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Review Article

Do Morphological and Ethnic Factors Affect the Outcome of Total Knee Arthroplasty? - A Review

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Abstract

Total Knee Arthroplasty (TKA) is one of the ‘last resort’ prosthetic treatments for patients with acute arthritis or other degenerative knee debilities. The primary objective of this non-ablative modality is to alleviate chronic pain and reinstate functionality of the impaired limb. Total knee arthroplasty has seen successive evolutionary changes from ivory implants with plaster of paris to cobalt chromium implants assisted by computerized navigation systems. The evolutionary changes are aimed at improving the prosthesis design, surgical approach, effects and recuperation. Major and minor ethnic differences also must be considered to achieve an optimal rate of success. In this review, we discuss on some of the critical factors that help achieve favorable outcomes while conducting total knee arthroplasty. We have also identified the morphological differences in tibial and patellar structures of the knee that interfere in the prosthetic treatment.

Keywords: Arthritis; Knee morphology; Patella, Prosthetic treatment; Total knee arthroplasty; Tibia

Measuring The Success Rate

The health status of TKA patients are measured using different scales including Arthritis Impact Measurement Scales, Functional Status Index (FSI), Health Assessment Questionnaire (HAQ), Index of Well Being (IWB), and Sickness Impact Profile (SIP) [1,2]. Although the efficacy of the treatment is measured by various parameters, patient satisfaction is the principle parameter to measure success of the modality. One meta-analysis on existing reports conclude that 82% of the total knee replacements and 70% of unicondylar knee prosthetics can survive up to 25 years [3]. Despite all the achievements of TKA, many reports have claimed major flaws in the efficacy and durability of the procedure. Studies have reported practical problems in patients who underwent TKA (Table 1). To achieve greater longevity, bone resection (with high precision and proper balancing of the soft tissues) and accurate prosthetic component size that glues well with the resected bone are obligatory. A more understanding on the morphology of the different segments of the knee would help in developing exact prosthetic designs that yields higher longevity, safety and better prognosis.

Author	No. of subjects	Early failure <2 years n%	Causes	Late failure> 2 years n%	Causes
Mulhall et al., 2006	318	31	Infection	69	Instability, poly ethylene wear out, component loosening
Sharkey et al., 2002	212	55.6	Infection, instability, arthro fibrosis, loosening	42.4	Instability, poly ethylene wear out, component loosening
Fehring et al., 2001	440	63	Infection, instability, failure of ingrowth in porous implant, patellofemoral problems, osteolysis, aseptic loosening	Nil	Nil
Rand et al., 1982	227	55.6	Instability, infections, loosening, malalignment, malposition and fracture	42	Instability, poly ethylene wear out, component loosening
Hossain et al., 1982	349	32.1	Instability, infections, aseptic loosening, malalignment, fracture, wear, stiffness	67.9	Infection, Instability, poly ethylene wear out, component loosening, fracture, stiffness

n= no. of subjects

Table 1: A review on the causes of early and late TKA failures in published sources.

Why Tkas Fail??

Despite all the advantages of TKA treatment, there are an increasing number of failed TKA surgeries. It has been reported that about 22,000 TKAs have failed and are revised annually [4]. By the year 2020, the total number of TKA surgeries is expected to soar up to 1.3 million worldwide, which equates to about 127,000 revision surgeries would be needed [5]. Some distinguishing reasons for TKA failures have been identified as microbial infections, instability, malfunctioning of the prosthetic, aseptic loosening, implant fracture, gangrene in the patella, or improper axial positioning [6,7]. Loosening of the implant was a major cause of early resections because an older version of hinge prosthesis called "Guepar" was used which caused a high degree of interface stress on the prosthetic joints [6]. Earlier reports and meta-analysis on the durability and efficacy of prosthetic surgeries gave diverse results. The earliest review conducted between 1970 and 1980 reported the average lifetime of a TKA to be 2.7 years with loosening of the prosthetic (34.9%) followed by instability of the implants (16.7%) and misalignment (14.8%) being the chief reasons underlying the failure [7], while many other researchers have identified microbial infection as the chief cause of failures in TKAs [8,9]. Moreland reported that some surgical faults and manual errors affect the functionality of the implants. Inept trimming of the bone, bad ligament balance or faulty cementing are some of the hidden reasons in addition to patient factors like high mobility or osteolysis [10]. Between 66% and 76% of TKAs have been reported be oversized [11]. Many reviews have been conducted throughout the years tracing out the primary reasons for failure and researchers conclude that TKA failures can be greatly reduced if the resection techniques and designs are remodelled.

