Review Article

The Role of Intraoperative Navigation in Orthopaedic Surgery

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Abstract

An orthopaedic surgeon's knowledge of anatomical landmarks is crucial, but other modalities supplement this by providing guidance and feedback to a surgeon. Advances in imaging have enabled three-dimensional visualization of the surgical field and patient anatomy, whereas advances in computer technology have allowed for real-time tracking of instruments and implants. Together, these innovations have given rise to intraoperative navigation systems. The authors review these advances in intraoperative navigation across orthopaedic subspecialties, focusing on the most recent evidence on patient outcomes and complications, the associated learning curve, and the effects on operative time, radiation exposure, and cost. In spine surgery, navigated pedicle screw placement may increase accuracy and safety, especially valuable when treating complex deformities. Improved accuracy of pelvic and peri-articular tumor resection and percutaneous fixation of acetabular and femoral neck fractures has also been achieved using navigation. Early applications in arthroscopy have included surface-based registration for tunnel positioning for anterior cruciate ligament reconstruction and osteochondroplasty for femoro-acetabular impingement. Navigated arthroplasty techniques have addressed knee gap balancing and mechanical axis restoration as well as acetabular cup and glenoid baseplate positioning. Among these orthopaedic subspecialties, significant variation is found in the clinical relevance and dedication to research of navigation techniques.

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A surgeon's knowledge of relevant anatomy is critical, but intraoperative imaging and navigation capabilities currently supplement this knowledge to improve the surgeon's orientation. Today's imaging and computer technology allow real-time three-dimensional (3D) reconstruction and tracking of instruments within a surgical field. These technological advancements can potentially minimize risk and improve both accuracy and reproducibility of a surgical procedure.

The earliest concept of surgical navigation dates back to cranial stereotaxy described by Horsely and Clarke in 1908, in which a frame attached to the skull was used to target intracranial lesions based on a coordinate system.[1] Mechanical tools were combined with basic mathematical concepts to increase surgical accuracy. The advent of CT would later modernize this concept, with increasing availability of advanced imaging and complex computer processing. By the late 1990s, techniques for the first image-guided lumbar pedicle screw placement and computer-assisted total knee arthroplasty (TKA) were both published.[2,3]

