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Navigated "small implants" in knee reconstruction

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Abstract

Purpose At the beginning of this century, unprecedented interest in the concept of using less invasive approaches for the treatment of knee degenerative diseases was ignited. Initial interest in this approach was about navigated and non-navigated knee reconstruction using small implants and conventional total knee arthroplasty.

Methods To this end, a review of the published literature relating to less invasive compartmental arthroplasty of the knee using computer-based alignment techniques and on soft tissue-dedicated small implants is presented. The authors present and compare their personal results using these techniques with those reported in the current literature. These involved the use of a shorter incision and an emphasis sparing. However, nowadays most surgeons look at compartmental knee resurfacing with the use of small implants as the new customized approach for younger and higher-demand patients. The aim of this paper is to stimulate further debate.

Results Since the beginning of 2000, computer-assisted surgery has been applied to total knee arthroplasty (TKA) and later to compartmental knee arthroplasty. Recent studies in the literature have reported better implant survivorship for younger patients using navigation in TKA at longer-term follow-up. Only one published report was identified showing superior clinical outcomes at short-term follow-up using computer-assisted technology compared with conventional alignment techniques in small implant surgery. No studies were found in the literature that demonstrated similar clinical advantages with navigated small implants at long-term follow-up. Two published meta-analyses were identified reporting better implant and limb alignment and no increase in complications using a navigated unicompartmental knee arthroplasty. However, neither meta-analysis showed superior clinical outcomes or survivorship with the navigated techniques.

Conclusion In conclusion, we can assert that replacing just the damaged compartment and preserving the normal biomechanics will require not only new implant designs but also new technologies allowing the surgeon to make extremely precise adjustments to implant alignment and providing continuous feedback during surgery.

Level of evidence IV.

Keywords Small implants · Computer-assisted surgery · Unicompartmental knee arthroplasty · Bi-unicompartmental knee arthroplasty · Tri-unicompartmental knee arthroplasty · Patello-femoral arthroplasty · Soft-tissue-sparing surgery

Abbreviations

ACL	Anterior cruciate ligament
UKA	Unicompartmental knee arthroplasty
PFA	Patello-femoral arthroplasty
TKA	Total knee arthroplasty
CAS	Computer-assisted surgery
CT	Computed tomography
PSI	Patient-specific instrumentation
MR	Magnetic resonance

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Introduction

In the last few decades, both surgeons and technology providers have mainly defined less invasive surgery as a surgical approach using shorter incisions to implant the same prostheses used with the traditional techniques. Decreasing the access by performing the so-called key-hole surgery has resulted in increased risks including malalignment, bone avulsions and local wound issues. In addition, a biological contradiction has arisen with shorter incisions offering the potential for soft tissue sparing but also increased risk of damage to muscles and nerves [5, 14]. In early years of the last century, Giulio Bizzozero, an Italian biologist pioneer, classified the tissues and the cells into three categories. He identified the "reproducible" tissues, including epithelium (skin) and endothelium, the "stable" tissues, including mesenchyme (tendons and ligaments), that recover very well, and the "noble tissues" (muscles and nerves), which should not be damaged as they had limited ability to recover [35]. With this in mind, true less invasive surgery should involve not only shorter incisions but also the preservation of soft tissues and joint kinematics using new surgical tools and smaller implants, redefining it as tissue sparing surgery [11, 25].

Increasingly in daily practice orthopaedic surgeons treat patients affected by localized osteoarthritis involving one or both knee compartments. By aiming to replace only the damaged compartment, surgeons try to preserve the physiological kinematics and spare bone and soft tissue structures. As a result of this approach, unicompartmental knee arthroplasty (UKA) and patello-femoral arthroplasty (PFA) have become well-accepted surgical procedures for the treatment of knee arthritis [7, 11, 28, 32, 45, 51]. However, this technically challenging surgery has yielded satisfactory results only in "high-volume surgery" centres even when performed using new modern implant designs [1, 29, 57]. These compartmental procedures are more demanding, less reproducible and less forgiving compared with total knee arthroplasty (TKA). As a result, the great majority of authors still recommend TKA as the most reliable procedure even in compartmental diseases and few surgeons worldwide have experience with small implants for compartmental replacement with or without ligament reconstruction [4, 11, 44].

