Review Article | Journal of Karnataka Orthopaedic Association | January-February 2023; 11(1): 05-12

Technologies in Total Knee Arthroplasty

Ravikumar Mukartihal[1], Rajdeep Das[1], Chandan S[1], Vikram G K Bhat[1], Balakrishna Nallabolu[1], Sreedhish K[1], Bharath Krishna S, Sharan S Patil[1]

Abstract

Total Knee Arthroplasty (TKA) is a very impelling treatment for severe osteoarthritis. But, prosthesis longevity along with clinical and functional outcome of patients are intricately related to proper alignment and position of the prosthesis and how perfectly the artificial joint can mimic the native knee anatomy and kinematics. To minimize outliers and improve accuracy, precision and patients' outcome, promising new technologies have been developed in knee arthroplasty. TKA is advancing by leaps and bounds with the advent and introduction and application of technologies in its domain. The aim of this article is to put up and brief about the technologies in TKA, their concepts, advantages, and limitations.

Keywords: Total knee arthroplasty, Knee arthroplasty, Total knee replacement, Osteoarthritis, Technology, Biomedical technology, Robot-assisted surgery, Artificial intelligence, Augmented reality

Introduction

Total knee arthroplasty (TKA) is a proven and rewarding treatment for patients with advanced osteoarthritis of knee [1]. Traditionally, this is performed using intra- or extra-medullary alignment rods to 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. Hence, the 'one-for-all' principle is not practicable for every knee. Studies now testify that correct alignment improvises postoperative outcomes-pain, function, and longevity of the implant [2, 3, 4]. So, each surgery needs to be tailored according to the patient to achieve the gold standard of "the forgotten knee". This necessitates to follow the basic surgical principles along with precision [5]. Computer-navigated and robotic-assisted total joint replacement have presently blazed the trail to obtaining the best of outcomes in every possible aspect following TKA [6]. The aim of this article is to briefly highlight the technologies in TKA, their underlying concepts, advantages-limitations while discussing the relevant literature.

1. Patient Specific Instrumentation (PSI)

In PSI, 3D imaging models are created and anatomical landmarks are identified from the computed tomography (CT) scan or magnetic resonance imaging (MRI) images. The bony resections and implant variables are planned using an interactive, computer-based planning tool. Once the plan is approved by surgeon, cutting blocks (devices to cut directly through the custom block) or positioning templates (the surgeon uses a standard cutting block based on the pin placement of customized pin guides) that fit on the patient's native anatomy, are rendered with rapid prototyping technology. The jigs are delivered to the hospital, usually in sterile packaging acceptable for the operating room [7, 8]. PSI thus endeavours for accurate implant placement through accurate cutting guides. MRI-generated template has been found to be better than CT-based guides [9] because MRI incorporates residual articular cartilage; whereas CT does not account for residual cartilage and relies on multiple bony sites [7].

Advantages and Limitations

PSI can facilitate less-invasive surgical approaches and enhance surgical precision with reduced operative time and blood loss as there is no violation of intramedullary canal. However, PSI systems do not help with gap balancing or soft tissue releases, implant rotation and fixation, as well as patellar preparation [7].

To conclude, no study has demonstrated any difference in the clinical, functional or gait pattern outcomes according to the technique [10, 11, 12, 13].

[1]Department of Trauma and Orthopaedics, Sparsh Hospital for Advanced Surgeries, Bengaluru, India.

Address of Correspondence :
Dr. Ravikumar Mukartihal
Consultant Orthopaedic and Robotic Joint Replacement Surgeon, Department of Trauma and Orthopaedics, Sparsh Hospital for Advanced Surgeries, Bengaluru, India.
E-mail: ravikumarmukartihal@gmail.com

Submitted: 11-09-2022; Reviewed: 08-10-2022; Accepted: 15-10-2022; Published: 10-01-2023

Journal of Karnataka Orthopaedic Association | Available on www.jkoaonline.com | DOI: *https://doi.org/*10.13107/jkoa.2023.v11i01.057

2. Individual Knee Arthroplasty Implant

Chronic residual pain, stiffness, or laxity after TKA can be due to inadequate anatomical restitution of native joint by the implant [14, 15]. A customized individually made implant device is designed to mimic the native knee (pre-arthritic) anatomy, using single-use customized instrumentation. These implants aim for precise and stable bone-implant fit to optimize ligament balancing, patello-femoral tracking, knee joint kinematics and native limb alignment. A 3D knee model is used to produce customized implant and instrumentation by using additive manufacturing/3D printing technologies. Operative planning, implant size, design, positioning and overall limb alignment are always validated by the surgeon. Customized cutting femoral and tibial blocks are used for surgery [7]. Some recent studies have reported better implant positioning and limb alignment with minimal deviations between planned and postoperative angles and fewer outliers as well as increased patient satisfaction rates as compared to conventional technique [16, 17, 18, 19, 20]. Whereas others found no significant difference in clinical outcomes [21, 22].

Advantages and Limitations

Customization of implants enables the surgeons with lighter implants, lesser bone resection and simpler ligament balancing. Nevertheless, it does not take into account ligament balancing. Moreover, customization is done using imaging of an arthritic knee and could still be unsatisfactory with no guarantee of superior results [7].