Table 1

Navigation Systems Widely Available in the United States

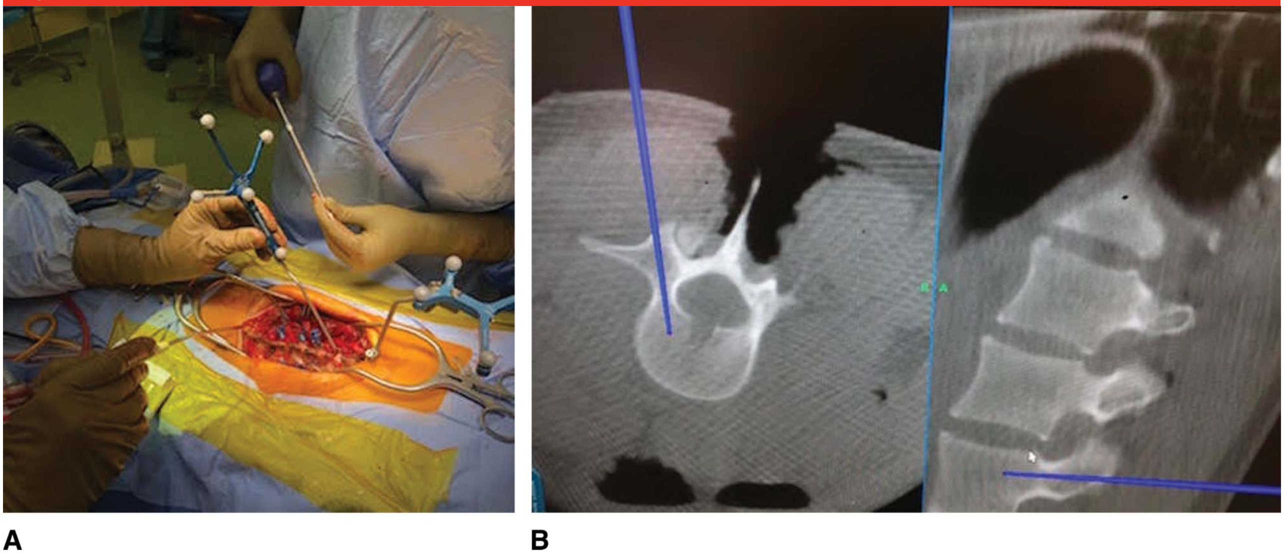
System	Company	Guidance Type	Applications	Imaging Required?	Additional Info
iASSIST	Zimmer-Biomet	Stereotactic/ accelerometer	TKA	No	—
Orthosoft	Zimmer	Optical	TKA	No	—
BrainLab Navigation systems	BrainLab	Optical (VectorVision)	Spine, Trauma, THA, TKA, Tumor	CT (Airo Mobile), fluoroscopy	Dual pins drilled into the femur
MAKO Rio	Stryker	Semiactive robotic	TKA, TKA, THA	CT	Semiactive robotic arm with haptic feedback
Nav3i	Stryker	Optical	THA, TKA, Trauma, F&A, Spine	CT, Fluoroscopy	—
Intellijoint	Intellijoint Surgical	Infrared/optical	THA	No	—
OrthoAlign	OrthoAlign	Stereotactic/ accelerometer	THA, TKA	No	—
Radlink GPS	Radlink	Stereotactic	THA	Fluoroscopy	—
The Corin OPS	Corin Group	Premade jig for cup position	THA	CT	Not approved by FDA
ROBODOC	Integrated Surgical Systems	Semiactive robotic	THA, TKA	CT	Fully active robotic arm
TSolution One	Think Surgical	Active robotic	THA, TKA	CT	Fully active robotic arm
StealthStation	Medtronic	Optical	Spine, Trauma, Tumor	Intra-op CT with O-arm interface	—
NAVIO	Smith and Nephew	Optical	Knee	No	—
FireFly	Mighty Oak Medical	Premade jig	Spine	CT	—
Renaissance	Mazor Robotics	Optical	Spine	CT	—
ExcelsiusGPS	Globus	Semiactive robotic	Spine	CT, fluoroscopy	—

F&A = foot and ankle, THA = total hip arthroplasty, TKA = total knee arthroplasty

Principles of Intraoperative Navigation

Intraoperative navigation can be fluoroscopy- or CT-based, or can rely on an imageless system. Table 1 summarizes navigation systems widely available in the United States. Fluoroscopy-based systems recognize markers that are placed on anatomic landmarks and captured on radiographs, whereas other systems can import an intraoperative CT or perform 3D reconstruction of two-dimensional images. These images are then coupled to a navigation software platform. Figure 1, A and B demonstrates the use of intraoperative navigation software coupled with an intraoperative CT for pedicle screw placement. Imageless systems, on the contrary, typically require the surgeon to place markers on anatomic landmarks that are recognized by an optical camera, and then a computer processes these markers in conjunction with a stored CT (preoperative or intraoperative) to generate a virtual model. Further, navigation systems can be categorized as passive or active. Passive navigation platforms provide imaging information without placing any restraint on the surgeon's actions.[4] For instance, a preoperative CT can be merged with the intraoperative robotic-arm guidance to help a joint arthroplasty surgeon adhere to planned joint resection boundaries, providing visual feedback to the surgeon when those boundaries are respected or violated. In contrast, active navigation systems directly perform a task or prevent a surgeon from violating a predetermined boundary or pathway. For example, Figure 2, A and B shows an imageless active navigation system, in use during pedicle screw placement for adolescent idiopathic scoliosis. A preoperative spine CT is used to 3D-print models of each

Figure 1



A, Photograph showing how the surgeon uses intraoperative navigation coupled with an intraoperative CT to place pedicle screws during posterior spinal fusion for adolescent idiopathic scoliosis. The reference array is placed on the spinous process (bottom right). The silver markers on the reference array and the coupled pointer (center) are recognized by an optical camera. B, The photograph shows the intraoperative navigation software interface during pedicle screw placement. The surgeon uses navigation to confirm safe pedicle screw placement by placing the coupled pointer into the pedicle screw tract created, which is superimposed on the axial (left) and sagittal (right) CT cuts visible to the surgeon.

vertebral level, which are then used to create patient-specific guides for each vertebral level which constrain drills to predetermined pedicle screw trajectories.

