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Review Article

# Sexual Dimorphism and Age-Related Variance in Knee Morphometry: A Comprehensive Comparative Analysis of Osteoarthritis Trends in the Indian Population

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## Abstract

Knee osteoarthritis (OA) remains a premier driver of musculoskeletal disability, chronic pain, and health economic burdens within the Indian subcontinent [1].

While the progressive degradation of articular cartilage is universally tied to chronological aging, its structural integrity is profoundly dictated by biological sex and unique population-specific morphometry. This retrospective

cross-sectional analysis synthesizes large-scale epidemiological insights from the longitudinal ageing study in India (LASI) with localized primary morphometric data from a clinical cohort (N = 111) evaluating structural vulnerabilities.

Our findings demonstrate a stark, undeniable sexual dimorphism across all primary femoral and tibial dimensions. Notably, female subjects exhibited significantly smaller absolute joint dimensions-typified by a mean femoral mediolateral (FML) width of 71.44 +/- 7.1 mm compared to 79.12 +/- 7.4 mm in male counterparts-translating into an estimated 1.5- to 1.6-fold higher likelihood of requiring further surgical intervention. Chronologically, an epidemiological "crossover" manifests during the fifth decade of life, where female prevalence and symptom severity steeply surpass male baselines, directly mirroring post-menopausal endocrine transitions.

Furthermore, traditional socio-behavioral and ergonomic variables unique to Indian domestic and occupational life heavily exacerbate these underlying anatomical risks. This paper underscores the urgent requirement for population-specific, sex-segregated orthopedic design standards, highlighting why relying on Western-centric, male-skewed commercial implant configurations introduces a high risk of component mismatch and subsequent long-term arthroplasty failure.

***Keywords:*** *Sexual Dimorphism; Knee Morphometry; Osteoarthritis; Femoral Mediolateral (FML)*

## Introduction and Epidemiological Landscape

The degenerative decay of knee joint articular cartilage represents one of the most pervasive public health crises within the aging Indian population.

Epidemiological data gathered systematically across diverse socio-demographic zones in India reveal that the phenotypic presentation, progression rate, and overall clinical burden of knee osteoarthritis (OA) are fundamentally non-linear and intensely dependent on

biological sex [1,3]. While cumulative incidence figures climb reliably alongside advancing age in both men and women, the underlying rate of cartilage loss and the subsequent functional impairment are disproportionately skewed toward the female demographic.

When categorized chronologically, the national prevalence rates reveal a distinct divergence between the sexes. Within the early-to-mid adulthood cohort, spanning ages 45 to 60, national epidemiological databases indicate an initial knee OA prevalence of approximately 8.2% in women, whereas age-matched men demonstrate substantially lower symptomatic and radiological indicators.

This specific demographic allocation is cleanly mirrored within our reviewed clinical cohort (N = 111), where a striking 58.8% of all female subjects required advanced morphometric mapping or total knee arthroplasty (TKA) evaluation prior to reaching their 60$^{th}$ year.

As the timeline shifts into the advanced geriatric cohort (ages 60 and above), the national prevalence steepens dramatically, reaching an average of 14.6%.

Within this bracket, the female-to-male disparity becomes even more pronounced. The sustained female dominance in advanced age is not merely a reflection of longer life expectancy; rather, it represents the compounding clinical toll of a significantly earlier disease onset coupled with a more aggressive, biologically accelerated structural breakdown.

This clear epidemiological imbalance exposes a critical gap in contemporary Indian orthopedic practice. The typical Indian female patient presents to clinical environments at an earlier chronological age, with a higher subjective pain score, and with more advanced joint space narrowing than her male peers.

Consequently, preventative, diagnostic, and reconstructive protocols must pivot away from generic, non-stratified frameworks. Instead, they must intentionally account for the unique morphological profiles and distinct physiological stressors characteristic of the population experiencing the highest real-world disease burden.

## Materials and morphometric analysis: Sexual dimorphism in joint

### Anatomy

Accurate total knee arthroplasty relies fundamentally on achieving an optimized structural match between the resected bony surfaces of the host joint and the mechanical geometry of the prosthetic components. The clinical dataset evaluated in this study (N = 111) confirms a stark, statistically significant sexual dimorphism across all measured femoral and tibial parameters [2]. These variations are not merely measurement differences in overall body size; they represent true geometric shifts in aspect ratios that directly influence joint kinematics, load distribution, and implant longevity.