Computer-assisted surgery (CAS) and robotic technologies for small implants, encompassing pre-operative planning, surgical navigation and patient-specific instrumentation, have the potential to address some of these technical challenges. Several papers have reported that the risk of overcorrection in the different planes is diminished by real-time information about the leg axis at each step during surgery. Use of accurate pre-operative image-based and/or image-less planning has been shown to be especially helpful for less experienced surgeons [27, 30, 34]. However, any positive effects of these navigation systems on clinical outcomes have still not been conclusively shown. At short-term follow-up, a few papers have reported statistical differences between navigated and non-navigated techniques in terms of clinical outcome, survivorship, knee function and ROM [33, 37, 54]. However, no clear advantages have been shown to support compartmental knee reconstruction using small implants and computer-assisted techniques at mid- and long-term follow-up [40, 54].

In this paper, the authors perform a review of the published literature relating to less invasive compartmental arthroplasty of the knee using computer-based alignment techniques and dedicated small implants. They present and compare their own results using these techniques with those reported in the current literature, to contribute to the debate between navigated and non-navigated knee reconstruction using small implants and conventional total knee arthroplasty.

Materials and methods

Computer- and robotic-assisted UKA

For several decades, surgeons have been seeking ways to standardize this highly demanding procedure. In the 1980s, Cartier [8] introduced a pre-tibial cutting guide to improve the reproducibility of this particularly difficult cut for inexperienced surgeons. However, despite improved implant designs, studies have shown that even intramedullary guiding systems do not ensure optimal reproducible surgical techniques for UKA [26].

More recently, the introduction of computer-assisted technology has allowed three different approaches to improve alignment and surgical performances [41, 59]. The first approach employs either image-free or image-based techniques using infrared cameras, metal body markers fixed to the limb (femur and tibia) and a detector to upgrade intraoperatively a predetermined anatomical model in the software application and guide the bone cut to achieve correct limb alignment. The second approach involves the use of robotic-based techniques with a semi-active robotic arm carrying the drill bit that is manipulated by the surgeon's hand. The robotic arm is prevented from moving outside of the milling path boundary, which is defined by computed tomography (CT) image-based pre-operative planning and an intra-operative measure of bony landmarks. The final approach employs the use of a patient-specific instrumentation (PSI) technique based on pre-operative CT and/or magnetic resonance (MR) images. PSI requires advanced skills to perform optimal pre-operative planning using dedicated software. Manufacturing a customized cutting block that fits intraoperatively on the bone surface to achieve the planned alignment of the instruments and implants can be expensive. No other hardware or additional equipment is needed in the operating theatre.

Jenny and Boeri [23] reported the first published study of computer-assisted UKA in 2003. In this study, 30 patients undergoing a UKA using a navigation system were matched with 30 patients undergoing UKA using a conventional alignment technique. The authors concluded that navigation improved the accuracy of UKA implantation without any significant difficulties. The authors did report a 20-min increase in operative time with use of the navigation system. Despite this initial promising work, there have been few further clinical papers describing the results of CAS UKA.

Recently, one meta-analysis and one systematic review, published, respectively, in 2013 and 2014, focused on navigated UKA [40, 54]. The meta-analysis by Weber et al. [54] reported a total of 258 prostheses implanted with a navigated technique and 295 with a conventional alignment system. This analysis concluded that the use of a navigation system leads to more precise component positioning but that better clinical outcomes at short- or mid-term follow-up have yet to be proven. Nair et al. in 2014 reviewed an extensive number of prospective and retrospective studies that compared navigated versus conventional UKA. The authors confirmed the conclusions of Weber et al. that better alignment was achieved using a navigated technique to implant a UKA and found no significant advantage in terms of clinical outcome and survivorship. The conclusions of these papers have discouraged universal adoption of navigation technology to implant a UKA by the orthopaedic community [40]. Our experience (Table 1) using a navigated UKA implantation technique and specifically designed software including an intra-operative kinematic assessment tool has been similar to significantly better implant alignment but no improvement in clinical outcome and survivorship [33]. However, Song et al. [48] compared navigated and conventional UKA implant techniques and showed at 10-year follow-up significantly better HHS and WOMAC pain scores in the navigated group.