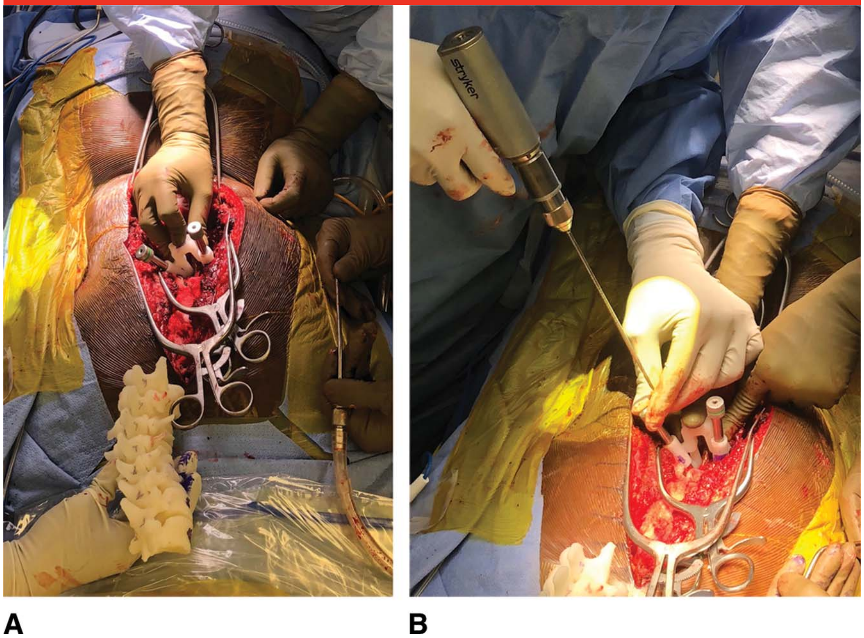
Regardless of the imaging modality or anatomic location, the basic principles of intraoperative navigation remain the same. The spatial relationship between preoperative imaging or intraoperative imaging and patient-specific anatomy must first be established.[4] Navigation software establishes this relationship through the *registration* of patient anatomy. Anatomic landmarks such as a spinous process or iliac crest are registered, or matched, to the corresponding points on the preoperative or intraoperative imaging that was imported into the navigation software. The registration process may occur *before* navigation, in which case any inadvertent movement of the landmarks at any time *after* registration can disrupt the accuracy of navigation. On the other hand, if intraoperative 3D imaging is used, the registration process may be automated during the operation.

Intraoperative Navigation in the Orthopaedic Subspecialties

Spinal Deformity and Degenerative Disease

The surgical treatment of spinal deformity and degenerative disease has evolved over the past 20 years with the widespread use of pedicle screws. A common goal for emerging intraoperative navigation platforms has been to maximize the safety of pedicle screw placement.[5] Pedicle screw placement can be technically demanding, as a surgeon must identify the correct entry point, trajectory, and length of the unexposed pedicle or risk injury to the nearby spinal cord, nerve roots, and great vessels. Rotational deformities and narrow thoracic pedicles make screw placement increasingly challenging. Freehand methods for pedicle screw placement are widely accepted and have had reported screw misplacement rates anywhere from 1.7% to 15.7%.[6,7] There is an abundance of literature on the accuracy and safety of pedicle screw placement, some of which is highlighted in Table 2. One multicenter registry reported the accuracy of pedicle screw placement using intraoperative CT-based navigation as 97.5%.[7] Other authors have shown that intraoperative (versus preoperative) CT-based navigation techniques for scoliosis may increase the accuracy and efficacy of placement of a single pedicle screw.[8] Robot-assisted navigation techniques have demonstrated decreased risk of pedicle screw breach compared with freehand fluoroscopy techniques.[9] Navigated pedicle screw placement safety has also been studied among cohorts with a complex anatomy and/or narrow pedicles. Cervical pedicle screws are biomechanically advantageous to other posterior cervical

