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A Comprehensive Guide to Robotic Knee Arthroplasty



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CHAPTER 1

Why Robotics? Challenges in Conventional Total Knee Replacement

Pramod Bhor, Sourabh Kulkarni, Sachin Yashwant Kale, Vishal Kumar, Shivam Mehra

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INTRODUCTION

Total knee replacement (TKR) and total hip replacement surgeries are one of the most successful surgeries in orthopedics. Conventional joint replacement done by competent surgeons has given amazing results. But humans are defined by inquisitiveness and hunger for progress and precision. The first knee replacement is dated back to 1968. Since 1968, we have done vast improvements in implant design, implant material, polyethylene material, cementing technique, and intraoperative and postoperative management protocols but nothing was done for human-/surgeon-related factors. The success of knee replacement depends on precise alignment, perfect duplication of natural anatomy of a native knee. The gap balancing is also equally important in the success of TKR surgery. Along with this, it is important to standardize and repeat the best results in every case. Achieving this is possible with use of AI and robotics due to various reasons.

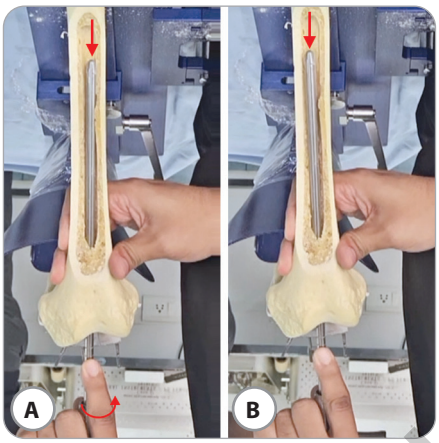
ANATOMICAL VARIATIONS

Femoral mechanical-anatomical axis angle (FMMA) as per the studies ranges from 3° to 7° in 75% of the population. Still 25% of the population lies outside this range. So just choosing a femoral zig angle of 5–7° valgus doesn't account for precision.

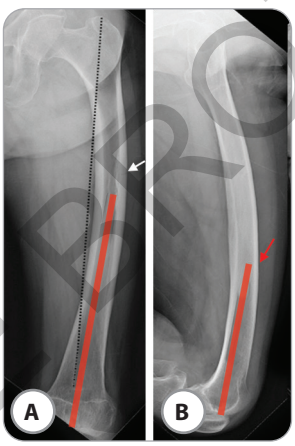
Intramedullary canal is wide in many patients. in such wide canals intramedullary rod may wobble with 1–3° of variation **(Figs. 1.1A and B)**.

The femoral bow varies amongst individuals and this bow also increases as the age progresses. With severe osteoporotic bowing it has been observed that intramedullary rod abuts the anterior cortex at shorter length. Hence, does not represent the anatomical axis perfectly **(Figs. 1.2A and B)**.

In some cases, it has been observed that FMMA is >10°. But conventional instrumentation sets do not have angle adjustments available.



FIGS. 1.1A AND B: Wobble of intramedullary rod.



FIGS. 1.2A AND B: Exaggerated femoral bow.

MALUNITED FEMUR FRACTURES

In cases of malunited femoral fractures intramedullary canal orientation, diameter and angle are changed. In such cases, the intramedullary canal does not represent the anatomical axis of femur **(Figs. 1.3A and B)**.

ERROR OF SAW

It has been observed that there is a possibility of error due to a human hand having various angular forces on a saw blade while cutting through the zig. Also due to friction with the saw blade, zig slots become wider with repeated use, which leads to more play of the saw blade within the slot **(Figs. 1.4A and B)**. As a result, through the same zig slot you can cut a few degrees in varus or valgus and also in different slopes.

