A PROSPECTIVE STUDY OF MANAGEMENT OF PRIMARY OSTEOARTHRITIS BY POSTERIOR CRUCIATE RETAINING KNEE ARTHROPLASTY IN RURAL BACKGROUND

BY

DR. BOLLA KAMAL CHAITANYA, MBBS

Under the Guidance of
Dr. ARUN H S
MBBS, MS ORTHOPAEDICS
PROFESSOR
DEPARTMENT OF ORTHOPAEDICS

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ABSTRACT

Background and Objective

OA knee signifies a significant burden worldwide, with advanced cases frequently requiring surgical intervention to lessen discomfort and also reinstate function. TKA remains the gold standard treatment for end-stage OA, with ongoing debate regarding optimal prosthesis design. PCR TKA offers theoretical advantages in preserving native knee kinematics and proprioception, potentially enhancing functional outcomes. However, limited evidence exists regarding PCR TKA efficacy in rural populations, who often present with advanced disease and unique functional requirements. This prospective observational study determined the functional outcomes of PCR TKA in patients with advanced OA from rural backgrounds, evaluated using the KSS and WOMAC at sequential follow-up intervals.

Methodology

Twenty patients with primary knee OA admitted to R.L. Jalappa Hospital and meeting predefined inclusion criteria underwent PCR TKA between May 2023 and October 2024. Preoperatively, patients were evaluated for intact posterior

cruciate and collateral ligaments, knee deformities, and baseline functional parameters. All procedures utilized a medial parapatellar approach under spinal and epidural anaesthesia, with standardized perioperative protocols. Postoperative mobilization commenced on day one with full weight-bearing under walker assistance. Functional assessment occurred at preoperative baseline and at 1, 3, and 6 months postoperatively using standardized instruments: KSS for objective evaluation and WOMAC for patient-reported outcomes. ROM was documented at each assessment interval. Demographic variables, surgical parameters, and complications were systematically recorded throughout the study period.

Results

Demographic analysis revealed a predominantly agricultural occupational profile (35% farmers, 35% housewives) with mean BMI of 24.80 ± 1.88 kg/m². Most patients (65%) presented with KL grade 4 OA, with varus deformity present in 70% and fixed flexion deformity in 20%. The mean surgical duration was 177.00 ± 17.58 minutes, with average hospitalization of 10.25 ± 3.45 days. No complications were reported during the 6-month follow-up period. ROM exhibited progressive improvement, with baseline measurements (most commonly 0-110° in 25% of patients) improving to predominantly 0-120° (40% of patients) and 0-125° (30% of patients) by 6 months postoperatively. KSS demonstrated statistically significant enhancement at each assessment interval:

from baseline (38.05 ± 2.52) to 1 month (44.65 ± 2.80), 3 months (54.6 ± 4.65), and 6 months (66.9 ± 7.44). The mean difference between baseline and 6-month KSS was 28.85 points (t=-16.164, p<0.001). Similarly, WOMAC scores showed consistent improvement, with values decreasing from baseline (66.25 ± 2.95) to 1 month (60.00 ± 4.94), 3 months (50.70 ± 5.10), and 6 months (43.00 ± 4.30), indicating reduced symptoms and improved function. Paired t-test analysis confirmed statistically significant improvements between all assessment intervals (p<0.001).

Conclusion

This prospective study demonstrates significant functional improvement following PCR TKA in rural patients with advanced knee OA. The progressive enhancement in both objective and subjective parameters across sequential follow-up intervals indicates the clinical efficacy of this intervention. The absence of complications, coupled with substantial ROM improvement relevant to daily activities in rural settings, supports PCR TKA as a viable treatment option when appropriate patient selection and surgical techniques are implemented. These findings contribute valuable evidence regarding PCR TKA outcomes in rural populations, addressing an important research gap and providing clinical guidance for orthopaedic practice in similar demographic contexts.

Keywords

Posterior Cruciate Retaining; Total Knee Arthroplasty; Osteoarthritis; Knee Society Score; Western Ontario and McMaster Universities Osteoarthritis Index; Rural Population; Functional Outcomes

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ABBREVIATIONS

Abbreviation	**Explanation**
OA	Osteoarthritis
TKA	Total Knee Arthroplasty
PCL	Posterior Cruciate Ligament
PCR	Posterior Cruciate Retaining
PS	Posterior Stabilized
KL	Kellgren-Lawrence
KSS	Knee Society Score
WOMAC	Western Ontario and Mcmaster University Osteoarthritis Index
ACL	Anterior Cruciate Ligament
MCL	Medial Collateral Ligament
LCL	Lateral Collateral Ligament
MMPs	Matrix Metalloproteinases
TNF-α	Tumor Necrosis Factor-A

IL	Interleukin
KOGS	Knee Osteoarthritis Grading System
ACR	American College of Rheumatology
NSAID	Non-Steroidal Anti-Inflammatory Drug
PRP	Platelet-Rich Plasma
HTO	High Tibial Osteotomy
UKA	Uni-Compartmental Knee Arthroplasty
ROM	Range Of Motion
OKS	Oxford Knee Score
SF-36	Short Form Health Survey
VAS	Visual Analog Scale
CAS	Computer-Assisted Surgery
PSI	Patient-Specific Instrumentation
SA	Spinal Anesthesia
SD	Standard Deviation
PT	Popliteal Tendon

INTRODUCTION

OA is a degenerative joint condition that affects millions of people and has a major influence on their QOL, especially as they become older. [1]The knee joint, bearing substantial weight and mechanical stress throughout life, remains particularly vulnerable to osteoarthritic changes. As the illness advances, advanced OA poses significant treatment hurdles. When conservative care fails to alleviate symptoms enough, the use of surgery may be necessary. [2]

With its remarkable ability to alleviate pain and increase functional abilities, TKA has become the gold standard surgical therapy for advanced osteoarthritis. Crucially, the procedure's success depends significantly on prosthesis design and surgical technique, with ongoing debate regarding optimal management of the PCL.[3,4] Two primary approaches have dominated TKA methodology: PCR and PS designs, each presenting distinct biomechanical advantages and limitations that influence postoperative outcomes.[5]

PCR KA preserves the native PCL, which theoretically maintains more natural knee kinematics, enhances proprioception, and preserves femoral rollback during flexion.[6] PCL retention, according to supporters, offers enhanced joint stability, better stair-climbing capacity, and maybe more physiologically appropriate gait patterns.[7] Furthermore, the preservation of natural anatomy might help patients with busy lives especially in terms of improved balance and coordination.[8]

Notwithstanding these possible benefits, much debate continues over whether PCR designs are better than PS designs. Many comparison studies have produced contradicting findings; some show similar results between the two techniques while others imply particular benefits for either design in certain patient groups.[9,10] Furthermore complicating clinical decision-making are long-term follow-up investigations displaying different survivability statistics.[3]

In India specifically, especially in rural areas, special difficulties arise. Higher frequency of advanced defects at presentation, different activity needs connected to daily life, socioeconomic limits, and different access to rehabilitation facilities need careful thought when choosing prosthetic design.[11] Few studies especially looking at PCR TKA results in rural Indian communities point to a clear knowledge gap that calls for further study.

Recent research has tried to compile the body of current data on PCR against PS approaches. Although these studies provide insightful information, they can highlight notable variation in research techniques, patient demographics, and outcome measurements.[12,13] Moreover, few studies have been targeted on patients with significant varus deformity and grade IV OA according on the KL classification, a typical presentation in rural Indian environments.

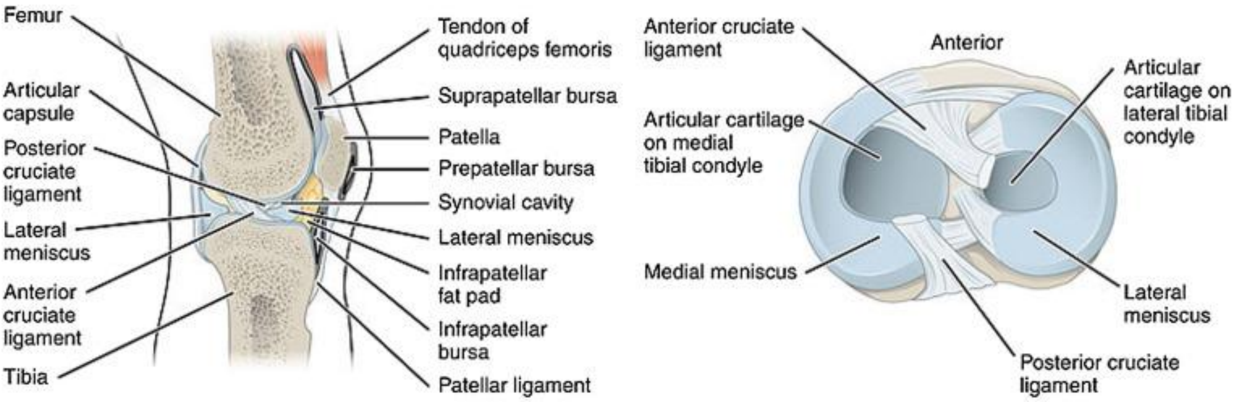
By assessing the functional results of PCR KA especially in patients with advanced OA in a rural Indian community, this prospective study seeks to fill in this research need. This study aims to provide clinically meaningful data by using validated outcome measures such the KSS and WOMAC, therefore guiding evidence-based decision-making in this particular patient population. The results might greatly help to maximize surgical techniques and enhance patient outcomes in resource- constrained environments for advanced knee OA.