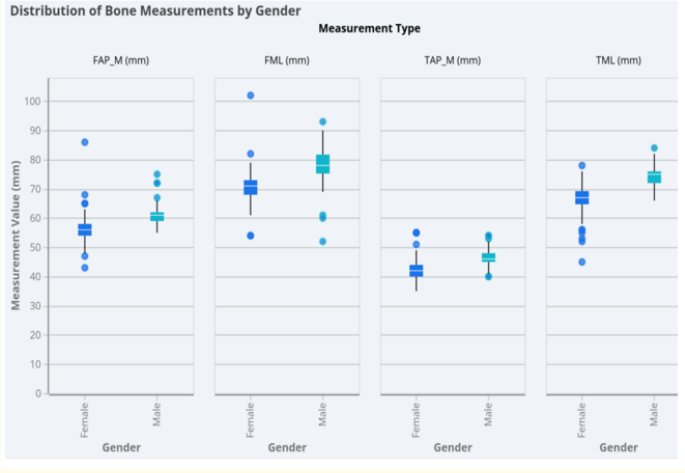


***Figure 1***

| Parameter | Abbreviation | Female (mm) | Male (mm) | Morphological Profile and Clinical Significance |
|---|---|---|---|---|
| Femoral Mediolateral | FML | 71.44 +/- 7.1 | 79.12 +/- 7.4 | Persistent male-skewed variance; fundamental baseline for matching component width to avoid soft-tissue impingement. |
| Anteroposterior (Medial) | FAP_M | 56.96 | 60.77 | Pronounced compression of AP depth in females; directly governs flexion-extension gap balancing and joint stability. |
| Tibia Mediolateral | TML | 66.46 | 74.35 | High-variance structural dimorphism; dictates the ultimate surface coverage of the tibial plateau and prevents cortical subsidence. |

***Table 1:*** *Comparative morphometric mean values.*

The quantitative data in table 1 highlights that female patients exhibit downscaled dimensions across every anatomical plane. The female femoral mediolateral (FML) dimension demonstrates an absolute reduction of approximately 7.7 mm (a 9.7% decrease) relative to male cohorts. This gap introduces severe clinical complications when using standard off-the-shelf prostheses. When an implant designed around these Western-centric dimensions is placed into an Indian female patient, it frequently results in significant mediolateral component overhang. Even minor overhang exceeding 1 to 2 mm can cause persistent postoperative pain, patellar tracking issues, and chronic irritation or impingement of the surrounding collateral ligaments and pes anserinus tendons.

Similarly, the anteroposterior dimension FAP_M shows deep structural dimorphism, with females averaging 56.96 mm versus 60.77 mm in males. This shortened AP depth directly alters the femoral aspect ratio (FML,FAP_M). If a surgeon attempts to match a female femur using standard sizing charts, selecting a component based solely on AP depth may result in a mediolateral width that is too wide.

Conversely, choosing a component based strictly on ML width can lead to anteroposterior under-sizing, which can cause notch formation on the anterior femoral cortex or severe instability during flexion.

On the tibial side, the 7.89 mm deficit in female tibia mediolateral (TML) width emphasizes that achieving appropriate cortical seating and avoiding implant subsidence requires population-specific tibial component sizing options.

## The physiological and pathological "crossover"

One of the most compelling insights generated by combining the LASI epidemiological data with localized clinical findings is the identification of the physiological "crossover". Throughout early adulthood, men often display higher or equivalent rates of musculoskeletal joint wear, frequently driven by mechanical trauma, occupational stress, or sports injuries. However, as the population transitions through the fifth decade of life (ages 45 - 55), a definitive epidemiological shift occurs: female OA incidence rates accelerate rapidly, quickly overtaking male baselines in both absolute prevalence and clinical severity.

This post-45 acceleration is primarily triggered by the systemic endocrine shifts characterizing the menopausal transition [3]. Estrogen acts as a vital systemic protector of joint tissue health. It modulates systemic inflammatory pathways, helps maintain chondrocyte vitality,