3. Sensor-assisted technology

Improper ligament balancing leads to pain, stiffness, instability, revision and overall dissatisfaction [23]. Hence, ligament balancing is so essential and at the same time, so tedious to assess and manage. Even in PSI, customized implants, accelerometers, robotic or navigated TKA, laxity assessment is manual and subjective. Arthroplasty surgeons achieve soft tissue balance subjectively rather than a scientific perspective [24, 25, 26, 27]. This subjective "feeling" is modulated by surgeons' own personal experience and condition like strength, as well as patient factors like BMI, gender, stature, ligament laxity and pre-existing joint contracture as well as type of anaesthesia [28, 29]. The subjective assessment of surgeons is insufficient to ensure an appropriate soft tissue balancing [30, 31].

Sensor-assisted total knee arthroplasty is a novel and objective technology where smart sensor (SS) devices are integrated into implants for delivering real-time data to monitor implant position, ligament balancing and soft tissue releases to improve balance and stability through a full range of motion, and post-implantation data of long term monitoring-implant performance and patient clinical parameters [32, 33]. Many companies produce this gadget, nevertheless VERASENSE™ Knee System (OrthoSensor Inc., Dania Beach, FL, USA) is the primarily used device. It is a wireless and disposable articular loading quantification device, which is incorporated in tibial tray. The capsule is approximated by few stitches. The leg is held in a neutral position- medial and lateral loading forces are monitored through full range of motion. Less than differential loading of 15 pounds between the medial and lateral compartments, is considered as adequately "balanced" [7, 34].

Advantages and Limitations

Coronal and sagittal load imbalances are reported by sensors, even after an appropriate gap balance using the tensiometer. Functional scores and range of motion (ROM) are improved after sensor-assisted TKA than after manually balanced TKA [35], arthrofibrosis rates are reduced [36]. Nevertheless, no study has demonstrated a significant improvement of patient satisfaction after TKA with these devices [37, 38, 39]. The "normal" values remain extended, and a personalized adaptation is probably required for each patient [7]. The clinical follow-up are yet too short for evaluating the clinical utility of this device [7].

4. Accelerometer

Accelerometer-based navigation is a handheld wireless and imageless sterile device to ascertain the distal femoral and proximal tibial resection planes in the coronal and sagittal planes [40]. They capture and display the data on pods which remain fitted to the resection guides within the surgical field. Movements of hip through a "stop-and-go" movement with star configuration, and knee from left to right with subsequent knee flexion movements help to determine femoral and tibial mechanical axes. After the cuts, a validation electronic pod validates the cut axis and enables for any adjustments or additional resection if any. Rest of the procedure is completed manually in conventional technique [7].

Advantages and Limitations

Accelerometer-based navigation can be used with all TKA systems. It is particularly useful for complex cases with extra-articular deformities which precludes use of intramedullary jigs. But its effect on functional outcomes are still not clear. Budhiparama et al. reported that they "found very inconsistent (and generally small) benefits in favour of accelerometer-based navigation in terms of alignment, but no benefits regarding the functional outcomes or the risk of complications or reoperations. Until or unless more compelling evidence in favour of the new technology emerges, they recommend against its widespread adoption" [41].

This system has limitations. The accuracy and precision of the references is surgeon-dependent. Moreover, it fails to guide regarding implant size, alignment, rotation, and ligament balancing. It can be considered simply as a tool to improve bone cut accuracy compared to extra or intramedullary guide techniques.

5. Computer-Assisted and Robotic-Assisted Total Knee Arthroplasty

Computer-Assisted Surgery (CAS) was nurtured to maximize precision and accuracy of bone cuts and minimize errors in alignment and positioning of implants in TKA. CAS consists of computer platform, tracking system and a rigid body marker [42].

Computer-assisted orthopaedic surgery is pillared on two technologies: navigation and robotic arm assisted technology. In Navigation, surgical planning is done pre-operatively, and intra-operative real-time feedback in obtained to enhance the accuracy. However, it fails to eradicate the surgical error due to surgeons' manual control, which is why navigation technology did not become popular in clinical practice [43]. To eliminate the surgeon-dependent manual inaccuracy, Robotic Assisted Technology was developed. It has a mechanized device (usually a robotic arm) that receives input from sensors to guide accurate positioning of the instruments and exact implants as per navigation input and planning. It also utilizes real-time data intraoperatively for surgical steps to overcome the manual surgeon-dependent errors [44].

Robotic Assisted Knee Arthroplasty amalgamates navigation, minimally invasive technology, and robotic arm usage for precise preoperative planning, proper implant selection, minimally invasive surgery, correct bone cuts, and accurate implant placements [44]. This robotic-assisted system also enables surgeon to check ligament balancing during the surgery by giving valgus or varus stress [7].

Difference between ROBOTICS and CAS: Three key parameters that differentiate robotics from CAS is the ability of robotics to create haptic boundary, provide real-time feedbacks, and the ability to leverage augmented reality for more real-time experience [45].

Image-Guided versus Image-Free Surgical Planning: Image-guided robotic systems need a 3D plan based on intraoperative bone morphology mapping, or a preoperative CT scan or MRI. A preoperative 3D reconstruction plan is built for virtual assessment of implant size, placement and alignment [46]. Intraoperatively, the robot validates bony landmarks and the software develops a virtual knee model [45]. The disadvantages include the cost of the preoperative imaging study, the patient inconvenience to obtain the study at certified centres, and the radiation exposure [43, 46, 47].

Image-free robotic systems require anatomical bone registration done by intraoperative surface mapping manually. A 3D virtual model is developed by software, and planning is doing during the surgical procedure. Hence, preoperative imaging and planning is not required or performed. Nevertheless, registration is dependent on surgeon's precision, and very much prone to subjective error [7].