OBJECTIVES

To determine the functional outcome of PCR KA in advanced stage OA of knee, measured using the KSS, WOMAC at 1st month, 3rd month and 6 months.

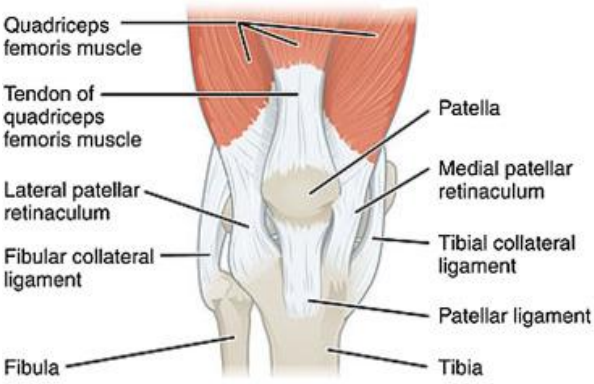
ANATOMY

Anatomy of Knee joint



(a) Sagittal section through the right knee joint

(b) Superior view of the right tibia in the knee joint, showing the menisci and cruciate ligaments



(c) Anterior view of right knee

Figure 1: Anatomy of the knee[14]

Osteology [15]

Three main osseous components define the knee articulation anatomically: the patella, distal femoral condyles, as well as proximal tibial plateau. Though it is a hinge joint, the knee shows complicated biomechanics incorporating fewer rotational movement outside basic flexion-extension.

With flattened anterior surfaces that help weight distribution, the femoral condyles show eccentric curvature. The patellofemoral groove separates these condyles anteriorly and the intercondylar notch posteriorly. While the lateral condyle, albeit broader, more nearly corresponds with the sagittal plane, the medial condyle has a longer articular surface and orientations around 22° to this plane.

The intercondylar eminence separates somewhat flat articulating surfaces formed by the tibial plateaus. Here are the menisci and ligaments attaching to the kneecaps. Especially, the rounded posterior part of the lateral plateau helps to facilitate meniscal movement during flexion.

The knee joint is characterized by articular incongruence; stability mostly relies on soft-tissue components instead of osseous morphology. The patella—a triangular sesamoid with asymmetric articular facets—demonstrates progressive articulation patterns during knee movement, traveling 7-8 cm relative to the femoral condyles throughout the flexion-extension arc.

The knee's anatomy follows a three-layered architecture as established by Warren and Marshall: layer 1 comprising the crural fascia; layer 2 containing the superficial MCL and posteromedial corner structures; and layer 3 encompassing the joint capsule as well as deep MCL.

Medial structures

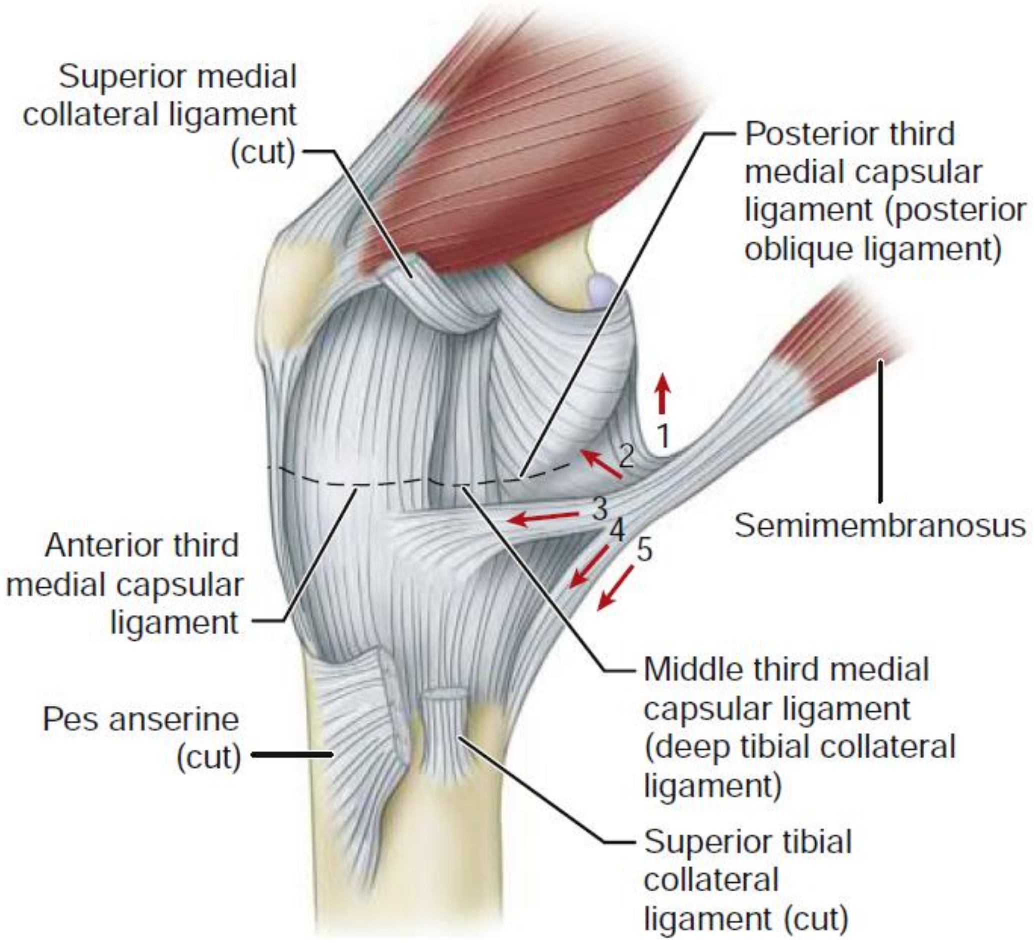


Figure 2: Medial supporting structures of knee[15]

Robinson and colleagues' cadaveric investigation further delineated this region into circumferential thirds: the anterior third spanning from patellar tendon to superficial MCL; the middle third constituted by the superficial MCL itself; and the posterior third—forming the posteromedial corner—extending from the posterior superficial MCL margin to the medial gastrocnemius head. This tripartite arrangement identifies three distinct ligamentous structures crossing the joint line: superficial MCL, deep MCL, as well as posteromedial capsule.