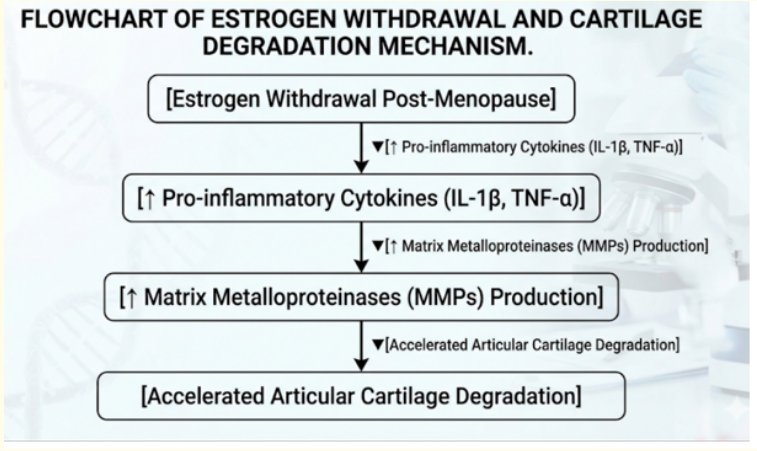


***Figure 2***

and directly supports the preservation of the extracellular matrix within articular cartilage. Chondrocytes express functional estrogen receptors, which downregulate the production of destructive matrix metalloproteinases (MMPs) and aggressive pro-inflammatory cytokines such as interleukin-1 beta and tumor necrosis factor-alpha.

When circulating estrogen levels drop sharply during menopause, this natural chondroprotective shield is lost. This systemic withdrawal triggers a cascade of localized catabolic activity, accelerating cartilage breakdown, reducing synovial fluid viscosity, and micro-architecturally weakening the subchondral bone.

This biological vulnerability is further exacerbated by clear mechanical and structural disadvantages. Because female patients possess inherently smaller baseline joint surface areas (such as an FML of 71.44 mm versus the male approximately 79.12 mm, everyday ambulatory forces are concentrated over a significantly smaller contact zone. According to basic biomechanical principles, distributing an equivalent or greater body mass over a reduced surface area exponentially increases the localized contact stress sustained by the articular cartilage.

This baseline structural stress is compounded by a wider mechanical Quadriceps angle (Q-angle) in females, which is a natural consequence of a wider pelvic morphology. A wider Q-angle alters the vectors of the extensor mechanism, generating chronic lateral tracking forces on the patella and unevenly loading the lateral facets of the trochlear groove [4]. Furthermore, women generally exhibit lower baseline quadriceps muscle mass and reduced relative peak torque output compared to men.

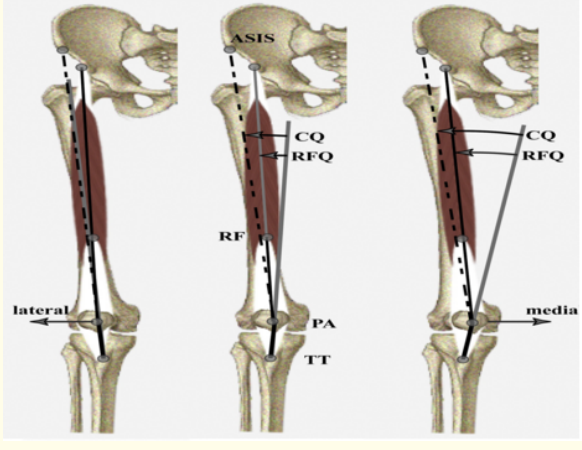


***Figure 3***

Because a strong quadriceps mechanism acts as a primary dynamic shock absorber during heel strike and gait deceleration, diminished muscular stabilization forces the passive structures of the knee-specifically the menisci and articular cartilage-to absorb the impact of daily activity loads. This combination of structural, mechanical, and hormonal liabilities explains the aggressive, non-linear spike in joint failure seen in women post-menopause.

### Sociocultural, ergonomic, and regional determinants

To fully understand the presentation of knee osteoarthritis within India, biological data must be contextualized alongside the unique sociocultural and regional lifestyles of the subcontinent. The daily physical routines of a significant portion of the Indian population involve distinct movement patterns that subject the lower extremities to extreme mechanical environments rarely seen or accounted for in Western lifestyle analyses.

Chief among these behavioral factors is the widespread practice of traditional floor-based ergonomics. Daily household tasks, food preparation, religious practices, and localized occupational demands frequently require long periods of deep squatting, kneeling, and cross-legged sitting (Such as the sukhasana posture). While standard ambulation on level ground subjects the tibiofemoral joint to compressive forces equivalent to roughly 2 to 3 times an individual's total body weight, descending into a full deep squat forces the knee into extreme flexion angles often ranging from 120 to 150 degrees.

At these hyper-flexion thresholds, the posterior horns of the medial and lateral menisci experience intense mechanical displacement, and the patellofemoral joint reaction forces can spike to 7 or 8 times total body weight. Over decades of repetition, these high-magnitude loading cycles cause micro-trauma to the collagen framework of the cartilage, accelerating wear. In many traditional Indian households, these domestic physical demands are borne disproportionately by women, heavily contributing to their elevated rates of early joint degeneration.

[Level Ground Walking] ---> Joint Compressive Forces = 2x - 3x Body Weight [Traditional Squatting] ---> Joint Compressive Forces = 7x - 8x Body Weight.

