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Computer Navigation in Joint Arthroplasty—Is This for Real?

Ryan D. Bauman, MD, and Douglas A. Dennis, MD

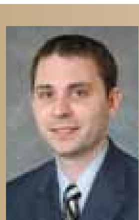
Early condylar total knee arthroplasty (TKA) designs were primarily implanted in elderly, low-demand patients with debilitating pain and loss of function. The excellent 10- to 15-year clinical outcomes in this patient cohort[1-4] led surgeons to begin performing TKA in younger patients, who have higher functional demands and need longer lasting implants. Increased patient expectations for longer lasting knee replacements have driven advances in implant design and surgical technique. Many TKA failures have been attributed to surgical technique errors, including inaccurate prosthetic component placement and subsequent limb malalignment.[5-7] Computer navigation was introduced to TKA to facilitate precise component implantation and reduce malalignment errors. In this article, we review the advantages, the disadvantages, and the future of computer navigation in TKA.

1 Improved Alignment and Accuracy

All surgeons who perform TKA strive for a well-aligned limb. Several studies have demonstrated improved survival when the mechanical axis is restored. Rand and Coventry[8] demonstrated 90% implant survival at 10 years when the mechanical axis was restored to within 4°. When alignment deviation was more than 4°, however, the 10-year survival rate dropped to 73%. Furthermore, analysis of TKA retrievals found a clear correlation between varus malalignment and increased polyethylene-wear rates.[9] Studies have demonstrated that 50% or more of early revisions after TKA are related to instability, component malposition, malalignment, or fixation failure.[5-7] Mulhall and colleagues[10] reported that almost half of TKA failures were secondary to premature polyethylene wear (24.5%) or tibial component loosening (22%), both of which are increased in the presence of prosthetic malalignment.

TKA with traditional instrumentation has numerous potential sources of error, including jig malposition, jig migration, saw blade divergence, intramedullary (IM) canal deformity, and limited IM jig accuracy. These problems can be worsened as each error propagates with each additional step. Computer navigation can reduce error by providing more accurate cutting jig placement than is possible with standard jigs alone, and by allowing verification of the accuracy of each bone resection to levels of less than 1° and 1 mm. Verification at each step can eliminate propagation of error from step to step. As many studies have demonstrated, computer navigation improves accuracy of component positioning and limb alignment, and there are fewer outliers.[11-15] Using the criterion of desired mechanical axis alignment of ±3°, a meta-analysis of studies revealed 31.8% outliers with traditional TKA versus only 9% with computer-assisted surgery (CAS) TKA (CAS-TKA) (P<.00001).[16] Computed tomography (CT) analysis of 70 knee arthroplasties performed with and without computer navigation demonstrated statistically improved coronal femoral component alignment, femoral rotation, coronal tibial alignment, tibial rotation, posterior tibial slope, and standing femoral-tibial alignment with computer navigation.[12]

As part of a prospective study recently conducted at our institution, 40 sequential bilateral TKAs were performed. In each patient's case, one of the TKAs was performed with traditional techniques, and the other with CAS-TKA. All surgical procedures were completed by 2 high-volume, fellowship-trained adult reconstructive orthopedic surgeons. A nonsignificant trend toward improved anatomi-



Dr. Bauman is Adult Reconstructive Orthopedic Fellow, Colorado Joint Replacement, Denver, Colorado.
Dr. Dennis is Adjunct Professor, Department of Biomedical Engineering, University of Tennessee, Knoxville, Tennessee; Assistant Clinical Professor, University of Colorado Denver Medical School, Denver, Colorado; and Clinical Director, Rocky Mountain Musculoskeletal Research Laboratory, Denver, Colorado.

Address correspondence to: Douglas A. Dennis, MD, Colorado Joint Replacement, 2535 S Downing St, #100, Denver, CO 80210 (tel, 720-524-1367; fax, 720-524-1422; e-mail, kslutzky@coloradojoint.com).

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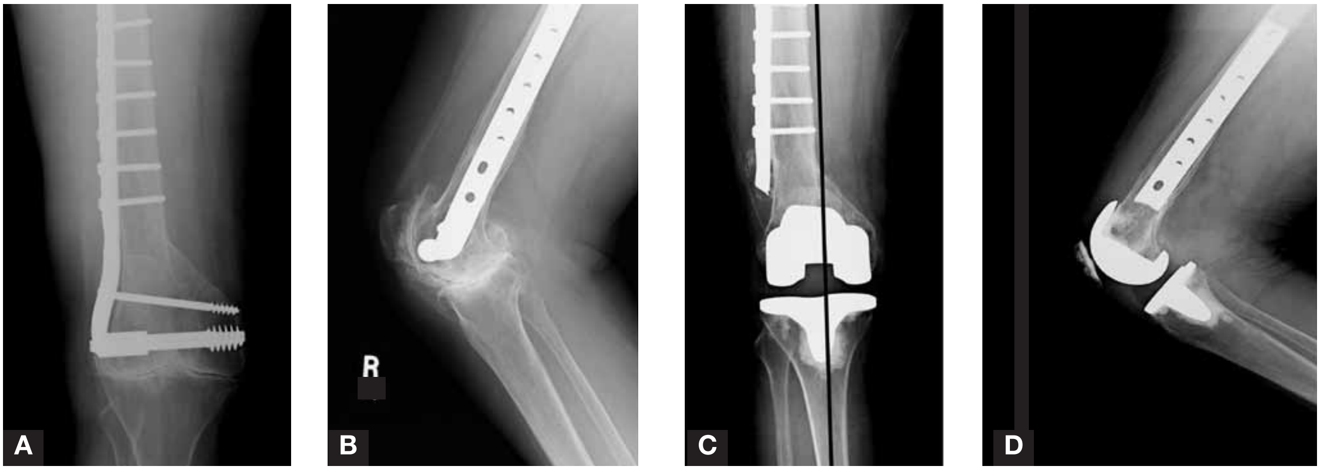