Failed Tkas in Diverse Ethnic Groups

Many researchers have reported difference in knee shape in diverse ethnic populations. Shape difference among the Caucasians was also reported. In arthroplasty, implants manufactured for Western patients were the criterion followed by Asian arthro-surgeons. Moreover, the resection techniques practiced by Western surgeons were faithfully followed by Asian medical professionals. After many failed TKAs, it was discovered that there were wide genetic and structural differences between the two populations. The Asians are generally short in stature with small bone structures as compared to the Westerners in addition to disparate lifestyles. As the ethnic differences between the two populations were gradually deciphered, interest to develop 'population-specific' implants and surgical techniques has been on the rise. Kim et al., reported the ethnic and anthropometric differences between Korean and Western patients. In contrast to Western patients, the Asians have small skeletal structure with vast majority of the people with varus alignment in the lower parts. In addition, their culture fosters diverse flexion postures like squatting, kneeling, crossing legs, etc [12]. High incidence of osteoarthritis during preoperative diagnosis in Asian female population has been reported. Other conditions like post-surgical deep vein thrombosis and pulmonary embolism are relatively low in Asian female population compared to Western women. Reports from a meta-analysis on Asian TKA patients reveal the overall incidence of varied arthro conditions like DVT, proximal DVT, symptomatic DVT and symptomatic PE to be 42.5%, 8.7%, 2.7% and 0.5% respectively. Many similar reports reveal that Asian patients face high risk of drug induced bleeding and relatively low risk of DVT unlike the Westerners who experience serious thrombotic conditions [13]. Therefore, prophylactic treatment for both the population considerably vary in view of their ethnic differences and prospective risks.

Morphology of The Tibia

Studies on the knee morphology with respect to knee arthroplasty include detailed examination of articular surfaces, geometry of the femur condyles or the patellofemoral junction or the axial dimensions [14]. Exact rotational alignment, less overhang and better coverage are prerequisites for better tibial stability after resection. Since improper orientation of tibial prosthetic elements are highly associated with TKA failures, accurate tibial tray design after a thorough understanding of the tibial morphology being mindful of all the ethnic and gender variations will aid in successful resection procedures. Ho et al., reported the wide ethnic diversity between Asian and Caucasian patients which has led to serious mediolateral prosthetic overhang in female Chinese patients. Many recurrent gender and ethnic based failures has led to serious research on different morphological dimensions of the tibia.

The functionality of the asymmetric, symmetric and anatomical based prosthetic designs is still debated over. Dai et al., reported that tibial designs based on the anatomical structure are more durable with high alignment precision than tibial structures designed in accordance with symmetric and asymmetric framework [15]. Yang et al., reflects that asymmetric tibial components are more fitting than other designs because the medial and lateral tibial surfaces are asymmetrical. Therefore, other prosthetic components would not completely overlay the tibial surface leading to extensive lateral overhang or undersized medial component [16]. The functionality and efficacy of both the designs can be fully unravelled only after methodical clinical studies.

Studies conducted in both osteoarthritic patients and cadaver specimens reveal that the mediolateral (ML), anteroposterior (AP), Medial Anteroposterior (MAP) and lateral anteroposterior (LAP) dimensions of the tibial structure in Asian females are slightly smaller than male [17]. The dimension of both male and female tibial structures was smaller than Caucasian tibias [18].

Since diseased knees generally lose their morphological structure, prosthetics based on normal knee structure do not match well for the diseased knee. Only a few researchers have attempted to study the morphological features of the diseased knee in view of finding better knee-prosthetic alignment [19]. Many studies on tibial resection reflect that the angle and depth of chopping at the tibial plateau influence the fixing of the prosthetic in place. A study conducted on both male and female population revealed that the lateral plateau was relatively smaller than the medial plateau by 5.2 mm and 4.3 mm (mean values) in males and females respectively [20]. A study on the Chinese population reveals similar results with a mean of 5.6 mm and 5.1 mm in male and female population respectively [21]. Yang et al., recorded similar observations with lateral plateau being smaller than the medial plateau by 4.1 mm and 4 mm mean values in both men and women patients respectively [17].

Geometry of The Tibial Surface and Its Functionality

The tibial and femoral junction with the associated ligaments assists in mechanical movement of the joint. The dimensions of the tibial plateau are crucial for the screw home mechanism (tibial - femoral rotation). The posterior slope of the tibial plateau with its characteristic elevated anterior end helps to maintain the configuration of the tibial ends during weight lifting activities [22]. The association between the mediolateral and anteroposterior referred as the aspect ratio plays a vital role in defining the shape of the prosthetic component. If the ML and AP dimensions are equal, the aspect ratio is 100% forming a circular tibial prosthetic component. When the aspect ratio exceeds, the shape of the prosthetic is more closely to oval shape. Surendran et al., reported that the higher aspect percentage fits for smaller AP dimensions and vice versa. Studies on Japanese female patients show higher aspect ratios from 138 to 142.86 [18]. Further as the ML dimensions increase, the aspect ratio also adds up. Fitzpatrick et al., calculated the mean overhang and undersize of the tibial surface to be 2.3 mm and 1.9 mm respectively [14].