Figure 2



A, The photograph shows the use of the FireFly system, an example of imageless, active navigation. A preoperative CT is used to create a three-dimensional (3D)-printed model of the spine (bottom center). Pedicle screw trajectories are planned preoperatively and used to 3D-print the corresponding jigs for each vertebral level (center). The jig is held at the corresponding vertebral level, and drill guides are placed into the jig. **B**, The drill guide placed into the jig *actively* guides the surgeon to drill in the pre-determined pedicle trajectory.

fixation techniques but technically challenging due to the risk of neurovascular injury; one study has reported a 99% accuracy rate of navigated cervical pedicle screw placement.[10] Authors have found real-time visual feedback from navigation useful for preventing attempted instrumentation of pedicles that were absent or otherwise appeared to be impassible and for improving implant density in the setting of syndromic scoliosis.[11,12] Intraoperative navigation has been shown to reduce the odds of unsafe screw placement in narrow thoracic pedicle screws by nearly four times and the odds of a medial breach by nearly eight times compared with a non-navigated cohort.[6]

Radiation exposure during spine surgery is of interest to the public because historically, patients with scoliosis were found to have increased rates of breast and thyroid cancer.[14] Radiation exposure does vary significantly for intraoperative navigation modalities as some rely on CT or fluoroscopy whereas others are imageless. The most recent evidence on patient radiation exposure using CT-based navigation versus fluoroscopy has been inconclusive. One study demonstrated higher effective radiation doses using CT compared to fluoroscopy for posterior spinal fusion, especially for obese children.[13] However, progress has been made to reduce the radiation dose. A pediatric "O-arm" protocol reduced the mean radiation dose (1.17 mSV) to 10 times less than the device's default protocol, which generated satisfactory images in all but one patient in one study.[14] Any comparison is confounded by the surgeon technique, as fluoroscopy time is highly variable, but authors have calculated that the effective dose (0.65 mSV) of one pediatric protocol (80 kV, 20 mA, 80 mA s) for instance, approximates 85 seconds of fluoroscopy time.[15] Surgeons can thus use this information to decipher which imaging modality is optimal for their patients based on their anticipated fluoroscopy time. The radiation dose received by the surgical team is also of interest. The reported yearly radiation dose for a pediatric spine surgeon using fluoroscopic guidance is 3.33 mSv, wearing a lead apron and standing adjacent to a C-arm.[16] Similarly, the highest yearly radiation dose for an unprotected person standing 2 m from the center of an O-arm is 3.32 mSv.[18] The latter suggests that navigation reduces occupational exposure because protective lead, standing behind a lead shield, or exiting the room during the scan can each lower this dose even further.

The operative time and cost associated with intraoperative navigation have also been studied in spinal surgery. The setup time and total operative time using navigation have been shown to be 10 to 20 minutes longer than those without navigation, but navigation has also been shown to cut the time for placement of a single pedicle screw in half.[17,19] Another study found a trend toward longer setup times in the navigated group but a significant decrease in operative length over time in navigated but not freehand cases, indicative of navigation's possible "learning curve."[20] Also, an economic analysis on adult spinal surgery using intraoperative navigation reported fewer reoperations for misplaced screws than a matched cohort for which conventional fluoroscopy was used.[21]

Arthroscopy

Over the past decade, intraoperative navigation in arthroscopy was largely focused on anterior cruciate ligament (ACL) tunnel positioning in ACL reconstructions to optimize graft

Table 2

Accuracy, Radiation Exposure, Operative Time, and Cost of Intraoperative Navigation in Spine Surgery