Open versus closed systems: Closed systems authorize and permit only one manufacturer's implant product to be compatible with the software and hardware and hence available as a bundled product. Open platforms are usually third party, independent developments and are compatible with many implant options giving allowing freedom of selecting implants at surgeons' choice. Open systems are argued to miss an individual implant design specifications and intricacies, and may not be reproduce and provide the finer adjustments which a specific implant design warrants [45].

Passive robotic system performs surgical planning and guide tool positioning but works only under the direct and constant supervision of the Orthopaedic surgeon who does the bone resections. It includes APEX ROBOTIC™ technology (OmniLife Science).

Active robotic system autonomously performs the planned resections after the surgeon performs the preoperative plan (bone resection, implant positioning and sizing), surgical approach and exposure of knee. The surgeon oversees and may deactivate in emergency if and when necessary. It includes CASPAR (Ortho-Maquet/URS, Schwerin, Germany) and ROBODOC® (Curexo Technology Corporation, Fremont, CA, USA).

Semiactive robotic system enables surgeons to keep overall control and synchronize with it by providing audible, tactile and visual feedbacks to limit deviation from surgical plan. It also provides haptic restraints for the margins of surgical resection with either a speed or depth control mode for the working instruments like burr and saw. It incorporates the image-less robotic Navio® (Smith+Nephew) and OMNIBotics® surgical systems (CORIN), the image-based MAKO® robotic system (Stryker) and ROSA® knee system (Zimmer Biomet) [45].

Advantages

Alignment and implant positioning: Robotic TKA has high accuracy of restoring femoral and tibial sagittal and coronal alignment, tibial slope, posterior condylar offset ratio, Insall-Salvati ratio, native limb alignment and joint line compared to a jig-based TKA [48, 49, 50]. This systems uses optical motion capture technology to assess intraoperative alignment, component positioning, range of motion, flexion-extension gaps, and medio-lateral laxity. The real time feedback information is then analysed and processed to pristinely resect bone and place the components dead-on for obtaining the best knee kinematics, avoiding the necessity for any unnecessary bony or soft tissue release [48, 51]. Improved accuracy leads to greater patient satisfaction, more stability, and improved joint motion kinematics [52, 53, 54].

Ligament Balancing: Present Robotic systems can register and plan for ligament balancing by giving valgus and varus stress manually. This enables surgeon to assess the ligament balancing in extension and knee flexion at 90°, or during all range of motion and make adjustments and necessary modifications during surgery. This facilitates for mid-flexion balancing, which is very problematic during conventional jig-based TKA [7]. However, these values are subjective and dependent on the surgeon and multiple patient and intraoperative factors as mentioned before in the article.

Periarticular soft tissue injury: Robotic TKA applies haptic boundaries by optical motion sensor technology confining the blade movement within the boundaries of bone resections, which minimizes iatrogenic periarticular soft tissue injury [1].

Early functional outcomes and time to hospital discharge.

Conservation of soft tissue and ligamentous envelope around knee joint in robotic TKA reduces postoperative swelling [55], pain and analgesics need, and results in earlier SLR and standing, earlier and better knee ROM and walking, and minimizes inpatient physiotherapy duration [51, 56].

Medium- to long-term functional outcomes

Precise implant placement and faster postoperative rehabilitation in robotic TKA did not create any significant differences in medium- to long-term functional outcomes when compared with conventional TKA [57, 58, 59, 60, 61, 62].

Limitations

Increased operative time and complications: Robotic-assisted knee arthroplasty has got a learning curve and require increased operative time, especially during the learning phase. This leads to concern for increased tourniquet time and related complications, infection rates, blood loss, and OT turnover time [1, 45].

Capital expenditure and maintenance costs: Robots require a substantial financial capital investment, which may not be feasible for all centres or surgeons. The newer generation of robots cost less than previous versions. Cost burden is amplified by mandatory servicing and software as well as the single use disposables and the consumables. Preoperative CT scan also adds up to the expenses [63, 64].

Musculoskeletal complications: The pins used for registration may cause peri-prosthetic fractures if placed in the diaphysis. Pin tract site infection and neurovascular complications are also a potential risk with pins placement [45].

Radiation exposure: Robotic systems that necessarily require CT scans cause significant radiation exposure. The radiation exposure related complications should be kept in mind. However, the image-free systems that need not require CT scan do not cause such potential hazards [45, 65].

Future of Robotics

Although far way off from reality, but the novel ideas and tools continue to be in constant making. It ranges from hand held tactile navigated burrs (as compared to the present bulky robotic arms), in-clinic 3D printing of patient specific prostheses from a CT scan, to smart robotic devices that enables operation remotely [66].

6. Artificial Intelligence

Artificial intelligence (AI) is a novel field in computer science using computer algorithms to reason, perform and emulate human cognitive functions [67] and perform operations at par or transcending surgeon performance [68, 69]. AI technology is used before, during and after knee arthroplasty. Nevertheless, the safety profile and effectualness of AI incorporated TKA are yet to be proven and validated [70].

AI in preoperative knee arthroplasty

AI can screen and predict high-risk patients and guide for strategizing preventive measures [71].The decision-making algorithm is ground upon valid and dependable predictive factors, for example, demographics or preoperative patient-reported outcome measurements (PROMs) [72]. AI algorithms can also define preoperative parameters, score osteoarthritis severity, and minimize inter-observer variability [73]. Preoperative patient-specific planning incorporates native alignment, prosthesis size and positioning and gap balancing. Component size can be anticipated based on algorithms using demographic data like age, gender, weight, height, ethnicity/race, and shoe size. In revision knee arthroplasty, it may help predict implant loosening with X-ray (precision > 95%) and suggest prosthesis designs [74].