Lateral structures

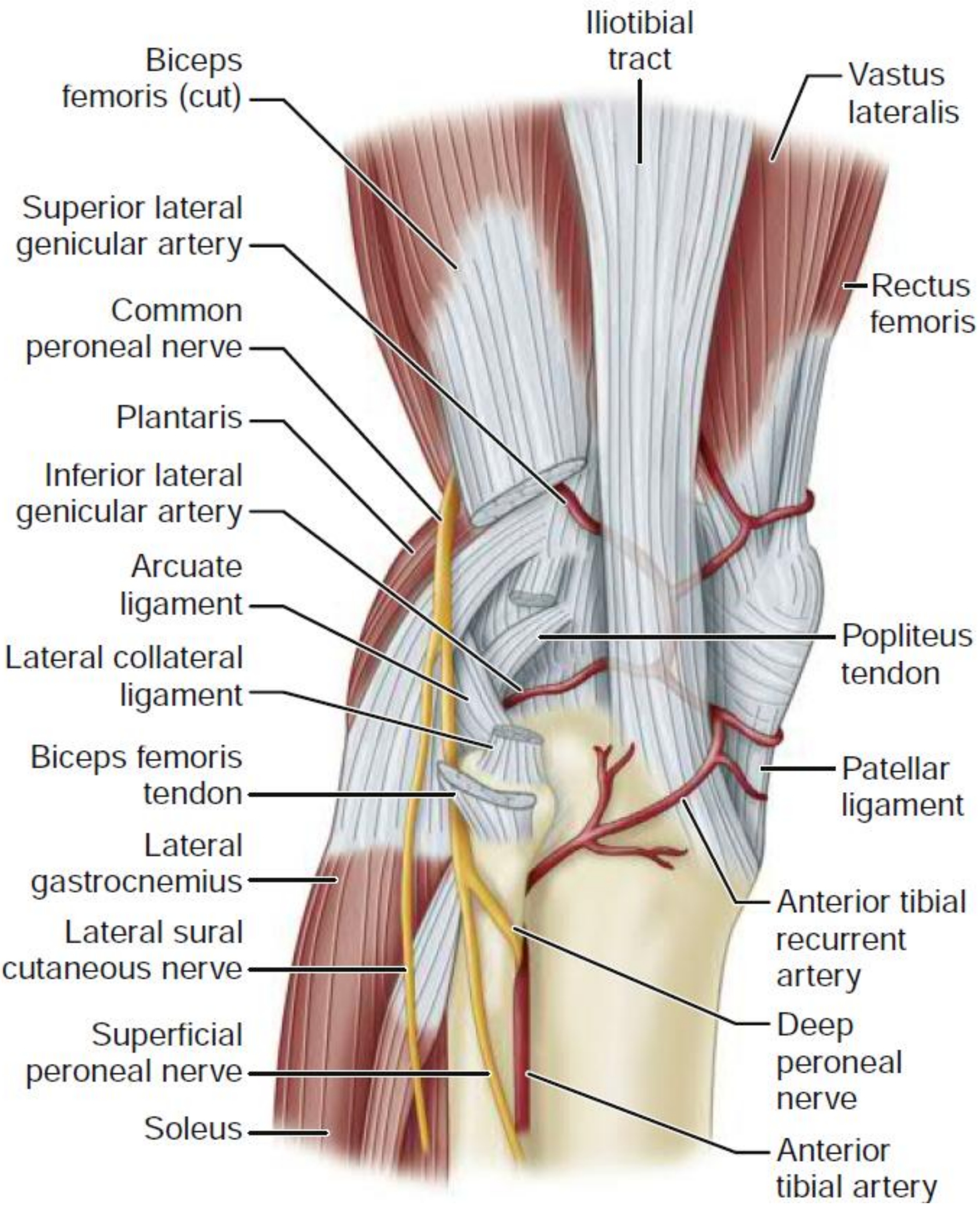


Figure 3: Tendinous and neurovascular structures of lateral side of knee.[15]

The lateral aspect of the knee exhibits stratified anatomical organization as documented by Seebacher, Inglis, Marshall, and Warren. Their analysis identifies distinct fascial planes with specific structural components. The superficial stratum (layer I) demonstrates a bipartite configuration comprising the anteriorly positioned iliotibial tract with its expansions and the posteriorly situated superficial biceps femoris with associated fascial extensions. Notably, the peroneal nerve traverses deep to this initial layer in close posterior relationship to the bicep’s tendinous insertion. The intermediate stratum (layer II) consists predominantly of quadriceps retinacular tissue, which courses anterolaterally adjacent to the patella.

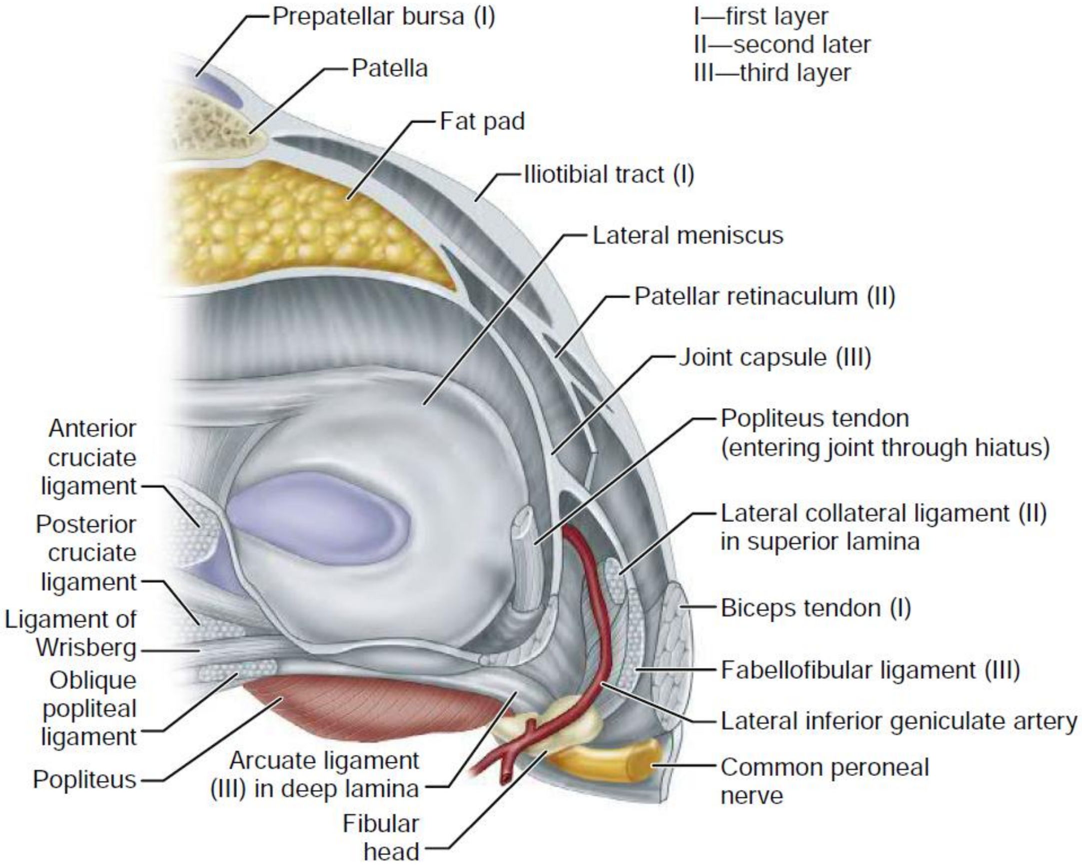


Figure 4: View of right knee joint from above after removal of right femur[15]

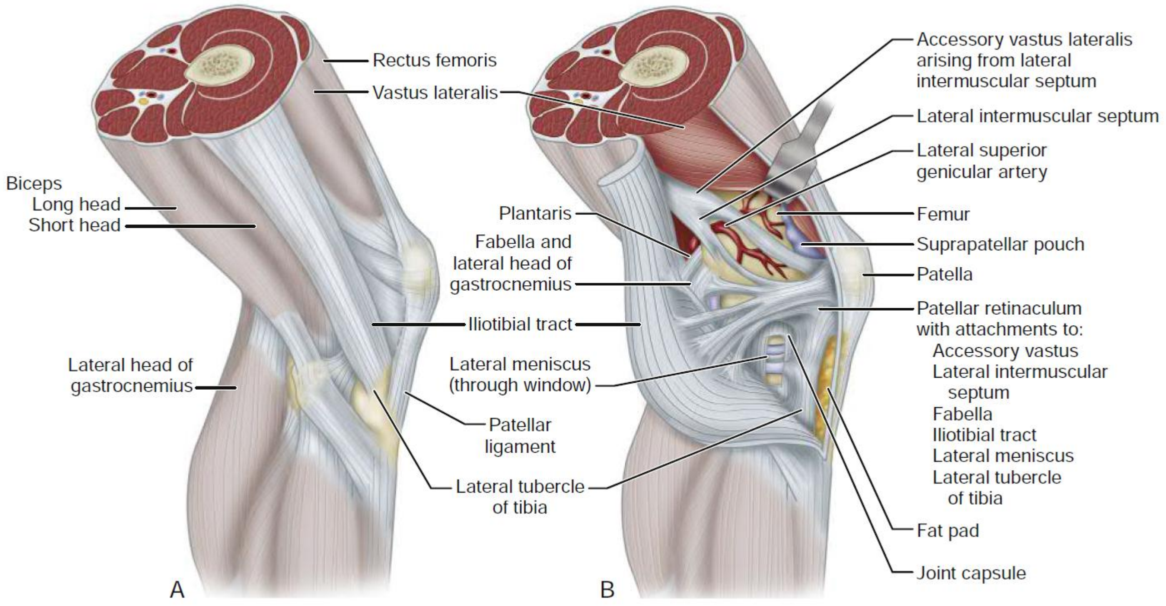


Figure 5: Layers I as well as II of structures of lateral side of knee.[15]

MCL

The MCL presents as an elongated, narrowly defined anatomical structure that occupies a superficial position relative to the medial capsule and its associated ligamentous components. This structure establishes its proximal attachment at the medial epicondyle and extends distally to insert approximately 7-10 centimeters inferior to the articular interface on the posteromedial tibial metaphyseal surface, deep to the pes anserinus tendinous insertions. This structure, alternatively designated as the superficial tibial collateral ligament or superficial MCL component, demonstrates significant biomechanical functionality.

