Innovations in Total Knee Arthroplasty: Improved Technical Precision, But Unclear Clinical Benefits

JAMES A. KEENEY, MD

Total knee arthroplasty (TKA) has been an effective treatment for advanced degenerative joint disease. Traditional knee designs and surgical approaches have resulted in consistently high performance, but some patients may remain dissatisfied after their surgery. Several surgical innovations, including accelerometer-based navigation, patient-specific instrumentation, and robotic-assisted total knee arthroplasty, have been developed to improve the accuracy and precision of total knee arthroplasty surgery, with anticipated secondary benefits of improved functional outcomes and implant survivorship. This article reviews the current status of these technologies as reported in contemporary orthopedic literature. [Orthopedics. 2016; 39(4):217-220.]

Abstract

Total knee arthroplasty has been an effective treatment for advanced degenerative joint disease. Traditional knee designs and surgical approaches have resulted in consistently high performance, but some patients may remain dissatisfied after their surgery. Several surgical innovations, including accelerometer-based navigation, patient-specific instrumentation, and robotic-assisted total knee arthroplasty, have been developed to improve the accuracy and precision of total knee arthroplasty surgery, with anticipated secondary benefits of improved functional outcomes and implant survivorship. This article reviews the current status of these technologies as reported in contemporary orthopedic literature. [Orthopedics. 2016; 39(4):217-220.]

Total knee arthroplasty (TKA) has been an effective treatment for patients with advanced degenerative joint disease. During the past 4 decades, changes in TKA materials, designs, and instrumentation systems have been incremental with an intention to improve technique consistency, functional implant performance, and implant survival. Advances in implant materials and polyethylene sterilization processes have contributed to reduction in late wear-related revision rates, but component loosening, infection, instability, and joint stiffness may still contribute to both early and late revision risk.1,2

The stepwise improvements in implant technology and surgical technique have contributed to broad success with TKA, but many patients do not experience their desired outcome. Published studies suggest that 15% to 20% of patients are dissatisfied with their knee replacement.3,4 Even when patients express satisfaction with their knee replacement, they may still experience undesired symptoms.5 The introduction of newer TKA designs may not have improved symptoms, particularly among the most active, younger, and higher demand patients.6 Implant designs made available in the United States within the past 5 years offer a wider range of implant sizes and polyethylene thicknesses. Although these may allow surgeons currently performing conventional TKA to optimize implant-bone interface sizing and soft tissue balancing, they have not been adequately studied to know whether they will successfully address concerns of TKA instability, component loosening, or patient dissatisfaction.

Several innovative technologies have been introduced during the past 2 decades to improve the accuracy and precision of TKA component placement. Their anticipated secondary benefits include more reliable component positioning, improved patient-reported outcome scores, enhanced prosthetic joint performance, and improved implant survivorship. This article focuses on 3 TKA innovations—accelerometer-based surgical navigation, patient-specific instrumentation, and robotic-assisted surgery—and summarizes the current state of published knowledge on these technologies and their

The author is from Adult Hip and Knee Reconstruction, University of Missouri School of Medicine, Columbia, Missouri. The author has no relevant financial relationships to disclose.

Correspondence should be addressed to: James A. Keeney, MD, Adult Hip and Knee Reconstruction, University of Missouri School of Medicine, 1100 Virginia Ave, Ste 4054, Columbia, MO 65201 (keeneyj@health.missouri.edu).

doi: 10.3928/01477447-20160628-03

**Surgical Navigation**

Component placement during the earliest TKA procedures involved free-hand techniques and was subject to component malposition, joint instability, and component loosening. Conventional instrumentation systems were developed more than 3 decades ago to improve the reliability of component placement in primary TKA surgery. During the past 2 decades, computer technologies have been adapted into surgical navigation systems to further enhance the precision and accuracy of TKA component placement. Initial computer-assisted surgery (CAS) navigation systems used line-of-sight between devices on the surgical field and remotely positioned sensors to assay lower extremity movement and define knee position alignment (optical CAS). Blakeney et al reported fewer mechanical alignment outliers greater than 3° when comparing CAS (19%) with extramedullary (38%) and intramedullary (36%) placed TKAs, but were not able to show that this resulted in significant differences in functional outcome scores. Cip et al also reported more accurate alignment among CAS TKAs (90%) compared with conventional TKAs (81%) but were not able to establish significance of a four-fold lower 5-year revision rate. Although some studies have reported no significant difference in alignment, functional outcome, or survivorship when comparing conventional and navigated TKA across a wide patient age spectrum, de Steiger et al suggested that CAS may be associated with a reduced revision rate among CAS-navigated TKAs when performed for patients younger than 65 years. Since the initial release of optical CAS systems, high capital expenses combined with inconsistently reported benefits of CAS navigation for clinical outcomes or surgical revision rates have prevented widespread adoption of these systems in clinical practice.

Newer, accelerometer-based navigation systems that incorporate dynamic motion sensors and radiofrequency communication systems within the surgical field have shown improved TKA alignment when compared with optically based CAS systems. Nam et al reported more frequent alignment within 3° of a neutral mechanical axis with an accelerometer-based system (92.5%) compared with a large console, imageless CAS system (86.3%). Goh et al noted slightly improved mechanical axis alignment with the accelerometer-based CAS system, but no difference in clinical outcome scores or patient satisfaction rates at 6 months after surgery. Although the reduced equipment footprint and decreased capital expenses for these portable systems may contribute to future availability, the current literature has not substantiated superiority of these systems over conventional TKA instrumentation.

