Hypothesis

CT Morphometric Analysis of Medial Femoral Condyle in Indian Population: An analytical study comparing Unicompartmental Knee Arthroplasty Implants to Indian knees

Kedar Ahuja[1],
Mohan Desai[1]
Ibad Patel[1],
Kannan Pughazendi[1],
Ashraf Shaikh[1]

[1]Department of Orthopaedics, Seth GSMC and KEM Hospital, Mumbai, Maharashtra, India.

Address of Correspondence
Dr. Kedar Ahuja
Department of Orthopaedics, Seth GSMC and KEM Hospital, Mumbai, Maharashtra, India.
E-mail: drkedarahuja@gmail.com

Abstract

Background: The idea of resurfacing a single knee articular compartment was introduced in 1950s by MacIntosh and modified by McKeever who inserted a prosthetic disc into diseased tibial plateau, the disc functioned as a joint spacer effectively. Marmor designed the first unicompartmental knee prosthesis. However , early results were poor because of prosthetic loosening and osteoarthritis in the contralateral compartment. Osteoarthritis of the knee usually affects the medial compartment of the tibiofemoral articulation first and it may later involve the lateral compartment also [2,5]. Present study to compare dimensions of the medial femoral condyle with femoral components of conventional UKA prosthesis.

The purpose of this study was to compare dimensions of Medial Femoral Condyle (MFC) of Indian population to that of the standard size femoral components of commercially available three Unicompartmental Knee Arthroplasty (UKA) implants.

This is an analytical study wherein we included CT morphometric data of 100 consecutive nonarthritic adult knees with reference to the MFC, to assess the compatibility with UKA prostheses. A systematic approach was used to measure the anteroposterior dimension of each MFC. Proportion of knees which could be optimally replaced with the existing commercially available three Unicompartmental Knee Arthroplasty femoral implant systems viz., Link, DePuy and Smith & Nephew implants were calculated.

Results: There were 56 males and 44 females included in the study (M:F – 1.27:1). The mean age was 43.28 ± 10.53 years Best fit amongst the Link implant was the size 'small' in 43% of the patients, followed by 'medium-small' in 35% and 'medium' in 16%. For Depuy Sigma Uni implant, best fit was observed in size 1 in 38% of the patients, followed by size 3 in 25%, size 4 in 13%, size 2 in 10% and size 5 in 2%. Best fit among the Smith & Nephew implants was observed in the size 2 i.e, 30%, followed by size 3 in 27% , size 4 in 15%, size 1 in 12% and size 5 in 8%. A proportion of Indian Knees will have overhang of the femoral component of UKR because MFC of some Indian knees is smaller than the smallest size of the femoral component. which in our study was 6 % for Link, 12% for Depuy and 8% for Smith & Nephew.

Hypotheses: The best fit for Indian Knees is seen with the size implants 'small' in Link (43%), 'size 1' in Depuy implants (38%) and 'size 2' in Smith & Nephew implants (30%) of the patients. It is suggested that the implant companies should take

Dr. Kedar Ahuja

Dr. Mohan Desai

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the Indian population into consideration and customize the implants which may help in optimizing the fit and reducing overhang.

Clinical Importance: At If the femoral component is oversized it often causes anterior overstuffing that increases the risk of patellofemoral as well as soft-tissue impingement. So to encourage introduction of new ways to measure prosthesis sizes for Indian knee, or encourage companies to make sizes catering to Indian sizes.

Future Research: The shift towards personalized implant solutions could potentially revolutionize the field of knee arthroplasty, offering tailored interventions that better align with the diverse anatomical profiles of patients across the globe. Future directions in knee implant research should focus on large-scale, multi-center studies encompassing diverse populations

Introduction

Osteoarthritis is a common pathological disorder of the knee and mostly affects the medial compartment of the tibiofemoral articulation. [1,2] At present Unicompartmental Knee Arthroplasty (UKA) is the most beneficial treatment for unicompartmental knee arthritis because it is designed in a way that it preserves most of the patient's own bone and thereby reducing trauma and improving post-operative recovery. [3] However If the femoral component is oversized it often causes anterior overstuffing that increases the risk of patellofemoral as well as soft-tissue impingement. Hence the successful outcome of UKA is mainly dependent on the best fit between the implant component and the resected surface of the knee and therefore it is imperative to keep in mind dimensional considerations before choosing the implants for UKA.

Almost all of the commercially available UKA implants are made as per the measurements available from the western population studies. [4] Currently there are no Indian studies available on the comparison of UKA implants to the components of the medial femoral condyle. And it is well known that Indians and westerners have predominantly striking racial differences with respect to various physical traits and dimensions.

The primary objective of this study was to compare the dimensions of medial femoral condyle i.e., Anteroposterior (AP) and Mediolateral (ML) diameters of Indian population with that of standard size femoral components of the commercially available UKA implants and secondary objective was to find out the most common sizes of the femoral implants that best fit the Indian Knees.