Biomechanical analyses confirm its primary role in resisting valgus force application across the knee articulation. The ligament exhibits characteristic excursion patterns during articular motion, translating anteriorly across the femoral condyle during extension and posteriorly during flexion. The longitudinal fibre arrangement of the MCL constitutes the principal stabilizing mechanism against both valgus stress and external rotational forces. A differential tensioning pattern exists within the ligament, whereby anterior fibres exhibit increased tension during flexion while posterior fibres simultaneously demonstrate reduced tension.

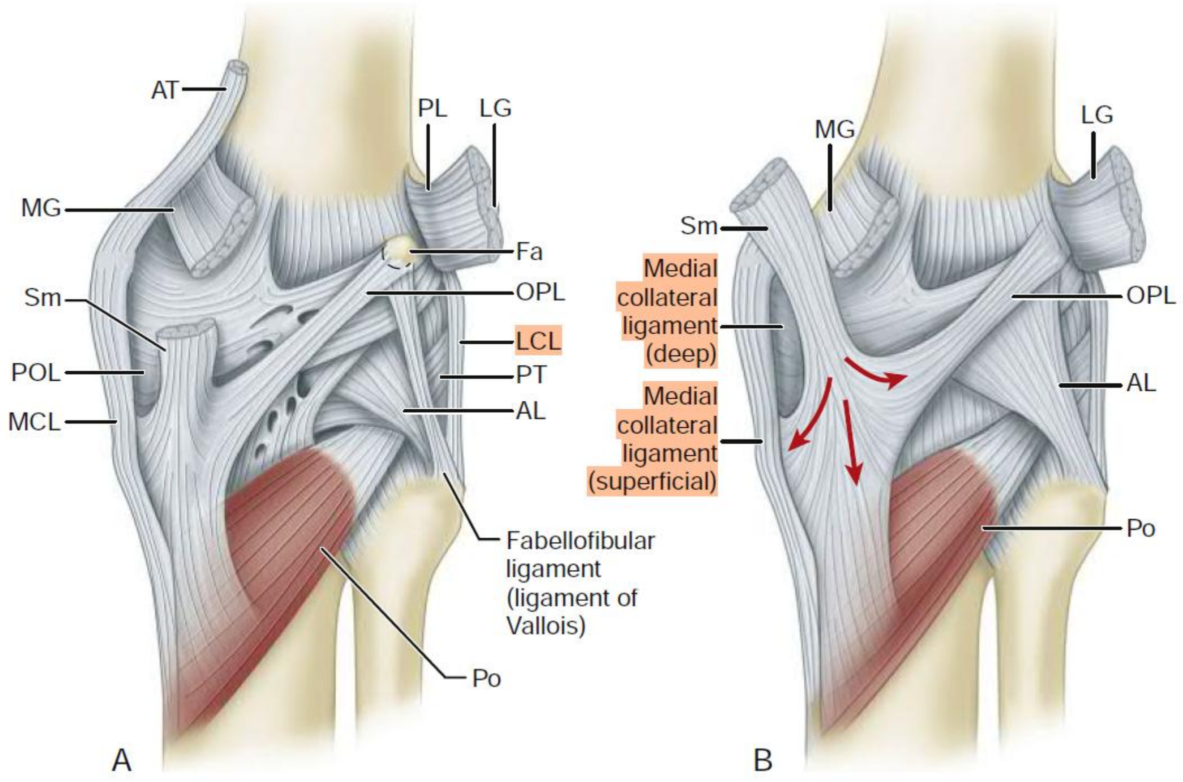


Figure 6: Figure showing MCL and LCL[15]

LCL

The LCL establishes attachments between the lateral femoral epicondyle and fibular head. Precise cadaveric measurements indicate its femoral origin averages 1.4 mm proximal and 3.1 mm posterior to the lateral epicondyle. Kamath and colleagues documented this attachment at approximately 58% across the condylar width and 2.3 mm inferior to Blumensaat's line, with minimal inter-specimen variation (<5 mm).

The distal insertion occurs 8.2 mm posterior to the anterior fibular head margin. Morphologically, the LCL manifests as a discrete tendinous structure rather than a broad ligamentous band. Its biomechanical function demonstrates position-dependent characteristics—providing primary stabilization against varus forces in extension, with progressive diminution of this stabilizing capacity as the knee transitions into flexion.

Iliotibial Band

The lateral stabilization mechanism of the knee incorporates multiple structural components beyond the primary ligamentous apparatus, with significant contributions from the iliotibial band, biceps femoris tendon, and popliteal tendon. The iliotibial band establishes proximal attachment at the lateral femoral epicondyle before expanding broadly between the patella's lateral border and the posteriorly positioned biceps femoris, ultimately inserting at Gerdy's tubercle on the lateral tibial surface.

The spatial arrangement of flexion generates crossing force vectors between the iliotibial band, popliteal tendon, LCL, thereby improving lateral compartment stability. Through its contribution to the arcuate complex and functional ability as both a strong flexor as well as external rotator of the tibia relative to the femur, the biceps tendon enhances this stabilizing mechanism. From the posterior tibial area via the popliteal hiatus, the popliteal tendon courses to connect near both anterior as well as deep to, the femoral insertion of the LCL.

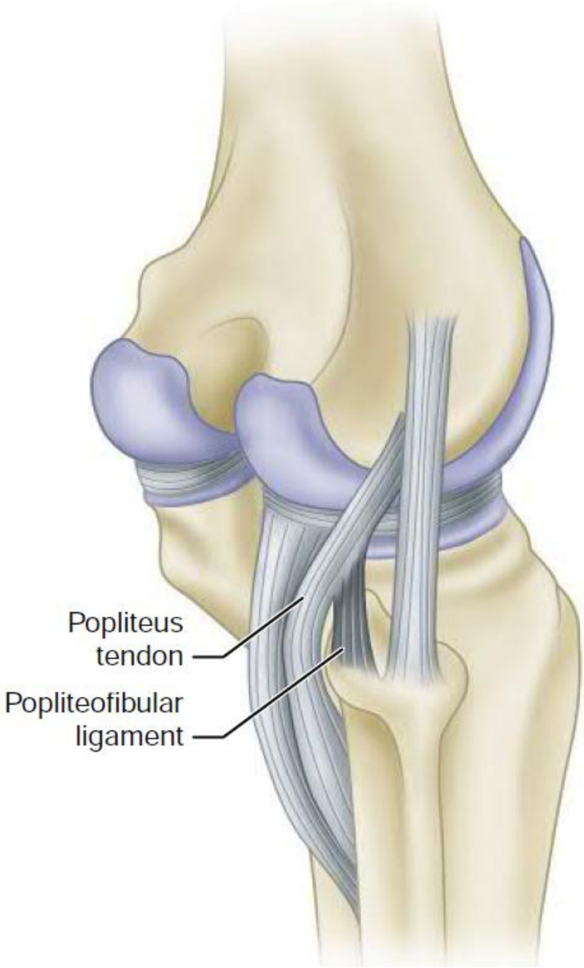


Figure 7: Popliteofibular ligament[15]

PT

The PT complex demonstrates sophisticated anatomical relationships elucidated through Warren et al.'s investigative work. Their research identified a robust fibular attachment of the PT, termed the popliteofibular ligament, which establishes a femoral-fibular connection via the popliteal tendon. This structure occupies a plane deep to the arcuate ligament's lateral division, originating from the posterior fibular region posterior to the biceps insertion and joining the PT proximal to its musculotendinous junction.

The resultant configuration presents as a Y-shaped musculotendinous complex with dual origins—muscular from the posterior tibial surface and ligamentous from the fibula—converging to a unified femoral insertion. This femoral attachment demonstrates consistent morphology as a broad-based insertion at the anterior and proximal fifth of the popliteal sulcus, consistently anterior to the LCL with an average inter-attachment distance of 18.5 mm.

The popliteofibular ligament exhibits bifurcate morphology with posterior and anterior divisions. The posterior division attaches approximately 1.6 mm distal to the posteromedial fibular styloid apex, while the anterior division inserts 2.8 mm distal to the anteromedial styloid apex. Functional analyses through selective sectioning protocols confirm the critical biomechanical contribution of both the tibial attachment and popliteofibular ligament in resisting posterior translation, varus rotation, and external tibial rotation.

POL

The POL, as characterized by Hughston, represents a substantive thickening within the medial capsular ligamentous complex. This structure establishes its proximal attachment at the femoral adductor tubercle while demonstrating a tripartite distal insertion pattern. The predominant central (tibial) arm attaches along the posterior tibial margin near the articular surface interface, positioned central to the semimembranosus tendon's superior margin. The superior (capsular) arm demonstrates continuity with both the posterior capsule and proximal OPL. The inferior (distal) arm, less distinctly defined, inserts into both the semimembranosus tendinous sheath and tibial surface immediately distal to the semimembranosus direct insertion.