AI-based teaching tool, known as Immersive Virtual Reality, gives access levels to surgical techniques in a 360-degree viewing mode. With practice of this tool, prosthesis alignment can be greatly improved and complications can be decreased in primary as well as revision knee arthroplasty [75]. The assistive mode of the tool gives feedback on key steps (bone cuts, component size and position, virtual knee range of motion, and gap balancing) to foresee difficulties or achieve desired goal [76].

AI in intraoperative knee arthroplasty

AI may enhance the capacity of present robots to comprehend more complicated in vivo environments, prognosticate, do real-time decision and execute work with higher accuracy and efficiency, and safety with or without surgeon's supervision and control [77, 78]. AI can thus help mitigating errors further and shorten operative times [79].

AI in postoperative knee arthroplasty

Remote monitoring using AI through smartphones can procure constant subjective and objective data postoperatively enabling trustworthy calibration of outcomes and simultaneously predict and identify the causes of unfavourable outcomes [70]. The first platforms lacked interconnectivity between applications, had poor user engagement, high cost, and inability to scale [80, 81, 82]. Recently, a remote patient monitoring system has been developed, which tracks in real-time patient's physical therapy and home exercise program participation and compliance through the patient's smartphone. The surgical team can track down patient's progress and step in if postoperative milestones are not achieved in proper time [83, 84].

7. Augmented Reality

Augmented Reality (AR) is "the concept of digitally superimposing virtual objects onto physical objects in real space so individuals can interact with both at the same time" [85]. The simulation in virtual reality (VR) happens in a computer-generated environment [86]. An AR system comprises special hardware and software to commix real-world live objects with computer-processed and generated images [86] and depict via a video projector, computer or tablet [87]. AR system consists of three components as elaborated by Nikou et al. [88]: real-time position tracking system, display tool, and system controlling software [89]. The position tracking system supervised object location and orientation in the operative field. Imaging modalities (e.g., fluoroscopy) are components of the tracking system. Markers (e.g., metal spheres) detectable by the imaging modality, attached to patient or surgical equipment enable orientation of the relative position of objects in the operative field. The system control software processes information from the tracking system and transforms the input data into images, which are directed to the display system, where the combination with the view of the real scene takes place [88, 90, 91].

Future implications of Augmented Reality

AR probably can be utilized for component's alignment in total joint arthroplasty [89] because it can provide legitimate measurements of lower limb's mechanical axis deviation, with fewer X-ray image acquisitions [92]. Pokhrel et al. [93] proposed an AR based system that may ameliorate the bone cutting precision to improve long-term outcomes in TKA. AR could also be an important educational medium [94], but the extent to which it can justify its role for training orthopaedic surgeons is to be further investigated. Cost-effectiveness of AR must be censoriously evaluated [95] prior to its routine use. Lastly, AR should be compared to other technologies regarding costs, operative time, accuracy, and clinical outcomes, since there is a lack of studies which include such comparison [87].

Conclusion

The hunger for innovation is a sign of progress of science and technology. Advancement in technologies used for TKA is the current trend worldwide. There is no doubt that these technologies impart greater accuracy and precision in every way a surgeon desires, and adds to surgeons' armamentarium. Robotics is the trend of the present, whereas augmented reality holds a platform for future to work upon, improvise and refine total knee arthroplasty. Whether augmented reality will enhance the experience of present technologies or will overpower them is a matter of debate and something to behold in future. No strong evidence exists presently as to how much and how significantly these technologies are adding value to our arthroplasty, but the rendition of their outcomes is something we ardently aspire to venture to in the future. The upcoming decade is surely greatly happening with escalating improvisations of technology and hopefully elimination of the downsides and limitations that we encounter today. We believe the future of technologies in total knee arthroplasty is truly soaring high, and we must keep ourselves contemporary with the trends of the time, technology and science.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his/her consent for his/her images and other clinical information to be reported in the Journal. The patient understands that his/her name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.
Conflict of interest: Nil **Source of support:** None