Figure 1. **Preoperative (A) anteroposterior and (B) lateral radiographs of knee with hardware (retained after femoral osteotomy) precluding intramedullary instrumentation. Postoperative (C) anteroposterior and (D) lateral radiographs after computer-navigated total knee arthroplasty show excellent alignment with restoration of mechanical axis.**

cal alignment with computer navigation techniques was observed, but there was no difference in clinical knee scores at a minimum follow-up of 2 years (mean, 2.4 years).[17]

Despite improvements in component positioning and limb alignment with use of CAS-TKA, reports of improved implant longevity over that obtained with traditional techniques are not yet available. Longer follow-up studies are needed to demonstrate any differences that may exist in terms of implant longevity.

2 Beneficial in Complex Cases

CAS is an ideal tool for use in difficult TKA cases. Numerous situations, including severe cardiopulmonary disease (particularly in patients with a patent foramen ovale), retained femoral hardware, and severe IM osseous deformity (Figure 1), preclude use of traditional IM guide rods. In addition, TKA in a patient with an obese leg with obscured anatomical landmarks is more difficult to perform with traditional techniques (Figure 2). CAS is also useful in patients with extra-articular deformity from a fracture malunion or previous osteotomy that may require corrective osteotomy (Figure 3). Navigation software allows the surgeon to determine if the extra-articular deformity can be corrected with intra-articular bone resections without violating the collateral ligament attachments. Last, cases in which it may be difficult or undesirable to penetrate a region of previous osteomyelitis with an IM rod can be treated with CAS techniques, and with good reliability. A study of 17 complex cases performed with CAS found excellent alignment in 94% of patients, and there was only 1 outlier.[18] Although computer navigation is certainly beneficial in the complex situations mentioned, it is wise for surgeons to frequently use computer navigation in standard TKA cases so that they can gain a thorough understanding of the technology before using it in more difficult cases.

3 Spares the Intramedullary Canal

Another potential advantage of CAS is the ability to perform the surgery without cannulating the IM canal of the femur or tibia. Sparing the IM canal during CAS-TKA has been shown to reduce blood loss.[12,19] In addition, insertion of an IM rod during standard TKA generates increased IM pressure and subsequent embolization of IM contents into the systemic circulation. With use of transcranial ultrasound, Riding and colleagues[20] demonstrated that paradoxical embolization into the circulation may occur through a patent foramen ovale or other venous-to-arterial circulatory shunts. This "paradoxical" embolization could account for post-TKA mental status changes in some patients. In a prospective comparative study, patients who had TKA performed with computer assistance had no more than 2 detectable cerebral emboli (mean, 0.64), whereas patients who underwent conventional TKA had as many as 43 detectable emboli (mean, 10.7).[21] The emboli in the conventional TKA group occurred almost exclusively at the time of IM rod insertion.

Figure 2. **In an obese leg with obscured visual landmarks, traditional total knee arthroplasty can be difficult.**

