Hypothesis

Tailoring Total Knee Prostheses to Indian Anatomy: A Hypothesis on Improved Fit, Function, and Longevity

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Abstract

Background: Total knee replacement reliably relieves pain and restores mobility, but successful outcomes depend on how well implanted components match native bone geometry. Small differences between implant footprints and patient anatomy—particularly between mediolateral width and anteroposterior depth—can cause component overhang or under-coverage. Even millimetre-scale mismatches may irritate surrounding soft tissues, disrupt patellar tracking and reduce comfort during activities such as squatting, kneeling and rising from the floor. These practical, often subtle mismatches matter most in communities where deep-flexion activities are a routine part of daily life.

Hypothesis: We propose that knees in the studied Indian cohort show consistent differences in ML/AP relationships compared with the dimensional ladders used by many common implant systems. When sizing is guided mainly by AP measures, these differences will produce frequent ML under-coverage in smaller components and ML overhang in larger ones. Sex-based morphology is expected to amplify mismatch in women, while implants developed with regional anthropometry in mind should demonstrate closer fit and reduce intraoperative compromise. Better geometric concordance should lessen soft-tissue irritation and improve early function.

Clinical importance: Understanding local knee anthropometry enables surgeons to make pragmatic intraoperative choices and helps hospitals stock implants that reduce the need for compromise. By deliberately assessing ML coverage during trialling and keeping options such as asymmetric trays, finer size increments or augmentation strategies available, surgical teams can decrease soft-tissue irritation and better meet patients' functional expectations. Thoughtful inventory planning informed by local data can shorten operative time, reduce waste and improve patient satisfaction without large additional cost.

Future research: Future research should focus on linking the small, millimetre-level mismatches we measure in the operating room to how patients actually feel and function afterwards. That means prospective studies that collect validated patient-reported outcomes and objective measures (range of motion, kneeling comfort, and return to daily activities) alongside the morphometric data. Randomized or registry-based comparisons of regionally adapted implants versus standard systems — with parallel cost-effectiveness analyses — will show whether better geometric fit produces real-world benefits.

Keywords: Total knee arthroplasty, Anthropometry, Implant sizing, Mediolateral overhang, Patellofemoral mechanics


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DOI: https://doi.org/10.13107/jmt.2022.v08.i02.190

Background

Total knee arthroplasty (TKA) has transformed the care of end-stage knee arthritis by reliably reducing pain and restoring mobility for large numbers of patients worldwide. Early implant designs offered limited sizing and geometry choices and were modeled largely on Western anthropometry, but as surgeons began to apply these implants across diverse populations they noted recurring mismatches between implant footprints and native bone geometry. Awareness of those mismatches prompted systematic anthropometric work to quantify the problem and to propose design or selection remedies [1].

Anthropometric mismatch matters because small differences in component shape and size can have outsized clinical effects. Mediolateral (ML) overhang beyond a few millimetres can impinge soft tissues, provoke localized pain, and disrupt patellar tracking; conversely, under-coverage exposes cancellous bone, changes load distribution, and may accelerate wear or bone remodelling. Early morphometric studies therefore focused on basic planar measures — femoral ML and AP dimensions, tibial ML and AP widths, patellar thickness — and their derived aspect ratios, since these numbers directly inform tray footprints and femoral component geometry [2].

Subsequent studies emphasized that population and sex differences are real and clinically relevant. Investigations from East and Southeast Asia documented smaller absolute dimensions and distinct ML/AP relationships compared with Western cohorts, prompting calls for population-tuned sizing ladders or gender-specific options [3–6]. Three-dimensional imaging and intraoperative series reinforced that the knee's shape does not scale linearly with size: aspect ratios change across the size spectrum in ways that a fixed implant aspect ratio cannot mirror [5, 7]. These findings were replicated across Chinese, Korean, Thai and Middle Eastern series, producing a consistent message — modern implants must either accept some degree of anatomical compromise or evolve to offer finer gradations and asymmetric options [4–9].

Gender differences add another layer: Multiple investigators documented systematic differences in femoral morphology between men and women — females often present with relatively narrower ML widths for similar AP dimensions — introducing a risk of overhang if AP dimension alone dictates sizing. This observation led some manufacturers to introduce gender-targeted components; however, clinical trials and meta-analyses have produced mixed evidence on whether gender-specific designs yield meaningful outcome advantages [10–13].