The use of robotic technologies for UKA implantation has only recently been introduced to the market, and as a result, no long-term systematic studies can be found in the literature. No study has shown any advantage in terms of clinical outcome or survivorship at a short- and mid-term follow-up using robotic compared with conventional UKA implantation systems [49, 53]. Robotic technologies have been shown to result in higher-accuracy implant alignment, longer surgical time and higher costs compared with conventional systems. In 2015, Moschetti et al. [37] argued that robotic-assisted UKA could become cost-effective for a clinical centre when the annual case volume exceeds 94 cases per year. Despite potential future applications in total hip and knee arthroplasty surgery, the use of robotic technology is unlikely to be employed in both low-volume and medium-volume arthroplasty centres.

The most controversial computer-based technique used for UKA implantation remains the PSI approach. This technique has no proven radiological and clinical advantages, even when performed by trained surgeons. In 2016, Ollivier et al. [42, 43] underlined that PSI-UKA technique requires a surgeon with a good working knowledge of the specific surgical principles. Ideal implant placement using PSI is influenced by patient morphology and requires an experienced surgeon.

Computer- and robotic-assisted patello-femoral arthroplasty

Few authors have proposed computer-assisted techniques in PFA rather preferring image-free navigation systems [3, 17]. However, experimental studies have demonstrated that computer-assisted patellar resection is a feasible approach leading to results equal to or better than those obtained with conventional techniques. This has even been shown in studies where the experimental conditions favour the conventional technique [17]. In 2006, Cossey et al. [13] confirmed the utility of the navigation system for patellar maltracking but also noted an increase in surgical time (average of 20 min) and costs associated with this technique. Hernigou et al. [21] reported a better trochlea rotation and overall clinical scores in a 15-patient matched study with navigated compared with conventional techniques. We were unable to find any other relevant studies using computerized techniques to implant an isolated PFA. No published studies could be found examining the use of robotic or patient-specific instrumentation for isolated patello-femoral implant surgery despite some authors suggesting this was the ideal situation for these techniques [3, 6, 27].

Computer- and robotic-assisted BI-UKA

Bi-cruciate ligament retention in TKA was extensively evaluated in the late 1960s when the first non-hinged implants were introduced. However, our group has published the only three studies of Bi-UKA performed using computer-assisted techniques in 2005, 2008 and 2009 [10–12]. In these studies, we showed that 12 % of our patients who underwent a conventional Bi-UKA suffered an intra-operative fracture of the tibial spines during implantation of the prosthesis. This was thought to be related to excessive tension on the ACL because of either an unbalanced extension/flexion space or failure to restore the joint line (Table 1). Computer-assisted Bi-UKA was shown in our studies to successfully overcome this complication (Figs. 1,

Table 1 Authors' experience in navigated "small implants"

Type of implant	References	Type of study	Number of patients	Results
Navigated UKA	"Computer-assisted unicompartmental knee arthroplasty using dedicated software versus a conventional technique". Manzotti A et al. Int Orthop. 2014 Feb; 38(2):457–63	Matched paired study 6-month minimum follow-up	31 navigated UKA matched to 31 conventional UKA	Significantly better alignment in navigated UKA No differences in outcome and survivorship
Navigated Bi-UKA	"Mini-invasive computer-assisted bi-unicompartmental knee replacement." Confalonieri N et al. Int J Med Robot. 2005 Dec; 1(4):45–5 "Bi-unicompartmental versus total knee arthroplasty: a matched paired study with early clinical results." Confalonieri N et al. Arch Orthop Trauma Surg. 2009 Sep; 129(9):1157–63	Matched paired study 48-month minimum follow-up	23 Bi-UKA matched to 23 TKA	Significantly better WOMAC stiffness and function in Bi-UKA Significantly better alignment using navigation No intra-operative tibial spine fractures in navigated Bi-UKA (common in conventional Bi-UKA technique) No differences in survivorship
Navigated UKA + PFA	15th ESSKA meeting, 2–5th May 2012 Genève Poster 28–699: "Bicompartmental knee arthritis: a prospective matched short term study using UKR + PFA" Confalonieri N. et al.	Matched paired study 4-year minimum follow-up	21 navigated UKA + PFA matched to 21 navigated TKA	Significantly better WOMAC stiffness and function in UKA + PFA No differences in survivorship
Navigated Tri-UNI (Bi-UKA + PFA)	16th CAOS Meeting, 8–11th June 2016, Oral presentation: "Customized Knee Reconstruction: Combined Partial Knee Replacement and Navigation In Post-Traumatic Arthritis" Confalonieri N. et al. Unpublished data	Matched paired study 22.8-month mean follow-up	12 Bi-UKA + PFA matched to 12 navigated TKA	No revision in both the groups No differences in survivorship