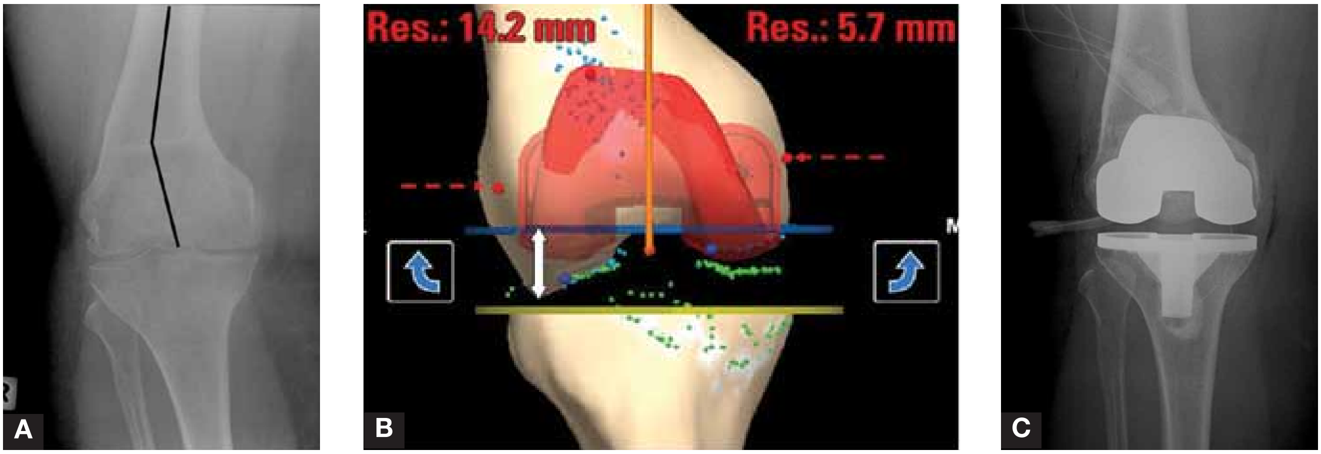

Figure 3. **(A) Preoperative anteroposterior radiograph shows distal femoral deformity (from previous varus distal femoral osteotomy) that may require repeat osteotomy. (B) Intraoperative computer image shows intra-articular resection that is needed to correct the extra-articular deformity and that does not compromise collateral ligamentous attachments (dashed arrows). (C) Radiograph obtained after total knee arthroplasty was performed with computer-assisted surgery. Repeat distal femoral osteotomy not required.**

The clinical implications of marrow embolization are unclear. A few small studies have failed to show a difference in oxygen requirements or mental status between conventional TKA patients and CAS-TKA patients.[21,22] A larger prospective study with adequate statistical power is needed to clearly determine if computer navigation can reduce post-TKA hypoxemia and mental status changes.

4 Drawbacks of Computer Navigation

Computer-assisted knee surgery is not without its drawbacks. Computer use has a significant learning curve. The user must learn the system's nuances, including registration of multiple points, use of the optical scanner, and proper placement of registration pins. This learning curve involves more surgical time and multiple additional steps over those needed for traditional TKA—including placement of pins, registration of the hip center and other anatomical bone landmarks, and verification of accuracy of bone cuts. Although these additional steps are eventually minimized, surgical times remain increased by 10 to 13 minutes on average.[12,14]

With these additional steps come potential additional complications. Potential pin complications include osseous or pin fracture, prolonged drainage from pin sites, and entrapment of soft tissues with tibial pins, which may preclude appropriate medial soft-tissue releases if these pins are placed proximally within the TKA incision. Inaccurate registration of anatomical bone landmarks results in operative error.

Although coronal plane alignment information has proved to be very accurate, guidance for rotational femoral component positioning has been less precise because of surgeon inability to accurately and reproducibly identify the critical bone landmarks (eg, transepicondylar axis) used to determine femoral component rotation. In addition, although CAS assists in performing and verifying the bone resection, positional errors can still occur during final implantation of prosthetic components.

In obese patients, there is another problem: accurate femoral head center identification. Attempting to identify the hip center by hip rotation in the obese patient with substantial buttock soft-tissue mass may lead to pelvic motion and aberrant identification of the hip center and subsequent limb malalignment.

Last, CAS is associated with the extra costs of increased operative time, expensive computer software, optical scanners, and registration pins. In a complex medical environment, validating the usefulness of CAS will be necessary to justify these extra costs.

5 The Future

As with other evolving technologies, CAS has many potential benefits. Preoperative imaging (CT, magnetic resonance imaging, ultrasound) can be used to produce precise 3-dimensional (3-D) bone models that can then be used during CAS-TKA to increase precision and reduce operative time, as much of the planning is done ahead of time. For example, whereas the femoral epicondyles are often not accurately identified during traditional TKA,[23,24] these important bone landmarks can be precisely identified through combined use of accurate 3-D models of the operative femur (made before surgery) and computer navigation. In addition, navigated surgery offers potential in unexplored areas. Using the computer to register the patella could offer increased precision of patellar resection and allow for more accurate intraoperative assessment of patellar tracking. Computer control of power saws can help prevent inaccurate bone resection and damage to adjacent soft-tissue structures. Intraoperative assessment of TKA kinematics is another area of potential benefit. Instead of assessing the stability of trial implants in static positions, the surgeon, aided by the computer, can track implant stability throughout the functional range of motion. Last, further developments in computer software are likely to help surgeons in assessing soft-tissue balance, and to provide them with more intraoperative feedback, so that they can more precisely assess the effect of individual soft-tissue releases.

Although CAS has drawbacks, its ability to improve accuracy, assist in difficult cases, and decrease marrow embolization—and its myriad future potential applications—should encourage surgeons to continue to contemplate its benefits. The continued evolution of CAS technology will reduce the learning curve and offers the potential of enhanced operative efficiency at acceptable cost. Computer use is omnipresent, and its benefits should not be ignored but embraced. Computer navigation is one more tool for surgeons, who will remain in control of the operative procedure.

Authors' Disclosure Statement

Dr. Bauman reports no actual or potential conflict of interest in relation to this article. Dr. Dennis wishes to note that he is a consultant to DePuy, Inc., and receives royalties on total knee arthroplasty products; he does not receive royalties on any computer navigation–related products.

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