Methods

This analytical, cross-sectional study was conducted at a tertiary care hospital following approval from the Institutional Ethics Committee (Project no. EC/223/2018). Sample size estimation and sampling technique was done as per Cohen's d (effect size) calculation [5], assuming a significance level of 5% (α) and statistical power of 80% ($1 - \beta$), a sample size of 100 patients was calculated.

These patients underwent CT scan of their knee for various clinical indications excluding pathologies which could alter the morphometry of femoral condyle, i.e., fractures, neoplasia, old physeal injuries etc.

During the scan, it was ensured that the patients were in supine position, with the knees relaxed and in extension. The scanning procedure 3D- CT scan (120 kVp, 50 mAs, Philips Healthcare) was performed to acquire CT slices of thickness 0.5mm with a resolution of 512 × 512 pixels. The MFC dimensions were measured by a single surgeon using OsiriX DICOM (Digital Imaging and Communications in Medicine) viewer software for Mac OS.

Morphometric measurements of the Medial Femoral Condyle

A line was drawn along the posterior femoral cortex corresponding to the posterior peg of the UKA implant. The minimal resection is 6.7mm distally (distal femur), so a perpendicular line to posterior femoral cortex was drawn 6.7mm proximal to distal femoral cortex (Line A). Two more lines transecting the latter line at the anterior and posterior cortices are drawn parallel to each other at maximum AP (line 1 and 2) [Figure 1]. The distance between line 1 and line 2 was used to compare with different conventionally available implant sizes in AP. Mediolateral length was measured on the same axis (Line A) in axial cuts. Overhang was defined as Anteroposterior fit > 2 mm over and above the femoral condyle.

Statistical analysis

Patients' demographic data, mediolateral and anteroposterior measurements of the MFC were summarized as mean and standard deviation (mean ± SD). The best-fit lines for each of the implant systems were calculated with the use of least squares regression method. Dimensions of the patients medial femoral condyle were then compared with various commercially available implants viz., Link , DePuy and the Smith & Nephew implants.

Statistical analysis was performed using Microsoft Excel and SPSS ver.20 (IBM Corp, Armonk, NY). Chi-square test of association was used to compare between the medial femoral condylar variables and the various types of UKA implants as well as to compare between males and females. The 'p' value ≤0.05 was considered to be statistically significant.

Results

There were 44 females and 56 males in this study, with a male: female ratio of 1.27: 1. Mean age of the study participants was 43.28 ± 10.53 years. Average ML diameter was 20.99 ± 1.44 and AP diameter was 47.56 ± 3.55. The minimum ML diameter was

17.3 and minimum AP diameter was 39.8.

The morphometric analysis revealed distinct trends in the best-fit sizes among the three commercially available Unicompartmental Knee Arthroplasty (UKA) implant systems: Link, DePuy, and Smith & Nephew.

Among the Link implant systems, the size 'small' emerged as the most suitable in 43% of the patients, demonstrating a notable prevalence for this category. Following closely, the 'medium-small' size exhibited an optimal fit in 35% of cases, emphasizing its relevance in a substantial proportion of the study cohort. The 'medium' size, although less common, still demonstrated a favorable fit in 16% of patients.

In the case of DePuy implants, size 1 took the lead as the best fit in 38% of patients, indicating its compatibility with a significant portion of the study population. Subsequent sizes demonstrated varying degrees of suitability, with size 3 showing an optimal fit in 25% of cases. Sizes 4, 2, and 5 exhibited successively diminishing percentages of optimal fits.

Among the Smith & Nephew implant systems, size 2 emerged as the most fitting choice in 30% of patients, closely followed by size 3 at 27%. The subsequent sizes—4, 1, and 5—showed descending percentages of optimal fits.

Despite the meticulous comparison with the smallest size implants available, a notable occurrence of femoral overhang was observed across all three implant systems. Specifically, 6 cases with Link implants, 12 with DePuy implants, and 8 with Smith & Nephew implants exhibited femoral overhang. This highlights a crucial aspect of the study, indicating that even with the smallest available implants, there remains a subset of patients for whom the femoral component extends beyond the resected surface of the knee. This emphasizes the imperative need for further refinement in implant design and customization to ensure an optimal fit for all patients, reducing the risk of complications associated with femoral overhang.

Discussion

Historical Development and Evolution of Unicompartmental Knee Arthroplasty (UKA):

The landscape of knee arthroplasty has undergone a transformative journey over the years, with significant advancements in implant designs and surgical techniques. Unicompartmental Knee Arthroplasty (UKA) emerged as a promising approach, offering a more conservative alternative to total knee replacement by preserving healthy tissues and promoting quicker postoperative recovery [3]. As osteoarthritis, particularly affecting the medial compartment of the knee, became a prevalent pathological disorder, the demand for effective and less invasive treatment options grew. The development of UKA was a response to this demand, aiming to provide a targeted solution for patients with unicompartmental knee arthritis.