Fig. 1 Post-traumatic right knee arthritis in active lady (golfer)

Fig. 2 Bi-UKA

Fig. 3 After 2 years, she chose the same implant. Follow-up 13 years *right* knee, 11 years *left* knee

2, 3). We could not find any report in the literature using either PSI or robotic implantation of Bi-UKA.

Computer- and robotic-assisted patello-femoral and unicompartmental arthroplasty

The combination of a unicompartmental and a patello-femoral implant is one of the cutting-edge topics today [31]. Several papers have discouraged the combined use of first-generation monolithic UKA and PFA devices [36, 38]. However, promising outcomes have been reported in the literature, at least equivalent to TKA, using this combination of implants at 5-year follow-up and with a significantly lower blood loss than seen with TKA [45]. Several authors have underlined that both an additional positional guidance system and an increased range of implant sizes can enable anatomically correct positioning of UKA and PFA implants. As a result, combined UKA and PFA surgery is seen as an ideal indication for computer-assisted or robotic-assisted techniques [36, 38, 50, 56]. However, only one retrospective clinical and radiological study, using a robotic-assisted technique, has been reported that 22 out of 29 patients had good and excellent results [49].

At the 2012 ESSKA meeting in Genève, we presented our early experience of 21 patients who had undergone a combined UKA and PFA by the single surgeon (Figs. 4, 5) at a minimum follow-up of 4 years. There were three lateral and 19 medial combined UKA and PFA using side shaped implants (medial/lateral). In our study, two different patello-femoral components were implanted depending on the distal femoral morphology using either an inlay or an onlay design in a deep or a shallow trochlea, respectively. In two cases, an anallergic femoral component and an all poly tibial component were implanted because of

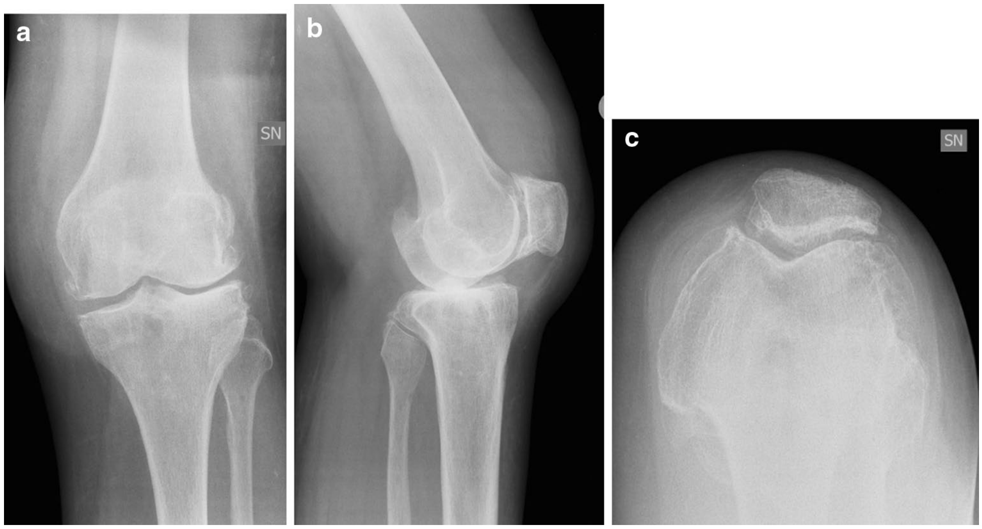

Fig. 4 Arthritis of the lateral compartment of the knee and of the patello-femoral joint in a 72-year-old lady