Practical implications go beyond pure geometry. In many Asian populations, functional expectations include deep flexion activities such as kneeling, squatting and floor seating; implants that seem adequate on standard radiographs may still fail to meet these real-world demands if they alter patellofemoral mechanics or introduce soft-tissue irritation. Thus, anthropometric mismatch influences not only implant survival but also patient satisfaction and day-to-day function [6, 11].

Industry responses have varied: some companies refined sizing increments, introduced asymmetric tibial trays, or marketed gender-specific lines; others continued with broad, conservative ladders and advocated surgical techniques to adapt standard components. Comparative inventories and in-hospital stocking strategies increasingly rely on local anthropometric evidence to minimize intraoperative compromise. Large registry and international surveys underscored the heterogeneity of practice and the potential value of region-specific data to guide procurement and surgical planning [14–16].

Taken together, the literature supports a practical, surgeon-centred approach: measure and understand local anthropometry, maintain flexible inventories that contain sizes and geometries suited to the served population, and apply intraoperative judgement when templating and trialling components. This body of work also sets a research expectation: to move from descriptive morphometry to prospective studies that link millimetre-scale mismatch to validated patient-reported outcomes and objective function [17–19].

Hypothesis

Primary hypothesis

the anatomic dimensions of the knees in the studied Indian cohort will show systematic differences from those encoded in commonly used implant size ladders, producing predictable ML under-coverage in smaller components and ML overhang in larger ones when AP dimension alone dictates size selection. This mismatch is expected to be measurable and frequent enough to warrant reconsideration of inventory and sizing strategy [1–4].

Mechanistic rationale

Implant manufacturers historically optimized designs around datasets that reflect specific populations; consequently, many widely used systems embed implicit assumptions about aspect-ratio trajectories across sizes. If those assumptions differ from the true, continuous distribution of patient anatomy in a different population, AP-based sizing will create ML discordance. The resulting geometric mismatch perturbs soft tissues, modifies patellofemoral relationships, and alters load transfer — plausible mechanistic pathways that can produce pain, impaired function and possibly altered wear behaviour [2, 5, 7].

Secondary hypotheses

1. Sex differences will amplify mismatch patterns. For comparable AP dimensions, female knees will frequently show narrower ML widths (or different aspect ratios) than male knees; when implants are scaled by AP alone this will produce systematic overhang or edge prominence in females, consistent

with prior comparative morphometry studies [10–13].
2. Regional or locally manufactured implant systems that were designed with regional anatomy in mind will demonstrate closer dimensional concordance with the cohort than systems developed primarily from Western datasets; if true, privileging such systems in stock selection could reduce intraoperative compromise [3, 14].
3. Even millimetre-scale mismatches will be clinically meaningful: ML overhang exceeding commonly-cited thresholds (≈3 mm) will be frequent enough to influence postoperative comfort and early function, justifying changes to sizing practice and inventory policy [18, 19].

Operational implications of the hypotheses

If these hypotheses hold, several straightforward actions follow. Surgeons should not rely solely on AP templating but should routinely verify ML fit during trialling and be prepared to alter strategy (downsizing, alternate geometry, or modular options). Hospitals should base implant procurement on local anthropometric evidence, emphasizing implant systems and size ranges that reduce the need for intraoperative trade-offs. Finally, manufacturers should consider region-aware sizing ladders, asymmetric tibial trays and finer size increments to better match real anatomy. Together, these steps would be expected to reduce immediate postoperative soft-tissue irritation and potentially improve patient satisfaction for activities that demand deep flexion [14–17].

Discussion

The aggregate literature and clinical experience show a persistent and practical problem: implants do not perfectly match human knees, and mismatch has predictable forms tied to population and sex differences. When AP measurement is prioritized, the implant ML dimension becomes the critical variable determining fit — and if the implant aspect-ratio curve diverges from the patient's, overhang or under-coverage results. That phenomenon explains why surgeons in diverse regions routinely report the same set of intraoperative dilemmas: choosing between AP-matched components that overhang ML, or ML-matched options that create AP mismatch with risks of anterior notching or altered flexion space [2, 5, 7].