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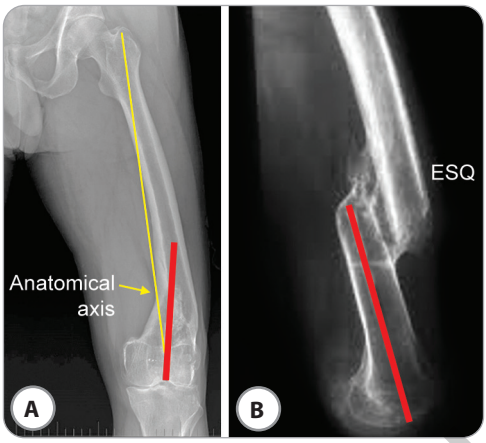
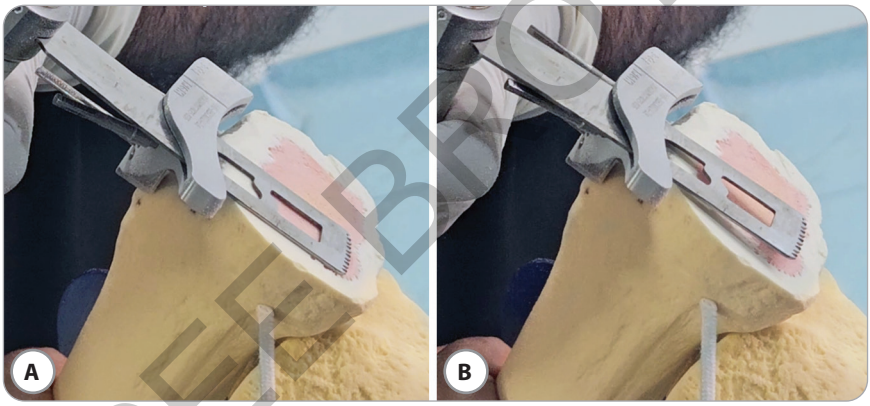


FIGS. 1.3A AND B: Malunited fractures.



FIGS. 1.4A AND B: Play of saw in zig slot.

ERRORS IN LIGAMENT BALANCING

A submillimeter precision in joint replacement is desirable. This submillimeter difference or variation in medial and lateral gaps is not quantifiable by human eyes. Surgeons can perceive this imbalance but cannot quantify in millimeters. Human eyes also cannot understand angle variations in precise degrees.

In conventional total knee arthroplasty (TKA), we can do gap balancing only after the bone is cut. Intraoperatively to balance the gaps, we might have to do more release leading to insertion of larger poly insert, which retrospectively signifies greater bone loss.

In conventional instrumentation, bone cut can be increased or decreased by 2 mm. Which means for ideal gap balancing if millimeter or submillimeter variation of cut is required, that is not possible.

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ALIGNMENT PHILOSOPHY

Recently, there are changes in alignment philosophies for better patient satisfaction and longevity of the implants. It has been changing from mechanical alignment to kinematic alignment. Many surgeons want to practice restricted kinematic alignment where precise limited angle variation is acceptable. In conventional TKA instrumentation being rigid, these angles are difficult to achieve whereas it is easily possible with robotics. Differences between these alignment philosophies and their requisites have been discussed in Chapter 3.

Total knee replacement has long been celebrated as among the most successful procedures in orthopedic practice. With decades of refinement in implant design, material science, and surgical techniques, these operations have drastically improved patients' quality of life. However, despite these advancements, a critical dimension—surgeon- and patient-related variability—has remained relatively unaddressed until the recent advent of artificial intelligence (AI) and robotic-assisted technologies.

The precision required in TKR surgery is immense. Success hinges on accurate anatomical replication, precise limb alignment, and meticulous gap balancing. Yet, these goals are often compromised due to inherent anatomical variations, technical limitations of conventional instruments, and the natural boundaries of human perception and manual dexterity.

Studies have shown that the FMMA varies considerably, and in 25% of the population, it lies outside the typical 3–7° range. In such cases, relying on a fixed valgus angle for distal femoral cuts introduces alignment errors. Similarly, variability in femoral bowing, especially in older or osteoporotic patients, and in cases of malunited femoral fractures, further challenges the reliability of intramedullary guides. Conventional instruments are often not adaptable enough to accommodate these patient-specific anatomical differences.