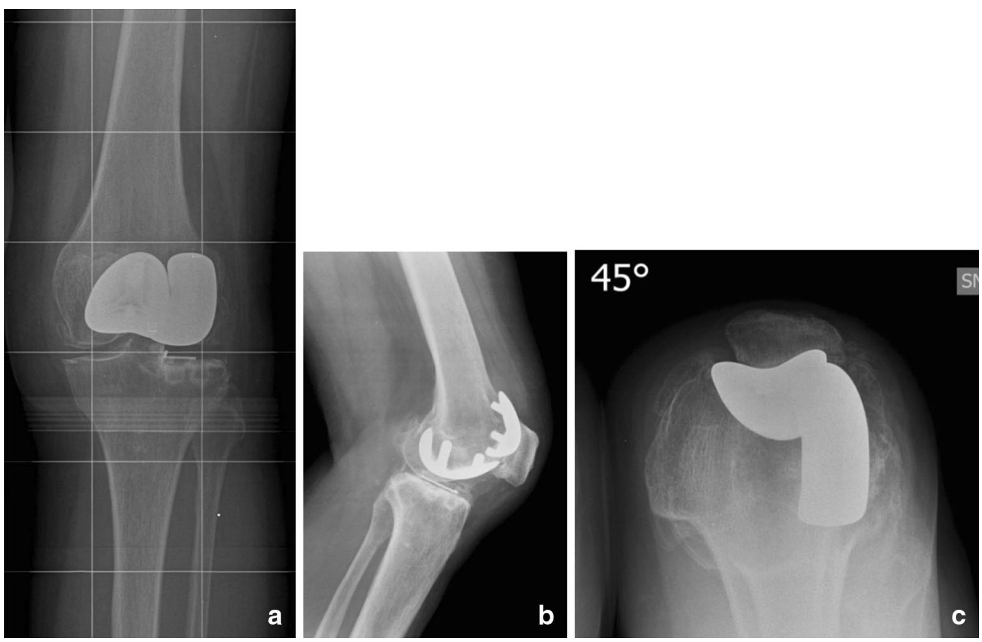

Fig. 5 Lateral UKA + PFA

known metal sensitivity. In this study, a computer-assisted technique was used to assess both the patellar tracking and limb alignment. The study compared the results of group of patients undergoing this technique with those achieved in a navigated cruciate-retaining TKA group. Each patient undergoing a combined UKA and PFA was matched to a corresponding patient undergoing a navigated cruciate-retaining TKA. Matching criteria included sex, age, pre-operative range of motion and arthritis grade. In both groups, all the patients were assessed clinically using the WOMAC and KKS scores. All the knees were radiologically investigated using the same protocol. No intra-operatively complications or differences in length of hospital stay were seen. No patient in either group required revision surgery. At latest follow-up, no statistically significant difference was noted in Knee Society and Functional scores between the two groups. However, a significantly better WOMAC Function and Stiffness indexes were seen in the combined UKA and PFA group with no difference in implant alignment (Table 1).

Computer- and robotic-assisted Bi-uni and patello-femoral (tri-compartmental: Tri-UNI) arthroplasty

This could be considered the most "extreme" application of the new philosophy of compartmental replacement taking place of a "monolithic" TKA using patello-femoral, medial and lateral unicompartmental implants and sparing both the cruciate ligaments. Currently, no clinical paper has been published dealing with this challenging approach, and we can only offer our personal experience (Table 1).

Our surgical technique involves the use of computer navigation to allow us to restore limb alignment by first replacing the most damaged tibio-femoral compartment using the implant thickness required to correct the deformity. Joint line restoration is then achieved with the appropriate implant on the contralateral tibio-femoral side. Finally, patello-femoral tracking is assessed using dedicated software. We used for all metal-backed medial and lateral tibial implants and either onlay or inlay PFA designs depending on the trochlea depth (Table 1).

Since 2010, 12 Tri-UNI implants have been performed (Figs. 6, 7) in 12 patients (nine males and three females) with a mean age of 46 years (range 28–54) and a mean follow-up of 22.8 months (range 8–70 months). The pre-operative diagnosis was a stable knee post-traumatic arthritis in 10 patients and primary tri-compartmental arthritis in two young patients affected by Parkinson's disease. In the latter two patients, it was assumed that this ligament-preserving surgery would help the surgeon to better cope with the "somato-agnosy" (loss of sensation of a body part) often associated with worsening of the neurological condition [16]. At a mean follow-up of 22.8 months, no implant had been revised and no major intra-operative or post-operative complications have been detected. The mean WOMAC score was 1.9, 0.6 and 4.8 for pain, stiffness and function, respectively. The mean Knee Society score was 84.6 and the functional score was 86.3 with no significant difference compared with a similar matched TKA group.