Study	No. of Patients (and Pedicle Screws)	Age at Time of Surgery	Surgical Indication	Results
Accuracy and safety of PS placement				
Van de Kelft et al[7]	353 (1,922-180 thoracic, 1,510 lumbar, 230 sacral)	58.4 yr ± 15.0 yr	Varied: adult degenerative disease	PS accuracy with O-arm + Stealth = 97.5%.
Zhang et al[8]	67 (1,118)	16 yr (range, 12-25 yr)	AIS	*PS accuracy same* between preoperative and intraoperative CT-based navigation groups
				Intraoperative group has a higher accuracy of *apical* vertebrae PS (94.8%, versus 89.2%).
Molliqaj et al[9]	169 (880)	57.6 ± 5 yr	Varied 78% adult degenerative disease 6.5% tumor, 15% trauma	83.4% accuracy with robot-assisted group (Mazor SpineAssist) and 76% freehand fluoroscopy-guided group.
Theologis and Burch[10]	21 (121)	63 yr (range, 32-83 yr)	Cervical spine deformity (primary and revision procedures)	PS accuracy with O-arm + Stealth = 99%
				1 screw (0.8%) demonstrated a medial breach, with acute C5 nerve root palsy, but no vascular complications due to aberrant screw placement
Larson et al[11]	14 (142)	8.8 yr (range, 0.8-17.8 yr)	Congenital spinal deformity	Navigated PS accuracy 99.3%.
Ughwanogho et al[6]	42 (547, all thoracic)	14 yr (range, 11-17)	AIS	Misplaced screw 3.8 times less likely with navigation.
				8.3 times more likely to be removed intraoperatively in the non-navigated cohort (P = 0.003). Medial breach 7.6 times higher without navigation ($P < 0.001$).
Jin et al[12]	32 (213)	15 yr (range, 11-27)	Neurofibromatosis	Higher accuracy in navigated versus freehand (79% versus 67%, P = 0.045), lower incidence of medial breach (2% versus 15%, $P < 0.01$), and higher apical region implant density (42% versus 58%, $P < 0.001$).
Radiation exposure				
Dabaghi Richerand et al[13]	76	Not reported (pediatric)	AIS	CT navigation radiation exposure is more than that of fluoroscopy (1.48 ± 1.66 mSv versus fluoroscopy 0.34 ± 0.36 mSv, P = 0.001), especially for obese children (3.0-8.5 mSv).[14]

(*continued*)

AIS = adolescent idiopathic scoliosis, PS = pedicle screw, PLIF = posterior lumbar interbody fusion, TLIF = transforaminal lumbar interbody fusion

Table 2 (*continued*)

Accuracy, Radiation Exposure, Operative Time, and Cost of Intraoperative Navigation in Spine Surgery

Study	No. of Patients (and Pedicle Screws)	Age at Time of Surgery	Surgical Indication	Results
Su et al[15]	37	14.4 yr (range, 5-18 yr)	62% scoliosis, 13% kyphosis, 9% spondylolisthesis	CT navigation radiation dose is four times that of intraoperative fluoroscopy ($P < 0.0001$).
Operative time and costs				
Silbermann et al[19]	67 (339)	60 yr in freehand group and 64 yr in navigated group	PLIF or TLIF for adult degenerative disease	Setup + position time: 34.5 + 183min, without O-arm navigation, and 53 and 193 min, with O-arm.
Rajesekaran et al[17]	33 (478)	—	AIS	PS placement time: 4.61 min freehand fluoroscopy versus 2.37 min using navigation (P = 0.01).

AIS = adolescent idiopathic scoliosis, PS = pedicle screw, PLIF = posterior lumbar interbody fusion, TLIF = transforaminal lumbar interbody fusion