The central component—representing the most substantial portion with presumed greatest functional significance—originates in proximity to the adductor tubercle region and courses posteromedially to insert at the tibial posteromedial corner adjacent to the semimembranosus direct head insertion. This component forms a prominent fascial reinforcement of both meniscofemoral and meniscotibial segments of the posteromedial capsule, with additional meniscal attachments.

The POL contributes significantly to knee stability mechanisms, particularly regarding valgus and rotational forces. Its tension characteristics demonstrate position-dependent properties—progressively relaxing with knee flexion during passive movement, while maintaining tension across all three arms during active semimembranosus contraction. This dual stabilization mechanism (both static and dynamic) underscores the structure's biomechanical importance in maintaining articular integrity.

Surgical implications emphasize the necessity of addressing central arm tension during reconstructive procedures, as passive stability remains unattainable without appropriate tension restoration in this critical component, regardless of concomitant surgical interventions.

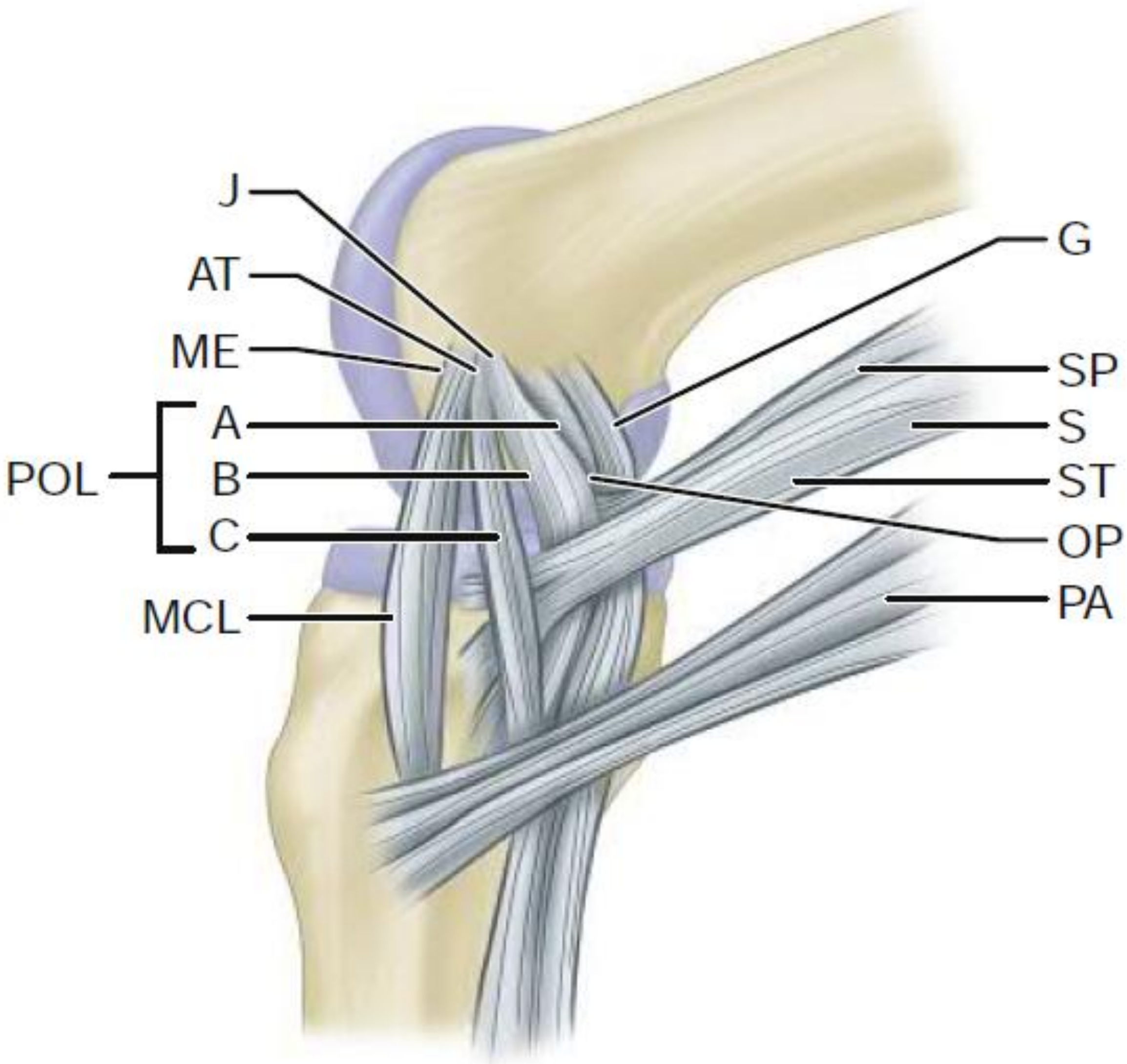


Figure 8: Posteromedial corner of the knee. [15]

Ligamentous Structures with Emphasis on the PCL

The knee joint relies on a complex ligamentous system for stability. The principal stabilizers include the ACL, PCL, MCL, and LCL.[16]

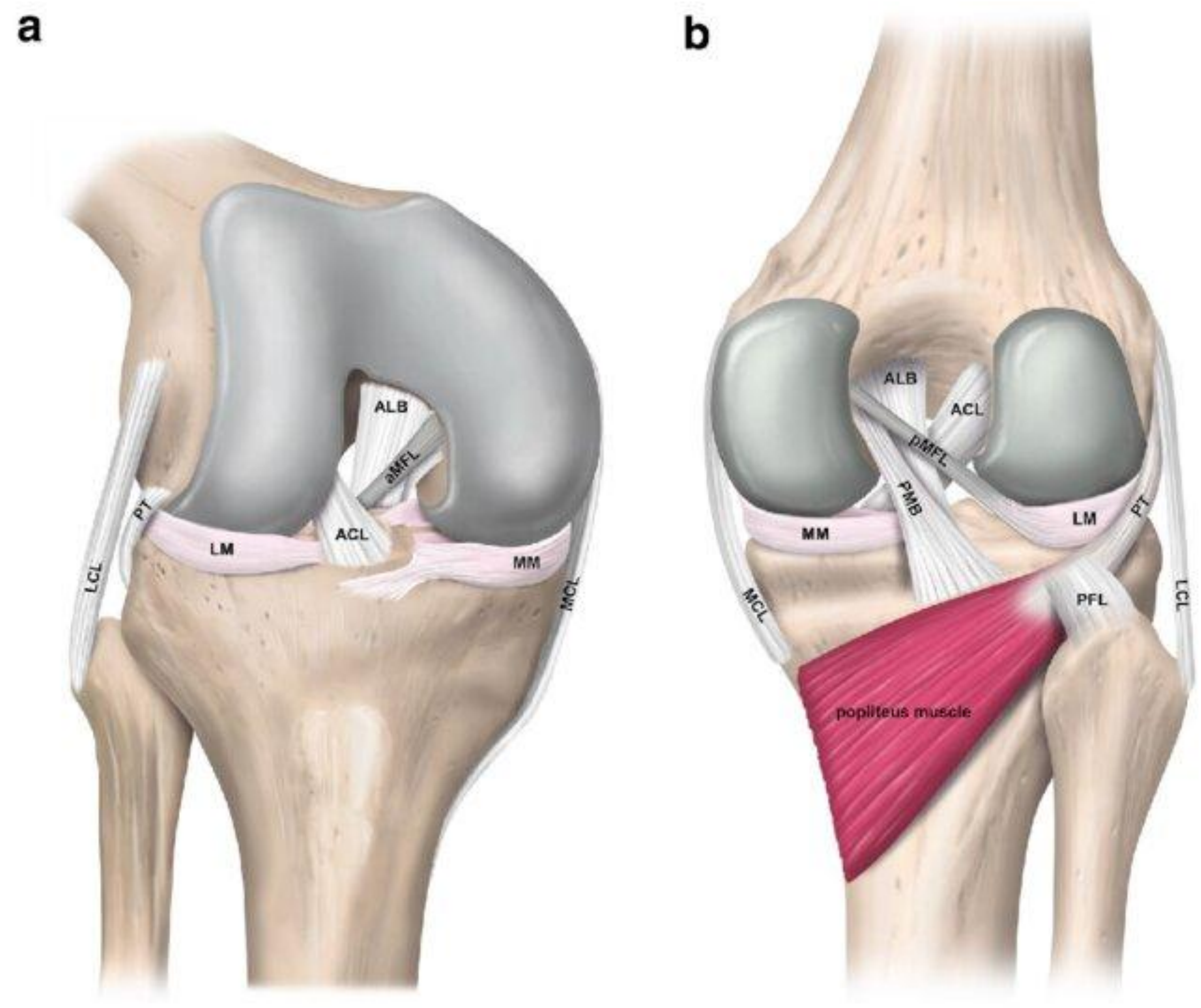


Figure 9: The posterior cruciate and meniscofemoral ligaments: anatomical aspects.[17]

The PCL represents a critical stabilizing structure within the knee joint, characterized by its complex anatomical configuration and biomechanical properties. Anatomically, the PCL originates from the posterior aspect of the medial tibial plateau and inserts onto the anterior intercondylar region of the femur, forming a crucial component of the knee's ligamentous stabilization mechanism.