References

1. Kayani B, Konan S, Ayuob A, Onochie E, Al-Jabri T, Haddad FS. Robotic technology in total knee arthroplasty: a systematic review. EFORT Open Reviews. 2019 Oct 1;4(10):611-7.
2. Berend ME, Ritter MA, Meding JB, Faris PM, Keating EM, Redelman R, Faris GW, Davis KE. The Chetranjan Ranawat Award: Tibial Component Failure Mechanisms in Total Knee Arthroplasty. Clinical Orthopaedics and Related Research (1976-2007). 2004 Nov 1;428:26-34.
3. Lewinnek GE, Lewis JL, Tarr RI, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am. 1978 Mar 1;60(2):217-20.
4. Wasielewski RC, Galante JO, Leighty RM, Natarajan RN, Rosenberg AG. Wear patterns on retrieved polyethylene tibial inserts and their relationship to technical considerations during total knee arthroplasty. Clinical Orthopaedics and Related Research (1976-2007). 1994 Feb 1;299:31-43.
5. Dorr LD. CORR Insights®: does robotic-assisted TKA result in better outcome scores or long-term survivorship than conventional TKA? A randomized, controlled trial. Clinical Orthopaedics and Related Research. 2020 Feb;478(2):276.
6. Waddell BS, Carroll K, Jerabek S. Technology in arthroplasty: are we improving value?. Current Reviews in Musculoskeletal Medicine. 2017 Sep;10(3):378-87.
7. Batailler C, Swan J, Sappey Marinier E, Servien E, Lustig S. New technologies in knee arthroplasty: current concepts. Journal of Clinical Medicine. 2020 Dec 25;10(1):47.
8. León-Muñoz VJ, Martínez-Martínez F, López-López M, Santonja-Medina F. Patient-specific instrumentation in total knee arthroplasty. Expert Review of Medical Devices. 2019 Jul 3;16(7):555-67.
9. Frye BM, Najim AA, Adams JB, Berend KR, Lombardi Jr AV. MRI is more accurate than CT for patient-specific total knee arthroplasty. The knee. 2015 Dec 1;22(6):609-12.
10. Abdel MP, Parratte S, Blanc G, Ollivier M, Pomero V, Viehweger E, Argenson JN. No benefit of patient-specific instrumentation in TKA on functional and gait outcomes: a randomized clinical trial. Clinical Orthopaedics and Related Research®. 2014 Aug;472(8):2468-76.
11. Abane L, Anract P, Boisgard S, Descamps S, Courpied JP, Hamadouche M. A comparison of patient-specific and conventional instrumentation for total knee arthroplasty: a multicentre randomised controlled trial. The bone & joint journal. 2015 Jan;97(1):56-63.
12. Vundelinckx BJ, Bruckers L, De Mulder K, De Schepper J, Van Esbroeck G. Functional and radiographic short-term outcome evaluation of the Visionaire system, a patient-matched instrumentation system for total knee arthroplasty. The Journal of arthroplasty. 2013 Jun 1;28(6):964-70.
13. Chen JY, Chin PL, Tay DK, Chia SL, Lo NN, Yeo SJ. Functional outcome and quality of life after patient-specific instrumentation in total knee arthroplasty. The Journal of arthroplasty. 2015 Oct 1;30(10):1724-8.
14. Bonnin MP, Schmidt A, Basiglini L, Bossard N, Dantony E. Mediolateral oversizing influences pain, function, and flexion after TKA. Knee Surgery, Sports Traumatology, Arthroscopy. 2013 Oct;21(10):2314-24.
15. Mahoney OM, Kinsey T. Overhang of the femoral component in total knee arthroplasty: risk factors and clinical consequences. JBJS. 2010 May 1;92(5):1115-21.
16. Bonnin MP, Beckers L, Leon A, Chauveau J, Müller JH, Tibesku CO, Aït-Si-Selmi T. Custom total knee arthroplasty facilitates restoration of constitutional coronal alignment. Knee Surgery, Sports Traumatology, Arthroscopy. 2020 Jul 17:1-2.
17. Arbab D, Reimann P, Brucker M, Bouillon B, Lüring C. Alignment in total knee arthroplasty—A comparison of patient-specific implants with the conventional technique. The Knee. 2018 Oct 1;25(5):882-7.
18. Levengood GA, Dupee J. Accuracy of coronal plane mechanical alignment in a customized, individually made total knee replacement with patient-specific instrumentation. The journal of knee surgery. 2018 Sep;31(08):792-6.
19. Schroeder L, Martin G. In vivo tibial fit and rotational analysis of a customized, patient-specific TKA versus off-the-shelf TKA. The Journal of Knee Surgery. 2019 Jun;32(06):499-505.
20. Reimann P, Brucker M, Arbab D, Lüring C. Patient satisfaction-A comparison between patient-specific implants and conventional total knee arthroplasty. Journal of Orthopaedics. 2019 May 1;16(3):273-7.
21. Schwarzkopf R, Brodsky M, Garcia GA, Gomoll AH. Surgical and functional outcomes in patients undergoing total knee replacement

with patient-specific implants compared with “off-the-shelf” implants. Orthopaedic journal of sports medicine. 2015 Jun 24;3(7):2325967115590379.

22. White PB, Ranawat AS. Patient-specific total knees demonstrate a higher manipulation rate compared to “off-the-shelf implants”. The Journal of arthroplasty. 2016 Jan 1;31(1):107-11.

23. Mihalko WM, Saleh KJ, Krackow KA, Whiteside LA. Soft-tissue balancing during total knee arthroplasty in the varus knee. JAAOS-Journal of the American Academy of Orthopaedic Surgeons. 2009 Dec 1;17(12):766-74.

24. Nagai K, Muratsu H, Takeoka Y, Tsubosaka M, Kuroda R, Matsumoto T. The influence of joint distraction force on the soft-tissue balance using modified gap-balancing technique in posterior-stabilized total knee arthroplasty. The Journal of Arthroplasty. 2017 Oct 1;32(10):2995-9.

25. Lee SY, Lim HC, Jang KM, Bae JH. What factors are associated with femoral component internal rotation in TKA using the gap balancing technique?. Clinical Orthopaedics and Related Research®. 2017 Aug;475(8):1999-2010.

26. Ferreira MC, Franciozi CE, Kubota MS, Priore RD, Ingham SJ, Abdalla RJ. Is the use of spreaders an accurate method for ligament balancing?. The Journal of Arthroplasty. 2017 Jul 1;32(7):2262-7.

27. Kim SH, Lim JW, Jung HJ, Lee HJ. Influence of soft tissue balancing and distal femoral resection on flexion contracture in navigated total knee arthroplasty. Knee Surgery, Sports Traumatology, Arthroscopy. 2017 Nov;25(11):3501-7.

28. Heesterbeek PJ, Haffner N, Wymenga AB, Stifter J, Ritschl P. Patient-related factors influence stiffness of the soft tissue complex during intraoperative gap balancing in cruciate-retaining total knee arthroplasty. Knee Surgery, Sports Traumatology, Arthroscopy. 2017 Sep;25(9):2760-8.