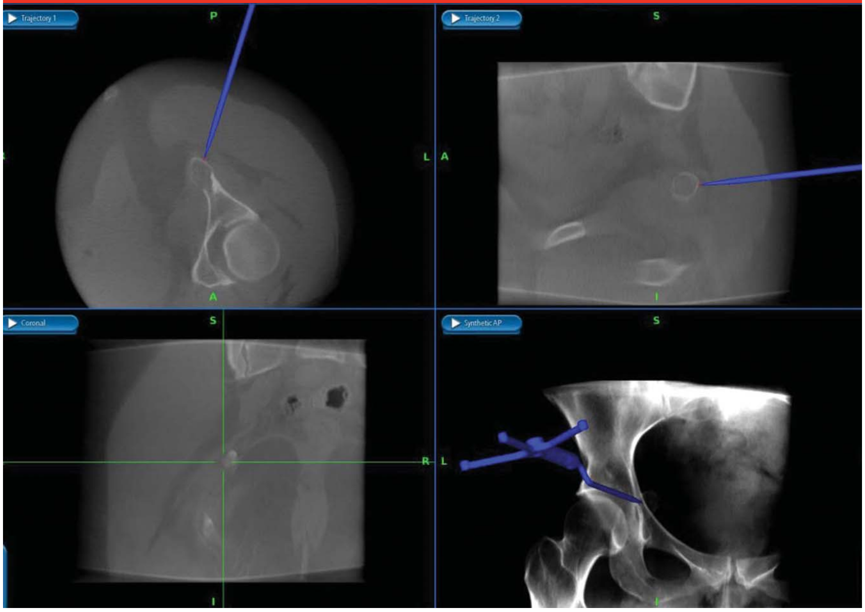
kinematics and isometry. Most failed ACL reconstructions are attributable to tunnel malposition, so navigation has been applied in an attempt to increase the accuracy of tunnel placement. A prospective, randomized controlled study comparing tunnel placement for primary ACL reconstruction using a manual technique and a CT-free navigation system did not find any significant differences in tunnel positioning, graft impingement, or function at 2 years postoperatively.[22] More recently, use of a novel optical tracking marker and landmark acquisition method for imageless navigation of ACL tunnel placement did show an improved accuracy of posterior wall margin with navigation.[23] Although navigation has had limited uses in knee arthroscopy, recent research on navigated hip arthroscopy has demonstrated potential to improve this operation. Osteochondroplasty for the treatment of femoroacetabular impingement poses a challenge to the surgeon who must rely on preoperative 2D imaging and intraoperative arthroscopic images to evaluate and then correct a 3D pathology. Navigation-assisted surgery has been proposed to increase its accuracy and success. Kobayashi et al[24] reported their experience with preoperative planning software and intraoperative navigation for the treatment of cam morphology femoroacetabular impingement. The authors performed impingement simulation to calculate an ideal resection area and depth for a virtual osteochondroplasty, and then visualized improvement in range of motion on the simulation model after the virtual surgery. Intraoperative fluoroscopic guidance was used to register anatomic landmarks, the preoperative plan was executed, and a tracked pointer was used to assess the volume of resection. The authors concluded that this technique would help surgeons to first preoperatively identify an impingement point and the extent of bone necessary to resect for effective osteochondroplasty, and then intraoperatively execute a precise plan that can be objectively assessed.

Orthopaedic Oncology

Intraoperative navigation was first introduced in tumor surgery as a means of improving surgical accuracy and margins, but its applications have evolved to improve both oncologic and reconstructive outcomes. The technology has been used in the treatment of pelvic and periarticular resections to help achieve adequate margins while also sparing important nearby structures or articular surfaces. Pelvic tumors pose a surgical challenge, considering the surrounding organs and neurovascular structures as well as the difficult 3D anatomy that surgeons conceptualize to plan resections. Sawbones and cadaver studies have illustrated that navigation improves the accuracy of surgical osteotomies and margins, even in the absence of any soft-tissue consideration.[25] The fusion of CT and MR imaging has enhanced the visualization of soft-tissue structures and soft-tissue tumor extension, further improving surgical guidance and safety.[26] Improved accuracy allows surgeons to pursue more ambitious joint-sparing and/or multiplanar resections, with the overarching aim of realizing better functional outcomes, reconstructive longevity, and quality of life. Figure 3 shows an intraoperative navigation software interface during a wide resection of a chondrosarcoma of the posterior acetabulum with sparing of the articular surface.