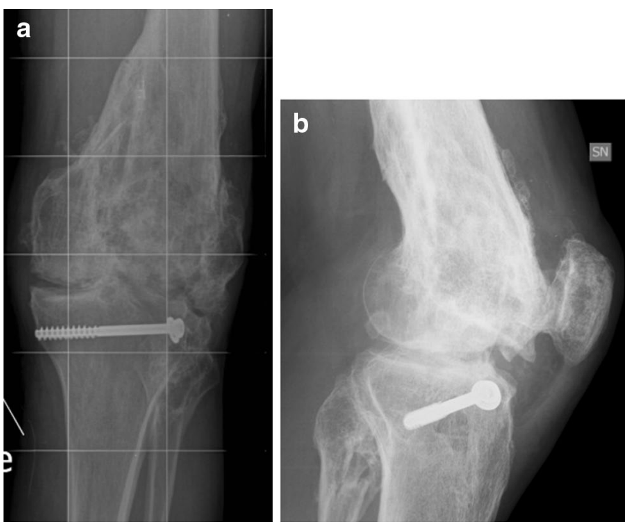

Fig. 6 Post-traumatic knee arthritis in a 44-year-old male. Rigid knee for patello-femoral ankylosis

Discussion

The shifting demographics of patients with localized knee arthritis, including younger and more active patients, are a major impetus for the growing interest in surgical alternatives such as compartmental knee resurfacing. As a result, in the last few years, the role of minimally invasive techniques for the treatment of knee arthritis has continued to evolve towards a concept of "tissue-sparing surgery" [11]. The initial enthusiasm for shorter surgical approaches for knee arthroplasty has been mitigated by the lack of evidence showing a long-term advantage combined with the emergence of new complications [5, 14]. However, small

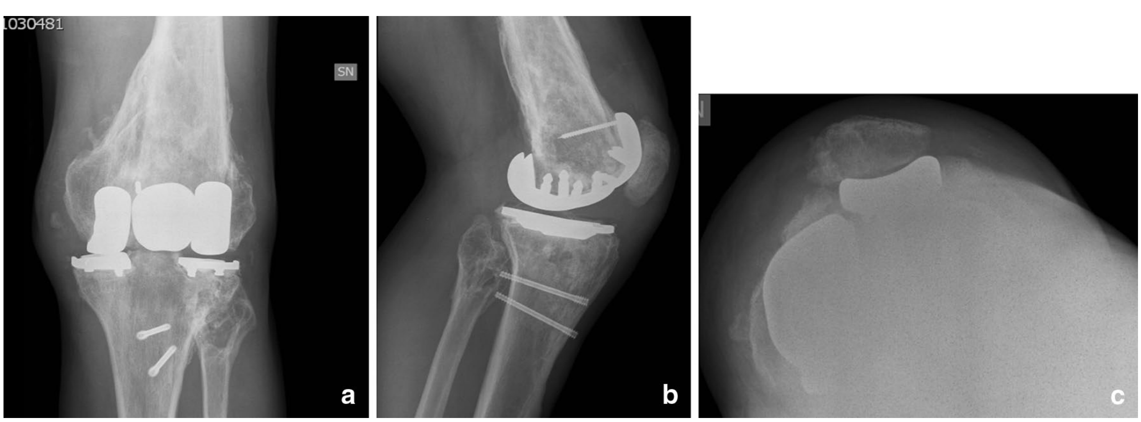

Fig. 7 Tri-UKA. Detachment of the anterior tibial tuberosity was necessary

implants and preserved joint biomechanics have theoretical appeal in knee arthroplasty and may represent a new direction in reconstructive surgery [53]. Several authors have pointed out that compartmental knee arthroplasty is a highly demanding procedure often best performed by experienced and high-volume surgeons [1, 29]. In addition, there is a significant learning curve associated with these procedures, and high failure rates can persist despite modifications to improve conventional surgical techniques.

