Thesis

Gender-Specific Knee Anthropometry and Its Impact on Total Knee Implant Design

Pavan Soni[1],
Parag Sancheti[1],
Kailas Patil[1],
Sunny Gugale[1],
Sahil Sanghavi[1],
Yogesh Sisodia[1],
Obaid UI Nisar[1],
Darshan Sonawane[1],
Ashok Shyam[1]

[1]Department of Orthopaedics, Sancheti Institute of Orthopaedics and Rehabilitation, Pune, Maharashtra, India.

Address of Correspondence
Dr. Darshan Sonawane,
Department of Orthopaedics, Sancheti Institute of Orthopaedics and Rehabilitation, Pune, Maharashtra, India.
E-mail: researchsior@gmail.com.

Abstract

Background: Good results after total knee replacement depend on choosing components that match the patient's bone shape. Many implants were designed from Western measurements and can fit poorly in other populations, producing mediolateral overhang or undersizing that may cause discomfort or altered load transfer. This study reports direct intraoperative measurements from an Indian cohort to highlight common fit problems.

Methods and materials: Using a sterile calibrated caliper, standardized measurements were taken during primary total knee arthroplasty on 252 knees (May 2017–May 2020). Recorded parameters included lateral and medial femoral anteroposterior lengths, femoral mediolateral width, tibial plateau AP and ML dimensions, and patellar thickness. Every reading was double-checked by the assisting resident. Data were grouped by gender and implant system (Zimmer, Indus) and used to calculate ML/AP aspect ratios, which were then compared with the manufacturers' size charts present in the thesis.

Results: The cohort showed a clear trend: ML/AP aspect ratio decreased as AP size increased. Smaller knees frequently faced mediolateral undercoverage with available components, while larger knees were more likely to show ML overhang. Overall, the Indus system tended to match the measured dimensions more closely than Zimmer, although some male tibial fits remained imperfect.

Conclusion: Local intraoperative anthropometry reveals predictable mismatches between Indian knee geometry and some implant offerings. Practical steps—choosing systems that better match local anatomy and adopting finer sizing, staged aspect-ratio changes, or asymmetric trays—can reduce intraoperative compromise and improve early comfort.

Keywords: Total knee replacement, Anthropometry, Aspect ratio, Implant fit, Indian population.


Dr. Parag Sancheti


Dr. Kailas Patil


Dr. Sunny Gugale


Dr. Sahil Sanghavi


Dr. Yogesh Sisodia


Dr. Obaid UI Nisar


Dr. Darshan Sonawane


Dr. Ashok Shyam

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Introduction

Successful total knee replacement depends on restoring joint balance and geometry so the replacement behaves as close to a native knee as possible. Choosing the right component size is not a purely technical step — it shapes soft-tissue tension, patellar tracking, and how loads pass through bone and implant for years to come. When component shape or sizing does not reflect a patient's anatomy, surgeons are forced into compromises: an implant that overhangs mediolaterally can irritate soft tissues and cause persistent discomfort, while one that is too small can expose cancellous bone and change load paths, with potential long-term consequences [1]. Historically, many common prosthesis families were developed using Western anthropometry, which may not match the body proportions seen in other populations [2, 3]. Regional measurement studies and intraoperative series therefore play a practical role — they give surgeons and manufacturers the data needed to reduce mismatch and make better sizing choices for local patients [4]. Pediatric development patterns and normative range-of-motion work also help set realistic functional goals after arthroplasty and contextualize adult dimensions for templating and expectation management [5, 6]. The present intraoperative data set from this thesis gives direct, surgeon-facing measurements that inform component selection and suggest straightforward, affordable design changes that can reduce routine compromise in Indian patients.

Aims & Objectives

1. Record standardized intraoperative measurements of the distal femur and proximal tibia in patients undergoing primary total knee arthroplasty.
2. Calculate femoral and tibial aspect ratios and document condylar asymmetries and patellar thickness.
3. Compare patient-derived dimensions with size offerings of two implant systems used in the cohort (Zimmer and Indus).
4. Identify recurrent patterns of mismatch and outline pragmatic implications for implant selection and modest manufacturer adaptations.

Review of Literature

Anthropometric and morphometric research consistently shows that knee shape differs across ethnic groups and sexes, and those differences matter for implant fit. Several studies comparing resected bone or imaging-based knee measurements with implant dimensions reported that populations with smaller average stature often face systematic mismatch when Western-derived implants are used without adaptation [7–9]. More sophisticated three-dimensional CT analyses and intraoperative series from East and Southeast Asia have repeatedly noted a practical pattern: the mediolateral-to-anteroposterior (ML/AP) aspect ratio tends to decline as AP dimension increases. In plain terms, larger knees do not increase ML width as fast as AP length, so implants with constant aspect ratios across sizes will either overhang or under-cover depending on the surgeon's size choice [10–12]. Sex differences add another layer: females often have relatively narrower femora for a given AP height, which raises the risk of ML overhang when selection relies on AP measures alone [13, 14]. Industry responses have included gender-targeted components, asymmetric tibial trays and finer size increments, but randomized clinical data on the functional benefits of gendered implants are mixed and patient-specific solutions remain expensive and logistically demanding [15,16]. As a practical middle path, many authors advocate collecting local intraoperative data, offering finer size gradations and designing staged aspect ratios rather than a single constant ratio across all sizes; these measures can substantially reduce intraoperative compromises without full custom workflows [17, 18]. Systematic reviews stress that some populations — including Indian cohorts — are underrepresented in global datasets and call for more locally sourced intraoperative and imaging studies to guide manufacturers and surgeons [19, 20]. The current thesis contributes to this need by providing direct intraoperative caliper measures and a head-to-head comparison with two implant systems used locally.