Navigation-assisted tumor resection can also help a surgeon to carry out a complex preoperative plan involving a custom allograft or megaprosthesis with precision, thereby improving allograft–host bone congruency (and, in turn, bone union) or prosthesis fit, respectively. Outcomes for extremity resection and allograft reconstruction have yielded a nonunion rate of as low as 6%, while encountering few technical limitations and a modest registration time requirement.[27] It remains difficult to compare oncologic outcomes in small reported series because of varying histologies, inherent biological properties, chemotherapy response, tumor sizes, and limited follow-up. However, improvements in intraoperative visualization, design and execution of a planned resection, and surgical accuracy all serve in support of navigation, even in the absence of more robust outcome data.

Figure 3



The intraoperative navigation software interface during the wide resection of an ischial spine chondrosarcoma. The ischial spine and posterior acetabulum were curetted down to the subchondral bone, and intraoperative navigation facilitated sparing of the articular surface. The interface displays axial (top left), sagittal (top right), and coronal (bottom left) CT cuts, as well as an AP pelvis radiograph (bottom right) with the surgeon's coupled pointer superimposed.

Arthroplasty

Intraoperative navigation has also been a valuable tool in the arthroplasty subspecialty. In TKA, the technology has been used to aid in component positioning, gap balancing, and mechanical alignment. Recent literature on navigated TKA is summarized in Table 3. One study demonstrated that navigation-assisted TKA has been shown to significantly decrease the incidence of postoperative component malalignment.[28] Navigated unicompartmental knee arthroplasty (UKA) may also benefit from increased accuracy, as one study reported a statistically significant increase in the proportion of implants within 2° of the target positions in all parameters when compared with a conventional group.[31] Another study echoed these benefits of navigated TKA but questioned whether navigation demonstrated a clinically relevant advantage, reporting no significant differences in functional outcome, quality of life measures, or satisfaction rates at 2 years postoperatively.[29] However, a study using the Australian Orthopaedic Association National Joint Replacement Registry found that patients under 65 years of age who underwent navigated TKA had a significant reduction in revision rates overall and revisions specifically for loosening when compared with conventional TKA.[30] In addition, a recent study on the U.S. Nationwide Inpatient Sample database demonstrated that navigated TKA was associated with lower transfusion rates and perioperative complications but with no significant difference in length of stay or hospital charges compared with conventional TKA.[32]

Intraoperative navigation systems have also been used to assist in successful component positioning for total hip arthroplasty and reverse total shoulder arthroplasty. In total hip arthroplasty, CT-based navigation has been shown to improve accuracy of cup positioning, including both cup inclination and anteversion, in a patient cohort with primary osteoarthritis and hip dysplasia.[33] Additionally, a study on passive navigation for reverse total shoulder arthroplasty using patient-specific glenoid baseplate drill guides has shown the potential to improve the accuracy of glenoid baseplate positioning when compared with a preoperative surgical plan.[34] Although navigated arthroplasty does have its benefits, it is important to note that the temporary reference pins placed outside of the surgical site can pose pin-site complications. A review on 3,136 pin sites in 839 patients reported five pin-site complications, including three infections, one neurapraxia, and one suture abscess, but no fractures.[35]

Orthopaedic Trauma

Surgical navigation has also been studied in various orthopaedic trauma

Table 3

Accuracy, Functional Outcomes, and Peri-operative Complications of Knee Arthroplasty Using Intraoperative Navigation

Study	No. of Patients	Results
Primary TKA		
Kinney et al[28]	50	Level 1 trial decreased incidence of >3° component malalignment in a navigated TKA group (iASSIST) compared with a conventional group (4% versus 36%, $P <$ 0.05), without significant difference in blood loss or tourniquet time.
Goh et al[29]	152	Level 1 trial compared navigated (iASSIST), computer-assisted (BrainLab, Ci Mi TKR), and conventional TKA and found a significant improvement in mechanical axis in navigated TKA but no significant differences in clinical outcomes.
de Steiger et al[30]	315,118	2003 to 2012 revision rate after all non-navigated and navigated TKAs performed in Australia. In patients under 65 yr of age, navigated TKA had a significant reduction in revision rates compared with conventional TKA (6.3% versus 7.8%, P = 0.011).
Primary UKA		
Bell et al[31]	120	Level 1 trial UKA with MAKO RIO system versus conventional UKA. CT 3 mo postoperatively reported robotic group had increased implants within 2° of the target position when compared with the conventional group.