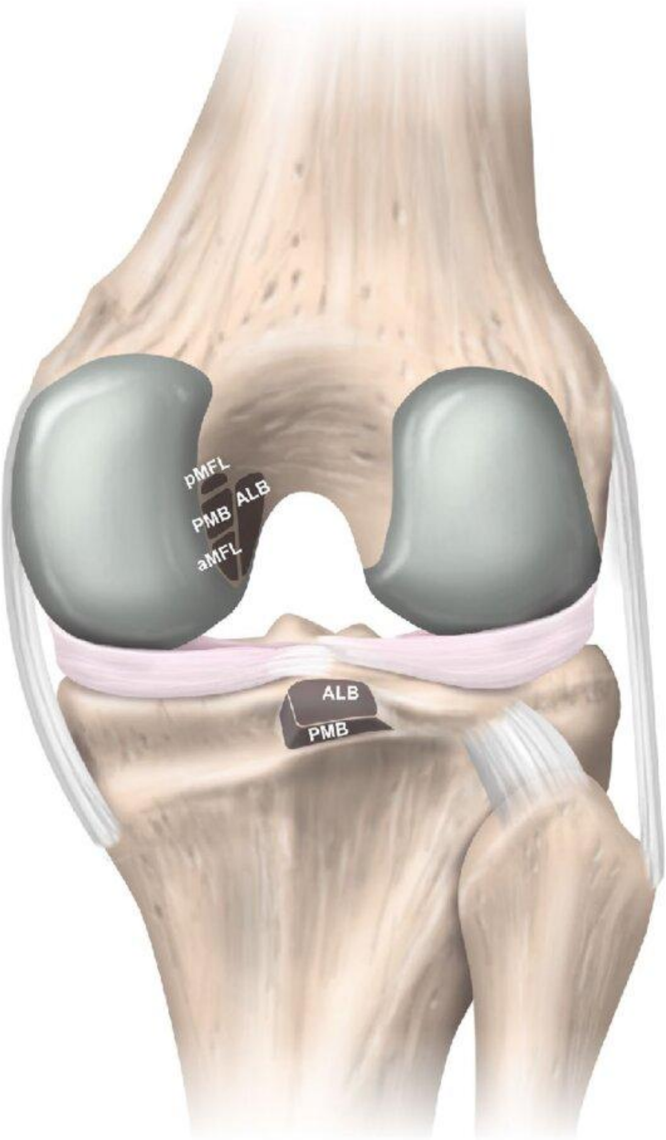


Figure 10: The right knee's PCL insertion points [17]

Structurally, the PCL comprises two primary bundles: the anterolateral and posteromedial bundles, which demonstrate distinct functional characteristics during knee movement. These bundles exhibit differential tension patterns throughout the ROM, providing nuanced biomechanical support during articulation. The ligament's intricate collagen fibre arrangement enables substantial load-bearing capacity, with an average cross-sectional area ranging between 32-38 mm².

Surgical interventions involving the PCL demand meticulous understanding of its anatomical complexity. Reconstruction techniques must replicate the ligament's original anatomical footprint and tension characteristics to restore knee kinematics effectively. Surgical approaches typically involve autografts or allografts positioned to mimic the native ligament's anatomical insertion points and fibre orientation.

Clinically, PCL injuries frequently result from high-energy trauma, presenting challenges in both diagnostic assessment and surgical reconstruction. Precise surgical techniques necessitate comprehensive preoperative imaging and a thorough comprehension of the ligament's intricate anatomical relationships.[18,19]

Muscular Support Around the Knee

Dynamic stability of the knee joint depends on the coordinated function of surrounding musculature. The quadriceps femoris group serves as the primary knee extensor, with the vastus medialis obliquus critical for patellar tracking and stability.[20] The hamstring group (semimembranosus, semitendinosus, and biceps femoris) functions as knee flexors and provides posterior stabilization.

The gastrocnemius contributes to knee flexion and stabilization of the posterior joint capsule, while the popliteus facilitates "unlocking" of the knee through internal tibial rotation during initial flexion.[14] The pes anserinus muscles provide dynamic stabilization to the medial aspect of the knee, particularly during activities requiring rotational control.

Patella Shapes

As the biggest sesamoid bone in humans, the patella displays a wide range of morphologies. Wiberg's classification, widely recognized in orthopaedic literature, categorizes patellar shapes into three primary types based on the relative dimensions of the medial as well as lateral facets.

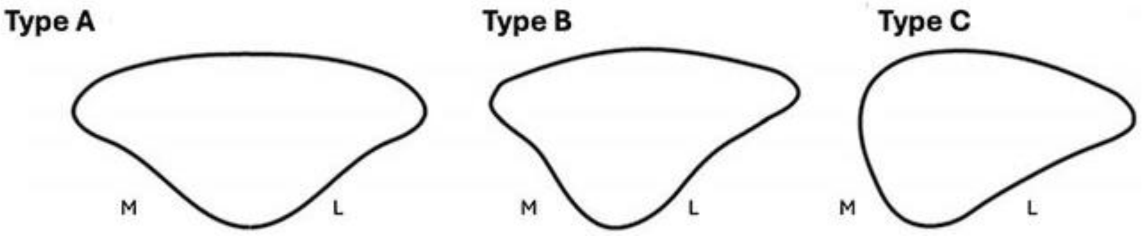


Figure 11: Wiberg's classification[21]

Type I features symmetrical facets of approximately equal size, Type II (most common) presents with a smaller medial facet than lateral facet, and Type III demonstrates a markedly smaller and convex medial facet.[22] Supplementing this classification, Baumgartl's Type IV describes a "jockey-cap" patella with absent medial facet, while the Irregular type represents patellae with structural aberrations. Recent morphometric analyses indicate that patellar shape variations significantly influence patellofemoral biomechanics and tracking patterns. Shape anomalies correlate with altered pressure distributions and potentially contribute to conditions like patellofemoral pain syndrome and chondromalacia patellae. Notably, variations in patellar shapes directly impact surgical considerations in TKA, particularly regarding component selection, positioning, and resurfacing decisions.[23]

Ligamentum Patellae

The ligamentum patellae (patellar ligament) constitute a critical structural component of the extensor mechanism, functioning as the distal continuation of the quadriceps tendon. From the top of the patella to the tibial tuberosity, this strong, curved band goes on for about 4-5 cm in length and 2.5–3 cm in width. [24]Histologically, it demonstrates a hierarchical organization of dense regular connective tissue comprised predominantly of type I collagen fibres arranged in parallel fascicles. The ligament's biomechanical properties facilitate the transmission of quadriceps forces across the patellofemoral and tibiofemoral joints, enabling knee extension and stabilization. Anatomical variations in ligament dimensions correlate with functional outcomes; shorter patellar ligaments can predispose to patella alta while elongated variants may contribute to patella baja. Structurally, the ligament demonstrates regional differentiation, with the posterior aspect containing the densest collagen fiber organization. Vascularity derives primarily from the inferior genicular arteries, with a relatively avascular region approximately 1-2 cm from the tibial insertion representing a potential vulnerability point for pathological processes.[24]

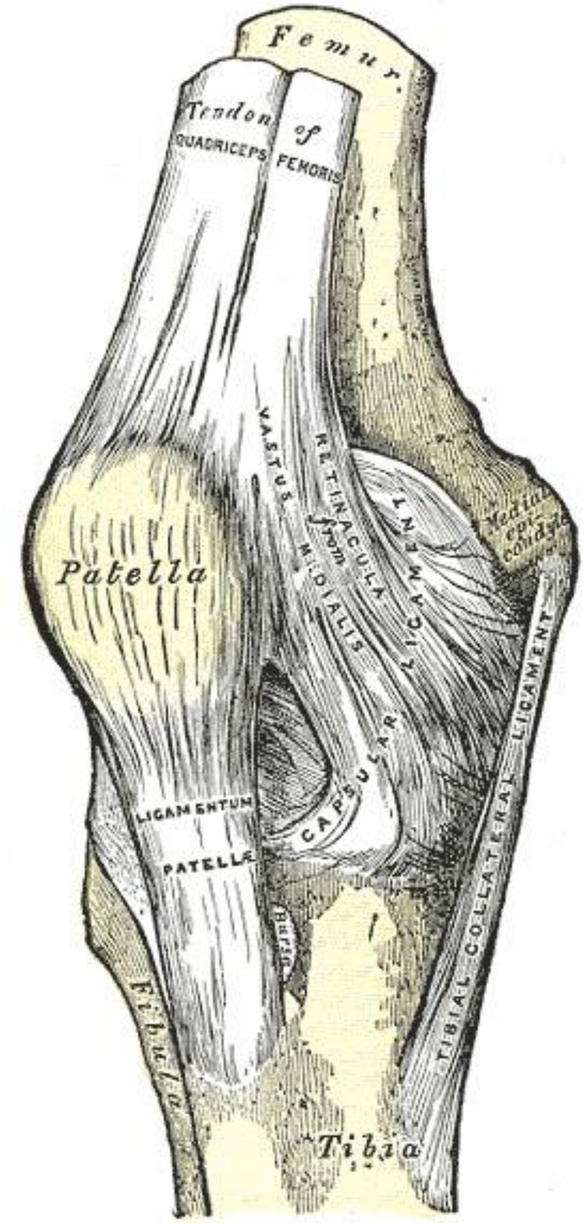


Figure 12: ligamentum patellae[25]