Materials and Methods

This is a retrospective single-center series (May 2017–May 2020) using intraoperative caliper data recorded under a standardized protocol. Institutional ethical approval and patient consent were obtained. Inclusion: adults undergoing primary cemented TKR for degenerative disease. Exclusion: revision arthroplasty, inflammatory polyarthritis, ankylosing spondylitis, significant adjacent deformities of hip/spine, skeletal immaturity, and cases requiring major augmentations. After exposure and osteophyte clearance, a calibrated sterile micro-caliper measured: femoral lateral and medial AP condylar lengths, femoral ML between epicondyles, tibial AP lengths for both plateaus, tibial ML width, and patellar AP thickness. Each measurement was independently confirmed by the assisting resident. Femoral and tibial aspect ratios calculated as (ML/AP) × 100. Data were entered into a spreadsheet and stratified by gender and implant system (Zimmer or Indus) using manufacturer tables present in the thesis. Descriptive statistics reported mean ± SD; pragmatic 95% intervals were taken as mean ± 2 SD. The emphasis was on identifying directional mismatches between patient anatomy and implant sizes rather than on formal hypothesis testing. Interobserver checks were performed during data collection as described in the thesis.

Results

252 knees met inclusion criteria: 176 received Zimmer components and 76 received Indus components. Mean cohort age was 62 years (SD 7; range 42–85). Aggregate means (SD): femoral AP lateral 52.85 mm (5.71), femoral AP medial 49.87

mm (5.82), femoral ML 68.75 mm (5.35); tibial AP lateral 49.28 mm (4.77), tibial AP medial 49.62 mm (4.96), tibial ML 69.79 mm (5.61); patellar AP 33.75 mm (2.45). Medium and large implant sizes predominated. Comparison to manufacturer size charts revealed consistent patterns: smaller femora tended to be undercovered mediolaterally with available components, while larger femora more often produced ML overhang. Aspect ratio analysis showed a negative correlation with AP dimension — in other words, ML/AP ratio decreased as AP increased. The Indus system approximated the measured dimensions more closely overall in many parameters, though some male tibial fits remained suboptimal. Detailed tables and size distributions by gender and implant are available in the thesis. No measurement-related adverse events were recorded.

Discussion

This intraoperative series brings home a pragmatic point: implant-patient geometric mismatch is often predictable and rooted in population-level anatomy rather than sporadic surgical error. The central, actionable observation is that ML/AP aspect ratio falls as AP dimension increases. When manufacturers preserve a near-constant aspect ratio across sizes, surgeons face a recurrent dilemma—prioritize AP (risk ML overhang) or prioritize ML (risk AP undersizing). Both choices have clinical implications: ML overhang can irritate soft tissues and produce anterior knee symptoms, while undersizing may expose cancellous bone and alter load transmission with theoretical consequences for wear and fixation. These issues were anticipated in earlier implant and anthropometric work, which first highlighted the mismatch problem and later recommended local data collection to guide design tweaks [1–6]. Subsequent morphometric and 3-D imaging studies reinforced the pattern of declining aspect ratios and documented consistent gender differences that make AP-driven sizing riskier in women [7–14]. Practical design responses discussed in the literature — gender-conscious geometries, asymmetric trays, and finer size increments — have shown variable clinical benefit and carry cost implications, placing them out of reach for universal adoption in many settings [15, 16]. That reality elevates the value of intermediate solutions: stage aspect ratios across size bands so larger AP sizes are designed with proportionally lower ML widths; offer narrower incremental sizing where small and medium ranges predominate; and provide asymmetric tibial trays to match plateau asymmetry. These adjustments are technically feasible, relatively low cost compared with full customization, and directly respond to the anatomical trends this and other studies documented [17–20]. Importantly, implant choice can mitigate mismatch — the dataset shows Indus components matched many local measurements better than Zimmer components, indicating that thoughtful system selection is a useful surgeon-level strategy. Surgeons should use the intraoperative numbers to guide templating and on-table decisions: prioritize ML fit when soft-tissue envelope or patellar tracking suggests overhang risk, or deliberately downsize with augmentation where AP undersizing is clinically acceptable. Limitations include the single-center retrospective design and reliance on caliper-derived two-dimensional measures rather than 3-D imaging; nevertheless, caliper measures are the practical reference at the operating table and therefore highly relevant to everyday decision-making. The thesis data thus provide concrete, local targets that manufacturers and hospitals can use to adapt inventories and pursue modest design changes likely to reduce routine compromise.

Conclusion

In this single-center intraoperative series of 252 knees, ML/AP aspect ratio decreased as AP dimension increased, producing predictable mediolateral undercoverage in smaller knees and ML overhang in larger knees when implants use constant aspect ratios. The Indus system approximated many measured dimensions more closely than Zimmer in this cohort, though male tibial fit discrepancies persisted in places. Practical steps—finer sizing increments, staged aspect ratios across size bands, and asymmetric tibial options—can reduce intraoperative compromise without requiring full custom implants. Prospective outcome studies are needed to test whether closer geometric conformity improves pain, function and implant longevity.

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Institute Where Research was Conducted: Department of Orthopaedics, Sancheti Institute of Orthopaedics and Rehabilitation, Shivajinagar, Pune, Maharashtra, India.
University Affiliation: MUHS, Nashik, Maharashtra, India.
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