29. Wyss TF, Schuster AJ, Münger P, Pfluger D, Wehrli U. Does total knee joint replacement with the soft tissue balancing surgical technique maintain the natural joint line?. Archives of Orthopaedic and Trauma Surgery. 2006 Sep;126(7):480-6.

30. Elmallah RK, Mistry JB, Cherian JJ, Chughtai M, Bhave A, Roche MW, Mont MA. Can we really “feel” a balanced total knee arthroplasty?. The Journal of Arthroplasty. 2016 Sep 1;31(9):102-5.

31. Nodzo SR, Franceschini V, Della Valle AG. Intraoperative load-sensing variability during cemented, posterior-stabilized total knee arthroplasty. The Journal of Arthroplasty. 2017 Jan 1;32(1):66-70.

32. Ghirardelli S, Bala A, Peretti G, Antonini G, Indelli PF. Intraoperative sensing technology to achieve balance in primary total knee arthroplasty: a review of the literature. JBJS reviews. 2019 Oct 1;7(10):e4.

33. Iyengar KP, Gowers BT, Jain VK, Ahluwalia RS, Botchu R, Vaishya R. Smart sensor implant technology in total knee arthroplasty. Journal of clinical orthopaedics and trauma. 2021 Nov 1;22:101605.

34. Gustke KA, Golladay GJ, Roche MW, Elson LC, Anderson CR. A new method for defining balance: promising short-term clinical outcomes of sensor-guided TKA. The Journal of arthroplasty. 2014 May 1;29(5):955-60.

35. Chow JC, Breslauer L. The use of intraoperative sensors significantly increases the patient-reported rate of improvement in primary total knee arthroplasty. Orthopedics. 2017 Jul 1;40(4):e648-51.

36. Geller JA, Lakra A, Murtaugh T. The use of electronic sensor device to augment ligament balancing leads to a lower rate of arthrofibrosis after total knee arthroplasty. The Journal of Arthroplasty. 2017 May 1;32(5):1502-4.

37. Lee DH, Park JH, Song DI, Padhy D, Jeong WK, Han SB. Accuracy of soft tissue balancing in TKA: comparison between navigation-assisted gap balancing and conventional measured resection. Knee Surgery, Sports Traumatology, Arthroscopy. 2010 Mar;18(3):381-7.

38. Rhee SJ, Kim HJ, Lee CR, Kim CW, Gwak HC, Kim JH. A comparison of long-term outcomes of computer-navigated and conventional total knee arthroplasty: a meta-analysis of randomized controlled trials. JBJS. 2019 Oct 16;101(20):1875-85.

39. Ek ET, Dowsey MM, Tse LF, Riazi A, Love BR, Stoney JD, Choong PF. Comparison of functional and radiological outcomes after computer-assisted versus conventional total knee arthroplasty: a matched-control retrospective study. Journal of Orthopaedic Surgery. 2008 Aug;16(2):192-6.

40. Jones CW, Jerabek SA. Current role of computer navigation in total knee arthroplasty. The Journal of arthroplasty. 2018 Jul 1;33(7):1989-93.

41. Budhiparama NC, Lumban-Gaol I, Ifran NN, Parratte S, Nelissen R. Does accelerometer-based navigation have any clinical benefit compared with conventional TKA? A systematic review. Clinical orthopaedics and related research. 2019 Sep;477(9):2017.

42. Camarda L, D’Arienzo A, Morello S, Peri G, Valentino B, D’Arienzo M. Patient-specific instrumentation for total knee arthroplasty: a literature review. Musculoskeletal surgery. 2015 Apr;99(1):11-8.

43. Banerjee S, Cherian JJ, Elmallah RK, Pierce TP, Jauregui JJ, Mont MA. Robot-assisted total hip arthroplasty. Expert review of medical devices. 2016 Jan 2;13(1):47-56.

44. Chen X, Deng S, Sun ML, He R. Robotic arm-assisted arthroplasty: The latest developments. Chinese Journal of Traumatology. 2022 May 1;25(3):125-31.

45. Jacofsky DJ, Allen M. Robotics in arthroplasty: a comprehensive review. The Journal of arthroplasty. 2016 Oct 1;31(10):2353-63.

46. Bagaria V, Sadigale OS, Pawar PP, Bashyal RK, Achalare A, Poduval M. Robotic-assisted knee arthroplasty (RAKA): the technique, the technology and the transition. Indian Journal of Orthopaedics. 2020 Nov;54(6):745-56.

47. Ponzio DY, Lonner JH. Preoperative mapping in unicompartmental knee arthroplasty using computed tomography scans is associated with radiation exposure and carries high cost. The Journal of Arthroplasty. 2015 Jun 1;30(6):964-7.

48. Kayani B, Konan S, Huq SS, Tahmassebi J, Haddad FS. Robotic-arm assisted total knee arthroplasty has a learning curve of seven cases for integration into the surgical workflow but no learning curve effect for accuracy of implant positioning. Knee Surgery, Sports Traumatology, Arthroscopy. 2019 Apr;27(4):1132-41.

49. Sultan AA, Samuel LT, Khlopas A, Sodhi N, Bhowmik-Stoker M, Chen A, Orozco F, Kolisek F, Mahoney O, Smith L, Malkani A. Robotic-arm assisted total knee arthroplasty more accurately restored the posterior condylar offset ratio and the Insall-Salvati Index compared to the manual technique; a cohort-matched study. Surg Technol Int. 2019 May 1;34(409):e13.