Patellar Fat Pad

The infrapatellar fat pad represents a specialized adipose structure occupying the anterior compartment of the knee joint. Located posterior to the patellar ligament and anterior to the femoral condyles and intercondylar notch, this extrasynovial but intraarticular structure serves multiple biological and biomechanical functions. Morphologically, it presents as a triangular wedge measuring approximately 9-11 cm² in cross-sectional area, with substantial individual variation.[26]

Figure 13: Infrapatellar Fat Pad[26]

The fat pad receives rich vascularization from the genicular arteries and innervation via branches of the tibial nerve, explaining its involvement in nociception during inflammatory conditions. Histologically, it comprises adipocytes embedded within a fibrous matrix containing nerve fibres, blood vessels, and lymphatics. Functionally, the infrapatellar fat pad serves as a protective cushion, enhances joint lubrication through synovial fluid production, and participates in nociceptive signalling. Recent investigations have identified its role as an active endocrine organ capable of secreting adipokines and inflammatory mediators that may influence knee joint homeostasis and OA progression.[26]

Hyaline Cartilage and Its Histology

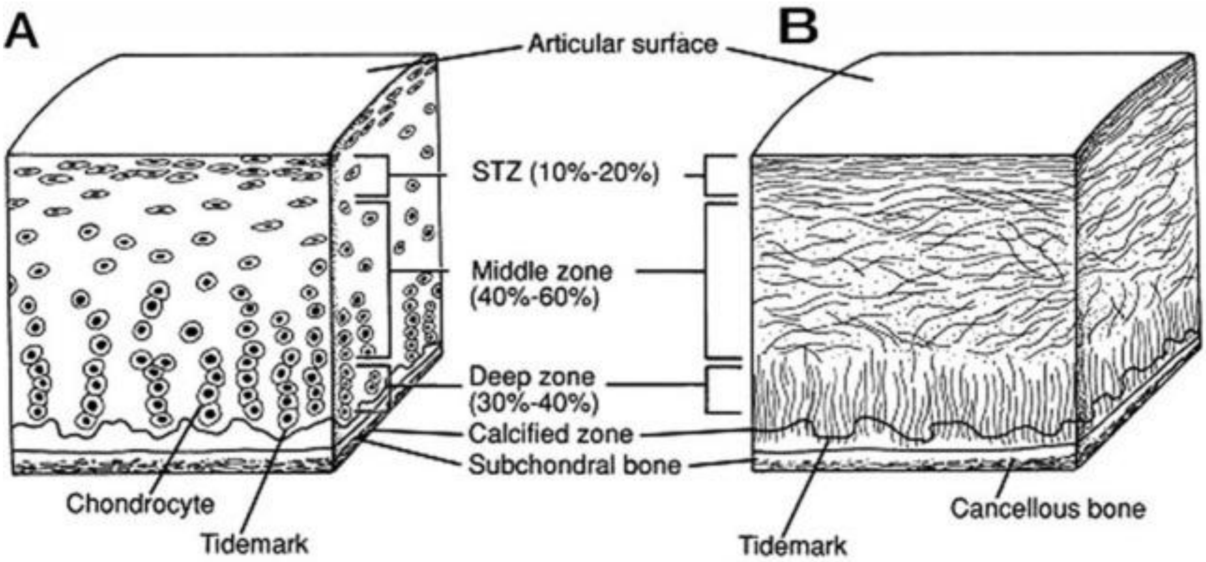


Figure 14: Cross-sectional diagram of healthy articular cartilage[27]

Hyaline cartilage represents a connective tissue that forms the articular surface of diarthrodial joints, exhibiting unique biomechanical properties that facilitate low-friction articulation and load distribution. Histologically, hyaline cartilage demonstrates a complex, avascular, aneural structure comprising chondrocytes (1-5% of tissue volume) embedded within an extensive ECM. The ECM consists predominantly of water, type II collagen, and proteoglycans, with minor constituents including non-collagenous proteins and glycoproteins. [27]

The architectural organization of hyaline cartilage reveals four distinct zones: superficial, middle, deep, and calcified. The superficial zone contains flattened chondrocytes with collagen fibrils oriented parallel to the articular surface, providing tensile strength and resistance to shear forces. The middle zone features spherical chondrocytes with randomly arranged collagen fibres, while the deep zone exhibits columnar chondrocytes with perpendicular collagen orientation, facilitating compressive resistance. Intrachondral bone and calcified cartilage are connected by interdigitating projections; the tidemark delineates this boundary.[27]

Chondrocytes maintain cartilage homeostasis through a delicate balance between anabolic and catabolic processes, responding to mechanical stimuli, growth factors, and cytokines. This equilibrium is critical for maintaining cartilage integrity, with disruption leading to degenerative conditions such as OA.[28]

PLC

The PLC represents a complex anatomical region comprising multiple static and dynamic stabilizers that provide crucial resistance to varus angulation, external tibial rotation, and posterior tibial translation. Anatomically, the PLC consists of three primary stabilizing structures: the FCL, PLT, and the PFL. Secondary stabilizers include the posterolateral capsule, fabello-fibular ligament, popliteo-meniscal fascicles, and the iliotibial band.[29]

The FCL is the principal structure that limits varus stress; it extends from the lateral femoral epicondyle and attaches to the fibular head. Protecting the lower limb from external and posterior tibial translation is the popliteus complex, which consists of the popliteus tendon and the popliteus ligament. A dynamic stabilizing system is formed by the PLT, which starts from the lateral femoral condyle and inserts on the posteromedial tibia, and the PFL, which extends from the popliteus musculotendinous junction to the fibular head. [29,30]

Biomechanically, the PLC structures function synergistically with cruciate ligaments, particularly the PCL. This functional relationship holds significant implications for KA procedures, as PLC integrity contributes substantially to postoperative stability and functional outcomes in PCL-retaining knee replacements. Accurate assessment and preservation of PLC structures during arthroplasty may enhance postoperative biomechanics and patient satisfaction.

Tibial Slope

Tibial slope refers to the posterior inclination of the tibial plateau relative to the perpendicular axis of the tibial shaft in the sagittal plane. This critical anatomical parameter demonstrates significant variation among individuals and populations, with reported means ranging from 7° to 13°.[23] Methodologically, measurement techniques include radiographic assessment using the posterior tibial cortex as reference or CT-based evaluation employing the anatomical axis of the tibia. The medial plateau typically demonstrates approximately 2° greater posterior slope than the lateral plateau, contributing to the complex rotational kinematics of the knee joint.