TKA = total knee arthroplasty, TKR = total knee replacement, UKA = unicompartmental knee arthroplasty

settings. Fractures that are amenable to percutaneous screw fixation lend themselves particularly well to intraoperative navigation. For percutaneous pinning of femoral neck fractures, fluoroscopy-based navigation has been shown to improve parallelism and spread as well as minimize overall complications and revision surgery rates compared with conventional C-arm fluoroscopy.[36] Along the same lines, applications in percutaneous screw fixation for pelvic and acetabular fractures have demonstrated high accuracy of screw placement compared with a CT-based preoperative plan.[37] A cadaveric study on percutaneous iliosacral screw placement by orthopedic trainees using intraoperative fluoroscopic navigation coupled with a CT-based preoperative plan showed that a navigation use significantly increased accuracy, decreased Kirshner wire insertions, and decreased radiation time.[38] A cadaveric study on scaphoid fracture percutaneous fixation showed similar benefits: although navigation required an average of five additional minutes of setup, it significantly reduced guidewire placement time and fluoroscopy time, and had the same accuracy as conventional fluoroscopy.[39]

Barriers to Widespread Acceptance of Intraoperative Navigation

Current navigation technology can provide substantial benefits including real-time feedback, increased accuracy, and improved visualization, but systems are still in their infancy. In an era of rising healthcare expenditures, the potential for increased cost, setup, surgical time, and staffing needs as well as the learning curve of navigated surgery must be considered by surgeons and hospital administrators alike. As with any evolving technology, using navigation in a clinical setting can often involve a degree of trouble-shooting on the part of the surgeon, circulating nurse, surgical technician, or manufacturer representative. Regardless of the technique, the surgeon is ultimately responsible for the patient and thus must recognize navigation as a supplemental tool, such that a procedure could continue within the standard of care in a conventional manner should the system fail.

In terms of direct costs, hospitals must consider the initial acquisition of navigation platforms and intraoperative imaging modalities as well as maintenance expenses. Navigation platforms that have broader applications may be a more fiscally responsible choice in a lower-volume setting (Table 1). Hospitals must also consider that some systems rely on reusable components (ie, reference arrays) whereas others rely on disposable, patient-specific guides (ie, screw trajectory jigs). Indirect costs dependent on total operative time and length of stay are likely variable and, as shown in the aforementioned studies, may decrease over time as surgical teams become familiar with the setup.[20] In terms of surgeon training, the real-time visual feedback may allow residents to become more technically involved without sacrificing patient safety.[38] Additionally, a current lack of long-term outcome data on this new technology is a barrier to surgeon acceptance, but this may be ameliorated with increasing availability of literature over time. In terms of patient acceptance, one study examining patient perception of robotic and navigated surgery in the United Kingdom in 2014 reported that half of the patients believed that this type of surgery was more accurate, faster, and easier for the surgeon whereas about 20% believed that it provided no benefit over conventional surgery.[40] Technological advancements in health care have provided tools that can improve clinical practice, but it is critical that surgeons and hospital administrations embrace navigation responsibly, recognizing its limitations and avoiding its use solely for the sake of marketing.

Summary

Intraoperative navigation has been used throughout orthopaedics, but tremendous variation can be seen in the clinical usefulness, acceptance, and volume of research across the subspecialties. Translating supposed benefits into improvement in clinical outcomes has been successful in some practice settings and subspecialties more than others. Based on the authors' interpretation of the literature, evidence for the use of navigation is strong in the areas of spine and oncology, moderate in arthroplasty, and weaker in trauma and arthroscopy. The recurring theme is the goal of improving surgical technique and outcomes, but as with any new technology, inherent concerns about navigation systems are valid. These modern tools will continue to evolve, and providers must adapt current practices with the knowledge of risks and benefits for each individual subspecialty and application.

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