Femoral Morphological Measurements

The aspect ratio for calculating the morphological geometry of different knee parts was followed by surgeons and prosthetic manufacturing companies. Based on the gender specifications, the femur implant component was classified as being ‘narrow’ or ‘broad’. But such a classification overlooks the more complex variations in the geometry of femur morphology [23]. Other researchers classify structure of the distal femur in the axial plane to be rectangular, trilateral, symmetrical or asymmetrical. Based on these classifications, the morpho structure of the femur has been classified into six structural types. Bonnin et al., demonstrated that the femur morphology is more complex than just being narrow or trapezoidal or symmetrical. He reported that major factors for sizable femur components are strait or trapezoidal femur size and a valgus arrangement [11]. Cue et al., demonstrated that the resected structure assist in building the implant through virtual resection cuts. Fitzpatrick et al., demonstrated the dimensions of the three knee structures with a view to prospective total knee arthroplasty using Principal Component Analysis (PCA) technique. He reported that simple linear measurements of femoral epicondylar and tibial mediolateral length are prerequisites for better knee size. The utmost oversize and under hang of the femur were 3.6 mm and 3.9 mm respectively [14].

Difference Between Ethnicities

Research on different Asian populations revealed lower tibial torsion angle and higher valgus alignment than the white population. In addition, females have petite medial and lateral dimensions and greater valgus disposition. Studies on Asian population were mostly done using 2D measurement methods like radiography or ultrasound techniques which provide information on the extension of the bone structure and can lead to mechanical errors by calculating the misaligned angle of the diseased knee correlating to the imaging planar. 3D measurements are more accurate than 2Ds and provide a clearer picture of the anatomical background of the plateau ([24]. Mahfouz et al., studied the ethnic and gender based anatomical differences in 1000 patients belonging to East Asian, Afro-American and Caucasian races. Based on statistical shape measurements and 3D structural analysis, reference bone atlases were created [23].

Fitzpatrick et al., demonstrated virtual resection on each of the bone surfaces to ensure proper resection while operating. The referral axis of both TEL and PCL, the resection of the femoral and tibial bone from this axis and the depth of the cut, determine the shape of the resected surface. Present systems depend on a range of mean resection angles and therefore it is important to scrutinize the size correlation between each bone structure. The femoral and tibial size ranges are corresponding with each other (r=0.95) whereas the patella size had less correlation between the tibial and femoral size ranges (0.65 and 0.69) [24].

Morphology of Patella

Many reporters have attempted to demonstrate the structure of the patella as ovoid with wider breadth compared to its height. Breadth-height and width ratio with medial ridge position play an important role in precise prosthetic patella structures in addition to patellofemoral contiguity stress and tracing in the trochlear groove. Determining the density of the patella is crucial in the success of the arthroplasty. Thin patella has less patellofemoral contact force which is more susceptible to fractures or anteroposterior instability. Similarly, dense patella can lead to patellar subluxation. Kim et al., surmised resecting options if the patellar is so flimsy i.e., i) not to resurface the patella and ii) increase the prosthetic component's density. The position of the medial ridge also helps in proper patellar alignment. Proper positioning with the medial ridge reduces the Q angle and helps in restoring kinematics post-surgery [12].

Gender Differences

Evidence based reports have documented the vast difference between male and female knee anatomy. Men have larger femur bones in respect to anterior and posterior height, greater transepicondylar width and taller lateral and medial condyles [25]. The mediolateral dimensions in women are narrower than men. The epicondylar axis in females is swirled externally forming the trochlear groove in contrast to male epicondylar groove which swirls internally. Slight anatomical variations in regards to patellofemoral joint are also evident. The average Q angle of the patellar tendon in women is relatively higher than males and is height dependent. This basically leads to the fact that males have larger sized patella compared to females. Research on cadaveric specimens showed that male patellofemoral contact space-ratio in the knee flexion angles is relatively higher than females. This may be a legitimate reason for some implant failures in female patients causing mediolateral overhang and severe irritation triggered by constant friction between the prosthetic and the capsular envelope of the knee. Following these reports, gender specific knee implants have been used in TKAs. Bellemans et al., surmised that the patient's morphotype plays an important role in determining the shape of femur and tibia besides gender related differences [26].

Conclusion

As TKAs is on the rise, innumerable explorative research has been conducted to identify the gender and ethnic differences of the anatomical structure of knee. Results may help surgeons and manufacturers to better understand their patient population and expected fit in them. Further studies need to be carried out to expand the knowledge of knee morphology and its implication in surgical technique or implant design to address good long-term outcomes and patient satisfaction across the population.

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