In this "computer age", several technological improvements have been proposed to standardize these surgical procedures and reduce the learning curve even for low-volume surgeons. Since the beginning of the 2000s, computer-assisted surgery has been applied to TKA and later to compartmental knee arthroplasty [22]. Computer-assisted surgery was proposed to improve implant positioning in joint replacement surgery without the need for an intramedullary guide [2, 58]. Unfortunately, no clear clinical advantages have been demonstrated in TKA using navigation; however, authors have proposed a long-term benefit related to a decrease in the number of implants requiring revision [39, 55]. Recently, better implant survivorship has been reported using navigated TKA in younger patients with longer follow-up [15]. Improvement in clinical outcomes using computer-assisted surgery may be expected in a more demanding surgery such as the UKA where traditional techniques can lead to poor alignment accuracy. Currently, no studies have demonstrated a clinical advantage in small implant surgery using these technologies. Oliver et al. [42, 43] showed that only surgeons experienced in using PSI to perform UKA surgery, gained an advantage with this new technology, underlining that it is not yet ready to be entrusted to low-volume UKA surgeons.

Rates of inaccurate component alignment as high as 30 % have been reported in the literature using conventional free-hand instrumentation to implant a UKA [52]. Authors have argued that coronal misalignment and tibial slope in UKA beyond 3° and 7°, respectively, increase the rate of aseptic failure and have greater effect on UKA than on TKA [20, 24]. Overcorrection in the coronal plane is a well-recognized reason for failure resulting in over loading of the contralateral compartment [46, 47]. In addition, studies have shown that the use of short narrow intramedullary guides cannot prevent misalignment in the three anatomical planes [19, 25]. Despite these concerns, some recent reports of the first series of UKA to treat degenerative knees have enthusiastically recommended the technique. The authors have, however, suggested technical and surgical improvements to enhance clinical success and ensure UKA implant longevity [4, 10, 41, 45].

One meta-analysis and a systematic review have shown better implant and limb alignment using a navigated UKA technique but failed to demonstrate a superior clinical outcome and survivorship [40, 54]. Only Song et al. in 2016 reported significantly better HHS and WOMAC pain scores at 10-year follow-up using a navigated UKA implantation compared with a conventional technique. Recently, Watanabe [53] reported stable knee kinematics consistent with intact and functioning cruciate ligaments in uni- or bi-compartmental arthroplasty using robotic assistance. The authors noted that improved knee kinematics resulted in tibiofemoral patterns of motion more similar to natural knees than those commonly observed in TKA. We have published several papers regarding "navigated small implants" all with excellent results at least similar to those seen with traditional techniques and implants. We believe that navigation is mandatory for this highly demanding technique allowing less invasive implantation techniques and better exploitation of the implants biomechanical features. We acknowledge a potential bias in our results as all the surgeries were performed in the same centre by surgeons highly trained in both compartmental knee arthroplasty and computer-assisted techniques.

Finally, these promising technologies have the potential to improve alignment and possibly clinical outcomes for UKA in a number of situations. Several papers support the teaching role of these emerging technologies in TKA showing a shorter learning curve with similar implant alignment between beginners and expert surgeons. In these studies, it has been suggested that these technologies could play an even greater role teaching surgeons how to accurately implant compartmental knee components [9, 18]. In theory, advanced tools might permit multi-compartmental arthroplasty to be performed through smaller incisions and with less bone resection. Of course, the challenges associated with a multi-compartmental approach increase with the number of components being implanted making the use of additional instruments and more sophisticated tools mandatory [42].

Conclusion

Since the beginning of this century, multiple advances in modern knee arthroplasty surgery have been proposed, however, we believe the most revolutionary emerging idea is a true customized resurfacing of the knee, replacing just the damaged compartment and preserving the normal biomechanics. This will require not only new implant designs but also new technologies allowing the surgeon to make extremely precise adjustments to implant alignment and providing continuous feedback during surgery. Unless these facilities are readily available, the dream of the true customized compartmental resurfacing knee arthroplasty will be reserved for highly experienced and high-volume surgeons who will still be considered artists and not scientists in this age of Mars exploration.

Compliance with ethical standards

Conflict of interest The authors declare they have no conflict of interest.

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Ethical approval According to the regulations of the Medical Ethical Committee of the 1st Orthopaedic and Trauma Department-CTO Hospital ethical approval was not indicated since the present contribute is featuring a review paper.

Informed consent Informed consent was not applicable.

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