**Patient-Specific Instrumentation**

Three-dimensional printing technologies have enabled implant manufacturers to develop cutting guides based on anatomic relationships derived from computed tomography or magnetic resonance imaging. These technologies have shown specific benefits for patients with complex extra-articular deformities or internal hardware that may complicate the use of conventional instrumentation. However, their adaptation of patient-specific instrumentation into primary TKA surgery has received mixed reviews. In one of the earliest reports, Ng et al noted fewer outliers among components placed using patient-specific instrumentation (9%) compared with components placed using conventional instrumentation (22%). In contrast, Stronach et al reported that TKAs performed using this same patient-specific instrumentation system required frequent adjustments by the surgeon. Although these were most commonly differences in component size, there were 12% of cases where the femoral jig was not accurately fitted and 5% where the tibia was not accurately placed. Other authors have noted no significant difference in either component alignment, patient-reported outcome scores, or measured physical function. Pfitzner et al reported slightly better control of coronal plane mechanical alignment using magnetic resonance imaging–based than computed tomography–based patient-specific instrumentation systems, but no significant difference in femoral component rotation and slope. Most of the published studies have not substantiated an advantage of patient-specific instrumentation over conventional TKA instrumentation, but DeHaan et al suggested that the net costs may be comparable when their use is associated with a consistent decrease in operative time.

**Robotic Surgery**

The potential for robotic surgery to improve the accuracy and precision of TKA was introduced in reports describing the early results of CAS navigation. Although the value for TKA procedures was considered, the comparisons of robotic CAS, navigation CAS, and instrumented surgery were initially described for unicompartamental arthroplasty, with improvement in coronal plane alignment, sagittal plane alignment, and individual unicompartamental arthroplasty component position reported in some studies. In contrast, Hansen et al reported no significant differences in unicompartamental arthroplasty component position, fixation, or clinical outcomes.

There appear to have been substantive improvements in robotic-assisted TKA. The first generation of robotic-assisted surgery was associated with improved component alignment, but a higher rate of surgical complications than conventional TKA. Other studies have reported improved component alignment, ability to restore flexion-extension gap relationships, and reduction in notch avoidance among robotic-assisted TKA.
benefits have generally been achieved with substantially increased operative time.\textsuperscript{32,33} As experience with these technologies improves, a decline in operative time would be expected.

**DISCUSSION**

Traditional knee replacement surgery has been performed with 3 central reconstructive goals: (1) restoring appropriate knee alignment, referencing off a neutral mechanical axis; (2) creating a balanced soft tissue envelope with symmetry as the knee moves through the flexion-extension arc; and (3) maintaining or restoring normal patellofemoral kinematic relationships.\textsuperscript{34} The importance of alignment restoration has been debated more recently in peer-reviewed, published literature. Although Parratte et al\textsuperscript{35} noted that revision knee replacements were accomplished at least as frequently for knees reconstructed within 3° of a neutral mechanical axis as for those that were malaligned, Fang et al\textsuperscript{36} reported optimal implant survivorship among knees reconstructed between 2.4° and 7.2° of anatomic valgus and a failure rate 3 to 4 times higher for knees reconstructed more than 1 standard deviation away from the desired alignment. Howell et al\textsuperscript{37} reported improved functional outcome scores when TKA was performed targeting a restoration of a kinematic axis close to the native position of the patient’s femur, rather than shifting the femoral implant position to result in a neutral mechanical position. Reconstructing to a neutral mechanical axis target may result in lower functional outcome scores than retaining components closer to the patient’s native anatomical position.\textsuperscript{38} However, Yim et al\textsuperscript{39} were unable to identify differences in alignment, soft tissue balance, or clinical outcome scores when targeting a kinematic as opposed to a mechanical alignment during robotic-assisted TKA.

Determining the importance of 2-dimensionally defined alignment positions for TKA performance is complicated by the complex nature of knee movement, which includes the effects of both angular and translational movement in coronal, sagittal, and axial planes. Other factors that may contribute to implant and soft tissue balance may be difficult to assess: femoral component design, posterior cruciate ligament management, femoral axial plane rotation, Tibial axial plane rotation, and the presence or severity of soft tissue contractures among patients with chronic deformity. Adjustments made in 3-dimensional component position in coronal, sagittal, and axial planes can impact implant loading and the generation of tensile forces through the supporting soft tissue structures. Internal axial plane TKA malrotation has been associated with increased rates of postoperative anterior knee pain.\textsuperscript{40,41} Gustke et al\textsuperscript{42} noted that the presence of measurable soft tissue imbalance is associated with poorer patient-reported outcome scores following TKA.

Although ideal component position targets are currently under debate, achieving consistent component placement remains a desirable goal of contemporary TKA surgery. Balancing the soft tissue envelope around the knee is assisted by balancing the soft tissue contractures among patients with chronic deformity. Adjustments made to the predictability of achieving intended component position, whether this is based on a kinematic or a mechanical alignment target. Computer-assisted and robotic-assisted surgery techniques generally achieve a high level of precision and accuracy, but have not uniformly provided improved patient-reported outcome scores or reduced TKA revision risk. Patient-specific instrumentation has not proven to be as successful in reproducing alignment targets for routine TKA surgery, but may be particularly beneficial when extra-articular malalignment or retained components complicate the use of conventional instrumentation.

Innovations in TKA component design, materials, and surgical techniques are important to increase the proportion of patients who experience their desired outcome following TKA. Although computer-assisted technologies have shown consistency in achieving desired component alignment, patient-reported outcomes and implant survival have not been confirmed using contemporary implant designs. The wide range of implant sizes and polyethylene thicknesses available with contemporary implant systems may help to improve the outcomes of knee replacement when combined with CAS techniques. The relative cost associated with the implementation of many of these technological advancements remains a barrier to their widespread incorporation into routine TKA procedures.

**REFERENCES**