50. Liow MH, Xia Z, Wong MK, Tay KJ, Yeo SJ, Chin PL. Robot-assisted total knee arthroplasty accurately restores the joint line and mechanical axis. A prospective randomised study. The Journal of arthroplasty. 2014 Dec 1;29(12):2373-7.

51. Khlopas A, Chughtai M, Hampp EL, Scholl LY, Prieto M, Chang TC, Abbasi A, Bhowmik-Stoker M, Otto J, Jacofsky DJ, Mont MA. Robotic-Arm Assisted Total Knee Arthroplasty Demonstrated Soft Tissue Protection. Surgical technology international. 2017 Jul 1;30:441-6.

52. Abdel MP, Ledford CK, Kobic A, Taunton MJ, Hanssen AD.

Contemporary failure aetiologies of the primary, posterior-stabilised total knee arthroplasty. The Bone & Joint Journal. 2017 May;99(5):647-52.

53. Kutzner I, Bender A, Dymke J, Duda G, Von Roth P, Bergmann G. Mediolateral force distribution at the knee joint shifts across activities and is driven by tibiofemoral alignment. The bone & joint journal. 2017 Jun;99(6):779-87.

54. Haddad FS. Evolving techniques: the need for better technology. The Bone & Joint Journal. 2017 Feb;99(2):145-6.

55. Siebert W, Mai S, Kober R, Heeckt PF. Technique and first clinical results of robot-assisted total knee replacement. The Knee. 2002 Sep 1;9(3):173-80.

56. Kayani B, Konan S, Tahmassebi J, Rowan FE, Haddad FS. An assessment of early functional rehabilitation and hospital discharge in conventional versus robotic-arm assisted unicompartmental knee arthroplasty: a prospective cohort study. Bone Joint J. 2019 Jan;101(1):24-33.

57. Song EK, Seon JK, Yim JH, Netravali NA, Bargar WL. Robotic-assisted TKA reduces postoperative alignment outliers and improves gap balance compared to conventional TKA. Clinical Orthopaedics and Related Research®. 2013 Jan;471(1):118-26.

58. Song EK, Seon JK, Park SJ, Jung WB, Park HW, Lee GW. Simultaneous bilateral total knee arthroplasty with robotic and conventional techniques: a prospective, randomized study. Knee Surgery, Sports Traumatology, Arthroscopy. 2011 Jul;19(7):1069-76.

59. Liow MH, Goh GS, Wong MK, Chin PL, Tay DK, Yeo SJ. Robotic-assisted total knee arthroplasty may lead to improvement in quality-of-life measures: a 2-year follow-up of a prospective randomized trial. Knee Surgery, Sports Traumatology, Arthroscopy. 2017 Sep;25(9):2942-51.

60. Yang HY, Seon JK, Shin YJ, Lim HA, Song EK. Robotic total knee arthroplasty with a cruciate-retaining implant: a 10-year follow-up study. Clinics in Orthopedic Surgery. 2017 Jun 1;9(2):169-76.

61. Cho KJ, Seon JK, Jang WY, et al. Robotic versus conventional primary total knee arthroplasty: clinical and radiological long-term results with a minimum follow-up of ten years. Int Orthop 2019. Jun;43(6):1345-1354.

62. Cotter EJ, Wang J, Illgen RL. Comparative cost analysis of robotic-assisted and jig-based manual primary total knee arthroplasty. The Journal of Knee Surgery. 2022 Jan;35(02):176-84.

63. Sharkey PF, Lichstein PM, Shen C, Tokarski AT, Parvizi J. Why are total knee arthroplasties failing today—has anything changed after 10 years?. The Journal of arthroplasty. 2014 Sep 1;29(9):1774-8.

64. Blyth M, Jones B, MacLean A, Rowe P. Two-year results of a randomized trial of robotic surgical assistance vs manual unicompartmental knee arthroplasty. InAnnual Meeting of the American Association of Hip and Knee Surgeons 2017 Nov.

65. Pearle AD, van der List JP, Lee L, Coon TM, Borus TA, Roche MW. Survivorship and patient satisfaction of robotic-assisted medial unicompartmental knee arthroplasty at a minimum two-year follow-up. The Knee. 2017 Mar 1;24(2):419-28.

66. Pastides P, Nathwani D. The role of newer technologies in knee arthroplasty. Orthopaedics and Trauma. 2017 Feb 1;31(1):47-52.

67. Bellman R. An introduction to artificial intelligence: can computers think?. Thomson Course Technology; 1978.

68. Ahuja AS. The impact of artificial intelligence in medicine on the future role of the physician. PeerJ. 2019 Oct 4;7:e7702.

69. Myers TG, Ramkumar PN, Ricciardi BF, Urish KL, Kipper J, Ketonis C. Artificial intelligence and orthopaedics: an introduction for clinicians. The Journal of bone and joint surgery. American volume. 2020 May 6;102(9):830.

70. Batailler C, Shatrov J, Sappey-Marinier E, Servien E, Parratte S, Lustig S. Artificial intelligence in knee arthroplasty: current concept of the available clinical applications. Arthroplasty. 2022 Dec;4(1):1-6.

71. Purnomo G, Yeo SJ, Liow MH. Artificial intelligence in arthroplasty. Arthroplasty. 2021 Dec;3(1):1-7.

72. Noonan VK, Lyddiatt A, Ware P, Jaglal SB, Riopelle RJ, Bingham III CO, Figueiredo S, Sawatzky R, Santana M, Bartlett SJ, Ahmed S. Montreal Accord on Patient-Reported Outcomes (PROs) use series–Paper 3: patient-reported outcomes can facilitate shared decision-making and guide self-management. Journal of Clinical Epidemiology. 2017 Sep 1;89:125-35.

