants. The prostheses mimic the shape and contour of each patient's knee, which may increase the potential for a more natural feeling knee whilst preserving bone stock during implantation. The prosthesis is also sent with PSI cutting blocks, to allow the surgeon to place the implants according to a predefined plan. However, does this actually translate to an improvement in patient outcome? Although still in its infancy, early results in terms of patient satisfaction and outcome are extremely encouraging for both TKR[13,14] and UKR,[15,16] with almost all patients stating that the replaced knee feels more 'natural'. Furthermore, this technology is completely adaptable and malleable to be used in any of the three compartments of the knee joint; if either of the two tibiofemoral joints are affected in isolation (*iUni*), if all three compartments are affected (*iTotal*) or an individual tibiofemoral compartment alongside the patellofemoral joint (*iDuo*). We await peer reviewed publications of the above studies and also note there are currently several ongoing large prospective studies investigating the long-term outcome of the *ConforMIS* patient-specific implant.[17,18]

Computer navigation or computer assisted surgery

Computer navigation (or computer assisted surgery (CAS)) to aid component implantation has been widely available since the turn of the century. However, uptake has been relatively low in the UK; only 1% of all knee replacement surgery (including unicompartmental) is performed under any form of image guidance. This is in contrast to our colleagues in Australia, who have shown an increased rate over the last decade (2.4% in 2003 to 22.8% in 2012).

Broadly speaking, navigation systems are classified into 'open' (applied to any prosthesis) or 'closed' (applied to only a single specific prosthesis). Most systems do not require prior CT or MRI imaging and are termed 'imageless'. Instead, they utilize sensors on small pins that are implanted into the bone around the knee and a hand-held sensor to reference certain key anatomical bony landmarks. These are instantaneously recorded via an optical laser tracking camera, which uses computer software to create an image model of the joint. The procedure can then be carried out to allow live and accurate component sizing and positioning within the patient's own mechanical axis. Intra-operative range of motion analysis can also be performed and verified at the time of surgery.

Using data from the Australian Joint Registry,[19] de Steiger et al. analysed 44 573 surgical cases, or 14.1% of all primary navigated knee replacements performed.[20] Overall, the cumulative revision rate following non-navigated total knee arthroplasty at 9 years was 5.2% (95% confidence interval [CI] = 5.1—5.4) compared with 4.6% (95% CI = 4.2—5.1) for computer-navigated total knee arthroplasty (HR = 1.05 [95% CI = 0.98—1.12], p = 0.15). There was a significant difference in the rate of revision following non-navigated total knee arthroplasty compared with that following navigated total knee arthroplasty for younger patients (HR = 1.13 [95% CI = 1.03—1.25], p = 0.011). Patients less than 65 years of age who had undergone non-navigated total knee arthroplasty had a cumulative revision rate of 7.8% (95% CI = 7.5—8.2) at 9 years compared with 6.3% (95% CI = 5.5—7.3) for those who had undergone navigated total knee arthroplasty. Computer navigation led to a significant

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