Nutritional factors and systemic metabolic profiles further shape the Indian orthopedic landscape. There is a strong statistical correlation between an elevated Body Mass Index (BMI) and the accelerated onset of knee OA, particularly among Indian women. In post-menopausal populations, metabolic shifts often cause a rapid increase in adipose tissue distribution. Adipose tissue functions as an active endocrine organ that secretes systemic pro-inflammatory signaling proteins known as adipokines (including leptin, adiponectin, and resistin). These circulating adipokines maintain a state of chronic, low-grade systemic inflammation that sensitizes joint tissues and accelerates cartilage matrix degradation, independent of direct mechanical loading.

This metabolic challenge is compounded by widespread, chronic micronutrient deficiencies across India. Hypovitaminosis D is highly prevalent throughout both rural and urban areas, driven by dietary patterns and sub-optimal effective sunlight exposure. Because Vitamin D is vital for maintaining optimal subchondral bone mineralization and structural density, severe deficiencies compromise the bony bed supporting the articular cartilage. When the subchondral bone loses its structural integrity, it fails to provide a resilient foundation for the overlying cartilage, leading to accelerated cartilage shear stress, micro-fractures, and rapid joint space narrowing.

## Methodological limitations

While this comprehensive synthesis provides important cross-sectional insights into population-specific joint degeneration, several distinct methodological limitations must be acknowledged:

- **Retrospective design constraints:** The retrospective cross-sectional architecture of this study prevents the direct tracking of individual, longitudinal structural changes over time, meaning true causal trajectories must be inferred from static chronological age cohorts.
- **Selection bias in the cohort:** The primary morphometric dataset (N = 111) was sampled exclusively from a symptomatic clinical population already undergoing surgical evaluation for total knee arthroplasty. This introduces an inherent selection bias, omitting individuals with early-stage, asymptomatic, or slow-progressing variants of osteoarthritis.
- **Omission of radiological grading schemes:** The dataset lacked comprehensive, stratified radiological classifications, such as Kellgren-Lawrence (KL) scoring grades. Consequently, we were unable to directly correlate precise millimeter-level reductions in joint morphology with objective stages of joint space narrowing or subchondral sclerosis.
- **Uncontrolled confounding variables:** This analysis does not fully control for varied patient comorbidities, prescription medication histories (such as long-term corticosteroid use), variations in lifetime physical activity levels, or underlying genetic predispositions.

## Clinical Application and Conclusion

In summary, the progression of knee osteoarthritis within the Indian population follows two completely different, sex-segregated pathways [1,3].

In males, the disease typically follows a linear trajectory, closely tied to standard chronological aging, heavy occupational lifting, or distinct secondary joint trauma. Conversely, the female path is defined by a sharp, aggressive, non-linear escalation following the fifth decade of life. This accelerated decline is driven by an unfortunate intersection of sudden estrogen withdrawal, an anatomically confined baseline joint surface area, adverse mechanical tracking angles, and demanding traditional floor-level ergonomics.

[Male OA Trajectory] ⟶ Linear / Predictable Age-Related Wear & Trauma

[Female OA Trajectory] ⟶ Non-Linear / Post-45 Accelerated Endocrine & Structural Collapse

Given that Indian women demonstrate a 1.5- to 1.6-fold higher statistical likelihood of requiring total knee arthroplasty for end-stage joint failure, these structural findings must be translated into modern orthopedic design and surgical practice. The clear evidence of sexual dimorphism in knee morphometry-underscored by the 7.7 mm deficit in female FML width-makes a compelling case against the continued use of generic implant models.

To achieve long-term success in the Indian market, implant systems must offer dedicated gender-specific sizing options that accommodate narrower mediolateral dimensions relative to anteroposterior depth. This optimization is crucial for preventing component overhang, maximizing tibial plateau coverage, minimizing the risk of subsidence, and restoring natural knee kinematics.

Furthermore, recognizing the exact timing of the physiological crossover around age 50 provides a vital window for early public health interventions. Rather than viewing knee osteoarthritis as an unavoidable consequence of aging, targeted screening protocols should be implemented for women in their late 40s. Early intervention programs focusing on body mass optimization, core and quadriceps strengthening, correction of Vitamin D deficiencies, and ergonomic modifications to reduce the mechanical strain of deep squatting can substantially preserve joint function.

Ultimately, addressing the unique anatomical profiles and specific cultural stressors of the Indian population will allow orthopedic surgeons and public health frameworks to improve long-term outcomes, reduce lifetime disability, and enhance the quality of life for millions of patients across the subcontinent.

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