73. Paul HY, Wei J, Kim TK, Sair HI, Hui FK, Hager GD, Fritz J, Oni JK. Automated detection & classification of knee arthroplasty using deep learning. The Knee. 2020 Mar 1;27(2):535-42.

74. Shah RF, Bini SA, Martinez AM, Pedoia V, Vail TP. Incremental inputs improve the automated detection of implant loosening using machine-learning algorithms. The Bone & Joint Journal. 2020 Jun;102(6 Supple A):101-6.

75. Kazarian GS, Lawrie CM, Barrack TN, Donaldson MJ, Miller GM, Haddad FS, Barrack RL. The impact of surgeon volume and training status on implant alignment in total knee arthroplasty. JBJS. 2019 Oct 2;101(19):1713-23.

76. Goh GS, Lohre R, Parvizi J, Goel DP. Virtual and augmented reality for surgical training and simulation in knee arthroplasty. Archives of Orthopaedic and Trauma Surgery. 2021 Dec;141(12):2303-12.

77. Chand M, Ramachandran N, Stoyanov D, Lovat L. Robotics, artificial intelligence and distributed ledgers in surgery: data is key!. Techniques in Coloproctology. 2018 Sep;22(9):645-8.

78. Zhou XY, Guo Y, Shen M, Yang GZ. Application of artificial intelligence in surgery. Frontiers of medicine. 2020 Aug;14(4):417-30.

79. Panesar S, Cagle Y, Chander D, Morey J, Fernandez-Miranda J, Kliot M. Artificial intelligence and the future of surgical robotics. Annals of surgery. 2019 Aug 1;270(2):223-6.

80. Chiang CY, Chen KH, Liu KC, Hsu SJ, Chan CT. Data collection and analysis using wearable sensors for monitoring knee range of motion after total knee arthroplasty. Sensors. 2017 Feb 22;17(2):418.

81. Kang K, Geng Q, Xu HT, Zheng XZ, Dong JT, Li T, Zhao ZG, Gao SJ. Clinical study of a new wearable device for rehabilitation after total knee arthroplasty. Zhonghua yi xue za zhi. 2018 Apr 1;98(15):1162-5.

82. Kline PW, Melanson EL, Sullivan WJ, Blatchford PJ, Miller MJ, Stevens-Lapsley JE, Christiansen CL. Improving physical activity through adjunct telerehabilitation following total knee arthroplasty: randomized controlled trial protocol. Physical therapy. 2019 Jan 1;99(1):37-45.

83. Wang S, Summers RM. Machine learning and radiology. Medical image analysis. 2012 Jul 1;16(5):933-51.

84. Deo RC. Machine learning in medicine. Circulation. 2015 Nov 17;132(20):1920-30.

85. Azuma RT. A survey of augmented reality. Presence: teleoperators & virtual environments. 1997 Aug 1;6(4):355-85.

86. Vávra P, Roman J, Zonča P, Ihnát P, Němec M, Kumar J, Habib N, El-Gendi A. Recent development of augmented reality in surgery: a review. Journal of healthcare engineering. 2017 Aug 21;2017.

87. Chytas D, Malahias MA, Nikolaou VS. Augmented reality in orthopedics: current state and future directions. Frontiers in

Surgery. 2019 Jun 27;6:38.

88. Nikou C, Digioia III AM, Blackwell M, Jaramaz B, Kanade T. Augmented reality imaging technology for orthopaedic surgery. Operative Techniques in Orthopaedics. 2000 Jan 1;10(1):82-6.

89. Blackwell M, Morgan F, DiGioia III AM. Augmented reality and its future in orthopaedics. Clinical Orthopaedics and Related Research (1976-2007). 1998 Sep 1;354:111-22.

90. Navab N, Heining SM, Traub J. Camera augmented mobile C-arm (CAMC): calibration, accuracy study, and clinical applications. IEEE transactions on medical imaging. 2009 May 26;29(7):1412-23.

91. Fallavollita P, Wang L, Weidert S, Navab N. Augmented reality in orthopaedic interventions and education. InComputational radiology for orthopaedic interventions 2016 (pp. 251-269). Springer, Cham.

92. Fallavollita P, Brand A, Wang L, Euler E, Thaller P, Navab N, Weidert S. An augmented reality C-arm for intraoperative assessment of the mechanical axis: a preclinical study. International journal of computer assisted radiology and surgery. 2016 Nov;11(11):2111-7.

93. Pokhrel S, Alsadoon A, Prasad PW, Paul M. A novel augmented reality (AR) scheme for knee replacement surgery by considering cutting error accuracy. The international journal of medical robotics and computer assisted surgery. 2019 Feb;15(1):e1958.

94. Pokhrel S, Alsadoon A, Prasad PW, Paul M. A novel augmented reality (AR) scheme for knee replacement surgery by considering cutting error accuracy. The international journal of medical robotics and computer assisted surgery. 2019 Feb;15(1):e1958.

95. Gerrand C. CORR Insights®: can augmented reality be helpful in pelvic bone cancer surgery? An in vitro study. Clinical Orthopaedics and Related Research. 2018 Sep;476(9):1726.

How to Cite this Article

Mukartihal R, Das R, Chandan S, Bhat VGK, Nallabolu B, Sreedhish K, Bharath K S, Patil SS | Technologies in Total Knee Arthroplasty | Journal of Karnataka Orthopaedic Association | January-February 2023; 11(1): 05-12 | https://doi.org/10.13107/jkoa.2023.v11i01.057