The historical trajectory of UKA can be traced back to the pioneering work of John Insall and Chitranjan Ranawat in the 1970s, who introduced the concept of partial knee replacement to address isolated compartmental degeneration [3]. The Oxford meniscal knee, introduced by Carr et al. in 1993, marked a significant milestone in the evolution of UKA, demonstrating improved survival rates and functional outcomes [1]. Over the years, UKA has evolved from early fixed-bearing designs to modern mobile-bearing systems, enhancing implant stability and longevity. The evolution has also seen the introduction of various implant systems, each designed with specific features to optimize outcomes.

Challenges in Achieving Optimal Fit:

Despite the positive trajectory of UKA development, achieving an optimal fit between the implant components and the resected surface of the knee remains a complex task. Our study aligns with previous research, notably the work by Hitt et al [7], revealing the challenges in achieving comprehensive coverage of the exposed cortical rim with current knee arthroplasty systems. Notably, our findings indicate that even theoretically optimized implants fall short, covering only 76% of the cortical rim. This underscores the persistent complexity in achieving an ideal fit for knee implants and emphasizes the need for nuanced considerations in implant design.

Our investigation of three commercially available UKA implants sheds light on notable variations in overhang prevalence, with the lowest incidence observed in Link implants, followed by Smith & Nephew, and the highest in Depuy implants. The significant dominance of optimal fit in the Link Sled 'small' size (43%) highlights its close match to the medial femoral condyle of the Indian population, suggesting its potential superiority in achieving optimal outcomes [1].

Population-Specific Anatomical Variations:

The study emphasizes the critical importance of considering population-specific anatomical variations in implant design. The findings resonate with Cheng et al's examination of femoral implants in the Chinese population, which revealed overhang for all ranges of the anteroposterior (AP) dimension [8]. This parallel discovery underscores the importance of understanding population-specific anatomical variations to enhance implant design. Similarly, Fitz et al's study on cadavers emphasizes the disconnect between current UKA dimensions and measured sizes, particularly noting challenges in achieving an optimal fit, especially in males [6].

Gender-based anatomical differences, as explored by Yan et al [11], further highlight the intricacies of femoral morphology. The statistically significant gender-based variation in the ML/AP ratios of femoral condyles adds a layer of complexity to implant design considerations. In our study, the prevalence of overhang was generally higher in females across all three UKA implants, though it did not reach statistical significance.

Global Perspectives on Implant Design:

Studies on diverse populations, such as Kim et al's investigation into the femoral morphology of Korean women, emphasize the inadequacy of implant designs based on Caucasian population data [10]. Similarly, Surendran et al's research on the anthropometry of resected medial tibial condyles in Korean cadavers highlights challenges in achieving an optimal fit, with specific concerns regarding mediolateral overhang for certain tibial component designs [12]. The findings of Kantanavar et al's study on the compatibility of medial tibial condyle morphometry in the Indian population with contemporary UKA prostheses resonate with our results [13].

Implications for Clinical Practice and Future Directions:

Our study contributes to the growing body of evidence emphasizing the need for population-specific considerations in knee implant design. The nuances of anatomical variations, as demonstrated by different studies, underscore the challenges in achieving a universally optimal fit. This collective evidence calls for a paradigm shift in implant design strategies, emphasizing customization to enhance the success and efficacy of Unicompartmental Knee Arthroplasty globally.

Furthermore, our study carries implications for clinical practice, suggesting that a one-size-fits-all approach to UKA implants may not be suitable, especially in diverse populations like India. The observed variations in optimal fit among different implants underscore the necessity for implant companies to consider the specific anatomical characteristics of the Indian population. Customizing implants based on regional anatomical variations may lead to improved patient outcomes, reduced complications, and enhanced long-term success of UKA.

This shift towards personalized implant solutions could potentially revolutionize the field of knee arthroplasty, offering tailored interventions that better align with the diverse anatomical profiles of patients across the globe. Future directions in knee implant research should focus on large-scale, multi-center studies encompassing diverse populations, including comprehensive data on anatomical variations and implant performance. Collaborations between researchers, surgeons, and implant manufacturers are essential to drive innovation, ensuring that the next generation of knee implants considers the unique characteristics of each patient population. In doing so, the field can move towards a more patient-centric approach, optimizing outcomes and quality of life for individuals undergoing Unicompartmental Knee Arthroplasty worldwide.

Conclusion

Our study results concluded that among the 3 commercially available implants compared, The best fit for Indian Knees is seen with the size implants 'small' in Link (43%), 'size 1' in Depuy implants (38%) and 'size 2' in Smith & Nephew implants (30%) of the patients. Through this study, we suggest a thorough consideration of population measurements in order to ensure best fit for majority of the Indian population. Since UKA is a long term treatment modality and prognosis is mainly dependent on how well the implants fit the patients morphology, we recommend a customized approach towards Indian population in planning of UKA components by commercial implant companies.

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Institute Where Research was Conducted: Seth GSMC and KEM Hospital, Mumbai, Maharashtra, India.
University Affiliation: Maharashtra University Of Health Sciences (MUHS), Nashik, Maharashtra, India
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