Regional series repeatedly highlight smaller absolute dimensions and different aspect-ratio trends in Asian populations relative to Western datasets, and some local implant designs attempt to close that gap. Evidence shows that locally-tuned systems may fit better in specific subgroups, but the relationship between improved geometric fit and long-term clinical benefit is not definitively proven — randomized, long-term, comparative outcome studies remain scarce. Meanwhile, meta-analyses suggest that gender-specific designs do not consistently confer superior outcomes, underscoring that geometry alone is not the only determinant of success. Other variables — surgical technique, alignment philosophies, soft-tissue balancing, and rehabilitation — remain critical [11–13, 14].

From a pragmatic standpoint, these insights shape three domains of action. First, the surgeon's intraoperative algorithm should explicitly consider ML coverage as a decision point: accept minor ML mismatch only after weighing its likely impact on soft tissues and patellar mechanics, and use available technical options (downsizing with posterior augmentation, alternate trays, asymmetric options) when mismatch threatens function. Second, hospital procurement should be guided by local anthropometry: stocking implants that have demonstrated closer local fit reduces the frequency of unfavorable trade-offs and may improve operating efficiency. Third, industry should be encouraged to provide finer size increments and asymmetric tibial trays where feasible; modern manufacturing techniques make such options increasingly practical, though economic analyses are required [14–17, 20].

Limitations and perspectives

while morphometric mismatch is well described, translating tight geometric concordance into consistent, measurable patient benefit requires prospective outcome data. Several observational studies link ML overhang to early soft-tissue complaints, but confounding variables and the multifactorial nature of postoperative pain complicate causal inference. Large-scale registries and randomized trials that pair geometric data with validated patient-reported outcome measures and long-term survivorship would provide the strongest evidence to motivate industry-level redesign [18–21].

Finally, cultural and functional context matters. In populations where deep flexion and kneeling are essential for daily life, small geometric mismatches can disproportionally affect perceived outcome even if implant survival is acceptable. Surgeons and policy makers should therefore weigh local functional expectations when assessing the value of design modifications or inventory changes [6, 12, 16].

Clinical importance

Understanding local knee anthropometry directly affects patient care. Appropriate implant selection and intraoperative sizing reduce the risk of soft-tissue irritation, patellofemoral maltracking and discomfort during culturally important activities like squatting and kneeling. For surgical teams, anthropometry informs operative choices (size selection, re-cutting strategy, choice of asymmetric or modular components) and inventory planning. For hospitals and purchasers, stocking implants that better mirror local anatomy can decrease intraoperative compromises, improve patient satisfaction, and potentially shorten revision risk related to early mechanical irritation. These considerations combine patient comfort, functional expectations and health-economics into a persuasive argument for region-aware practice.

Future directions

Future work must prospectively link millimetre-scale geometric mismatch to validated patient-reported outcomes and objective function, ideally through randomized or registry-based studies. Comparative trials of locally-tuned versus standard implants, paired with cost-effectiveness analyses, will clarify whether design refinements justify higher procurement costs. Exploration of modular and patient-matched manufacturing methods may offer scalable solutions, but their adoption should follow evidence of functional and economic advantage.

Conclusion

Knee anthropometry varies by population and sex, and those variations produce predictable implant-bone mismatches when AP-driven sizing is used without attention to ML coverage. The practical consequence is a set of intraoperative decisions that directly influence early comfort and long-term function, particularly in populations that demand deep flexion. Surgeons and hospitals should use local anthropometric evidence to guide implant selection, maintain flexible inventories, and apply intraoperative strategies that prioritize both geometric fit and biomechanical function. Manufacturers should consider regionally informed sizing ladders and asymmetric options; most importantly, the community needs prospective outcome studies to link geometric concordance to clinically meaningful benefits.

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Conflict of Interest: Nil
Source of Support: None

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Year of Acceptance of Thesis: 2020

How to Cite this Article: Soni P, Sancheti P, Patil K, Gugale S, Sanghavi S, Sisodia Y, Nisar OUI, Sonawane D, Shyam A.| Tailoring Total Knee Prostheses to Indian Anatomy: A Hypothesis on Improved Fit, Function, and Longevity | Journal of Medical Thesis | 2022 July-December; 08(2):16-20.