Moreover, intraoperative execution is prone to human error. Factors such as saw blade play within the cutting jig slots, changes due to repeated use of instruments, and difficulty in achieving submillimeter precision all contribute to inconsistencies in bone cuts and ligament balancing. Surgeons may intuitively perceive imbalance but cannot reliably quantify the exact medial-lateral gap differences or angulation in degrees. This inability to measure and execute with precision can lead to suboptimal outcomes, increased polyethylene wear, instability, or early failure of the prosthesis.

The evolution in alignment philosophies—from mechanical alignment to kinematic and restricted kinematic alignment—further underscores the need for adaptable and patient-specific solutions. Such nuanced approaches, aiming to replicate the native joint mechanics more closely, are exceedingly difficult to implement with conventional tools. Robotic-assisted systems, however, allow for real-time planning, intraoperative customization, and execution with millimetric and subdegree accuracy. This not only helps in achieving perfect alignment but also in preserving soft tissues and minimizing unnecessary bone cuts or releases.

AI and robotics bridge the gap between the surgical plan and its execution. These technologies offer consistent, reproducible, and patient-specific outcomes—mitigating the influence of anatomical variability, reducing intraoperative human

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error, and allowing alignment philosophies to be accurately implemented. In essence, they enable surgeons to combine their clinical expertise with digital precision.

CONCLUSION

While conventional joint replacement performed by experienced surgeons will continue to yield good results, the integration of AI and robotic technology represents a transformative leap forward. It addresses the long-standing challenge of human and anatomical variability, setting a new standard for consistency, precision, and personalized care in joint arthroplasty. As orthopedic surgery continues to evolve, embracing these technologies is not just an option—it is a necessity for the future of precision joint replacement.

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A Comprehensive Guide to

Robotic Knee Arthroplasty

Salient Features

- **First-of-its-Kind Consolidated Resource:** This book is among the earliest comprehensive Indian publications that brings together in-depth clinical and technical perspectives on all currently used robotic systems in total knee arthroplasty (TKA), making it a one-stop reference for orthopedic surgeons at all levels.
- **Authored by an Expert Multidisciplinary Team:** Contributions from over 20 leading orthopedic surgeons, including pioneers and early adopters of robotic technology in India. The team comprises clinicians from academic, private, and surgical backgrounds, offering a well-rounded perspective.
- **Covers the Evolution from Conventional to Robotic TKR:** Begins with the rationale for robotics and challenges in conventional TKR, making it accessible even to orthopedic surgeons new to the field of computer-assisted and robotic surgery.
- **Detailed Breakdown of Each Robotic System:** Each of the leading robotic platforms—CUVIS, MISSO, MAKO, VELYS, CORI, and ROSA—is discussed in dedicated chapters, with focus on:
  - o System design and components
  - o Surgical workflow and steps
  - o Advantages, limitations, and clinical experiences
  - o Unique features and comparative insights
- **Simplified Understanding of Core Concepts:** Chapters on alignment techniques, robot classification, and robotic components are crafted to demystify the engineering and functional aspects of robotic systems, catering even to nonengineering readers.
- **Evidence-based Discussion on Complications and Prevention:** Real-world experience-backed insights into robot-specific complications, error minimization, and intraoperative risk management provide practical guidance for safe surgical practice.
- **Strong Focus on Outcomes and Advantages:** Includes a comprehensive chapter on the advantages of robotic knee arthroplasty, referencing improved alignment accuracy, component positioning, soft-tissue preservation, and patient satisfaction.
- **Dedicated Chapter on Preoperative and Postoperative Rehabilitation:** Guidance on rehabilitation protocols specific to robotic-assisted TKA, a commonly neglected area, with inputs from physiotherapists and orthopedic surgeons alike.
- **Involvement of the Next Generation:** Unique contributions from young minds like Sachiti Sachin Kale and Siddhant Pramod Bhor, reflecting the vision of passing the torch and incorporating intergenerational learning in orthopedic robotics.
- **Extensively Referenced:** The book ends with a well-curated bibliography and publications enabling readers to explore primary literature and recent studies for further research and academic engagement.

Shelving Recommendation
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