Biomechanically, increased posterior tibial slope enhances the anterior translation component of the femur on the tibia during axial loading and influences ACL tension. Chinese populations demonstrate mean posterior tibial slopes of 9.6±3.0° on the medial compartment and 8.1±3.2° on the lateral compartment.[31]

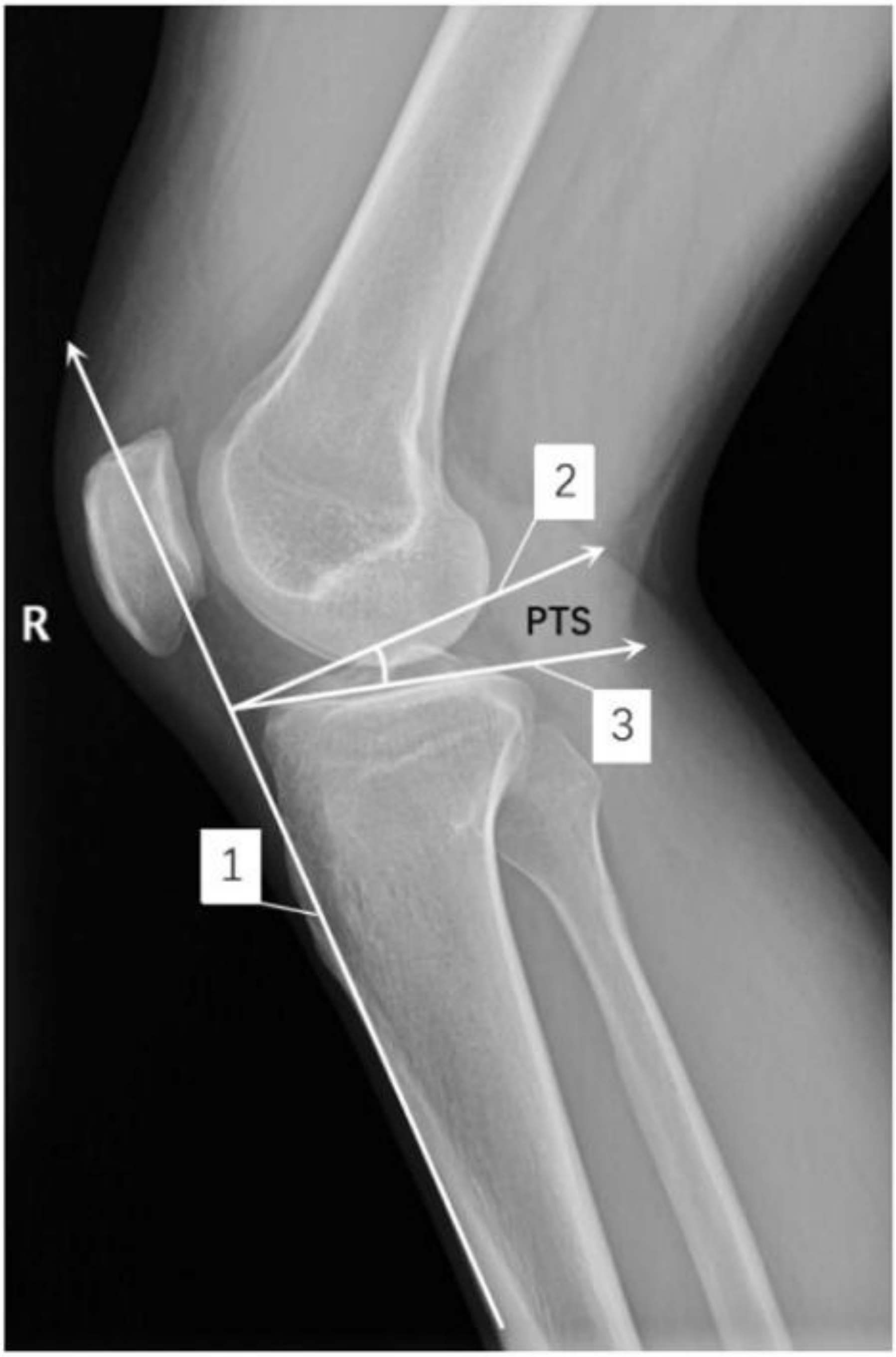


Figure 15: The measurement method of posterior tibial slope[31]

In TKA, tibial slope significantly impacts flexion range, stability, and wear characteristics, with optimal prosthetic slope generally recommended to reproduce the native posterior inclination within physiological parameters.

Biomechanics of the Knee Joint

The normal knee undergoes complex three-dimensional movements during ambulation, with motion occurring in sagittal, coronal, and transverse planes. The knee displays consistent biomechanical characteristics throughout the stance as well as swinging stages of the gait cycle. [32]

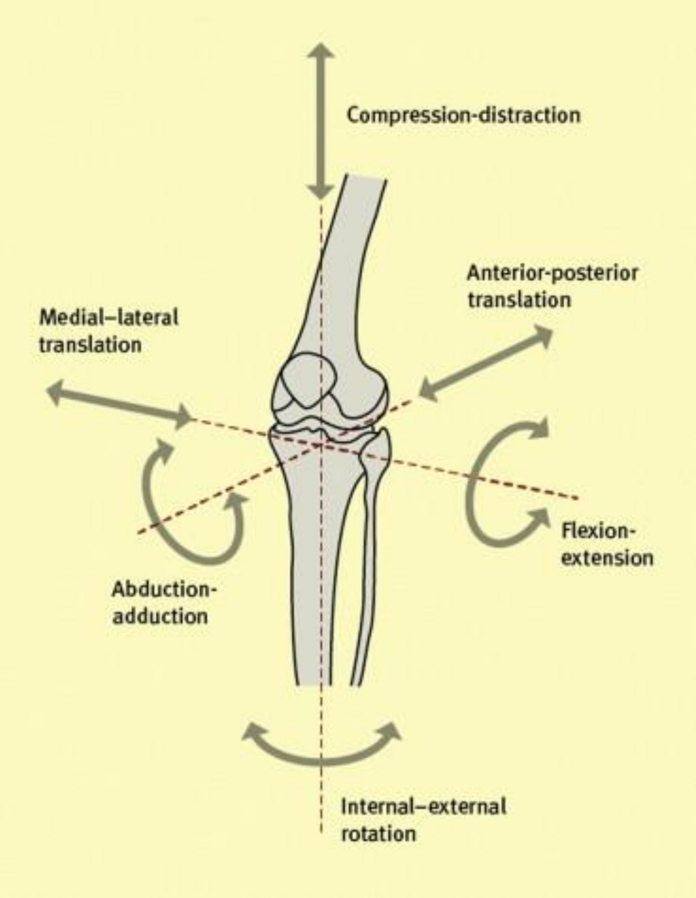


Figure 16: Biomechanics of knee joint[33]

During early stance, the knee flexes approximately 15-20 degrees for shock absorption and energy dissipation. Mid-stance features gradual extension to optimize stability and energy conservation.In terminal stance, the joint stability is improved by the tibia rotating from the outside relatively to the femur, a process known as the "screw-home mechanism," which allows for almost complete extension.[34]

The swing phase initiates with rapid knee flexion (approximately 60-70 degrees) to provide foot clearance, followed by controlled extension to prepare for subsequent heel strike. Throughout the gait cycle, compressive forces across the tibiofemoral joint typically range from 2-4 times body weight during level walking, increasing substantially during activities such as stair climbing or running.[32]

Biomechanics of the Osteoarthritic Knee

Osteoarthritic changes substantially alter knee biomechanics, creating a pathological cycle of aberrant loading and progressive joint degeneration. Cartilage loss and subchondral bone changes modify joint congruity, leading to altered load distribution across articular surfaces.[32] Medial compartment OA frequently results in varus malalignment, concentrating forces on the already compromised medial aspect and accelerating disease progression.

Kinematic analyses demonstrate reduced walking speed, decreased stride length, and altered temporal parameters in OA patients.[32] Sagittal plane motion typically shows reduced maximum knee flexion during both stance and swing phases, with an associated "stiffened knee" gait pattern. Compensatory mechanisms include increased hip and ankle motion to maintain function despite knee impairment.

Muscle activation patterns show prolonged co-contraction of quadriceps and hamstrings, increasing joint compressive forces while providing stability to the compromised joint.[32] These alterations collectively contribute to increased energy expenditure during ambulation and accelerated fatigue in OA patients.

Biomechanical Significance of the PCL in Knee Stability and Function

When it comes to managing rotational stability and avoiding posterior tibial translation, the PCL is crucial in keeping the knee kinematics correct. In order to maximize the biomechanical benefit of the quadriceps system, the PCL makes sure that the femur rolls back properly on the tibial plateaus while the body is bearing weight.

In the context of OA, PCL function becomes particularly significant as joint degeneration progresses. The PCL helps maintain joint congruity despite cartilage loss and osteophyte formation, potentially slowing disease progression.[16] Additionally, the PCL provides proprioceptive feedback critical for dynamic joint stability and protection against excessive forces during functional activities.

OA of the Knee

The most typically affected load-bearing joint by OA is the knee; thus, it is the kind of arthritis most common worldwide and a main cause of disability. Hallmarks of this degenerative joint disorder include synovial inflammatory conditions, osteophyte growth, subchondral bone remodeling, and articular cartilage deterioration.[35] With aging populations, rising obesity rates, and longer life expectancies, the burden of knee OA worldwide is growing and is therefore a major public health issue with major economic consequences.

Disease Burden and Epistemology

With frequency ranging across various areas and demographics, knee OA affects 250 million individuals worldwide. With radiographic evidence evident in over half of those over 65 years of age, the illness shows a definite age-related trend.[1] Knee OA prevalence in the general population in India is estimated to be 28.7%; rates in rural areas where agricultural activity and related occupational stresses cause joint degradation are much higher. Along with indirect expenses via lower production and early retirement, the financial load includes direct healthcare expenses including medical consultations, pharmacological treatments, and surgical procedures.

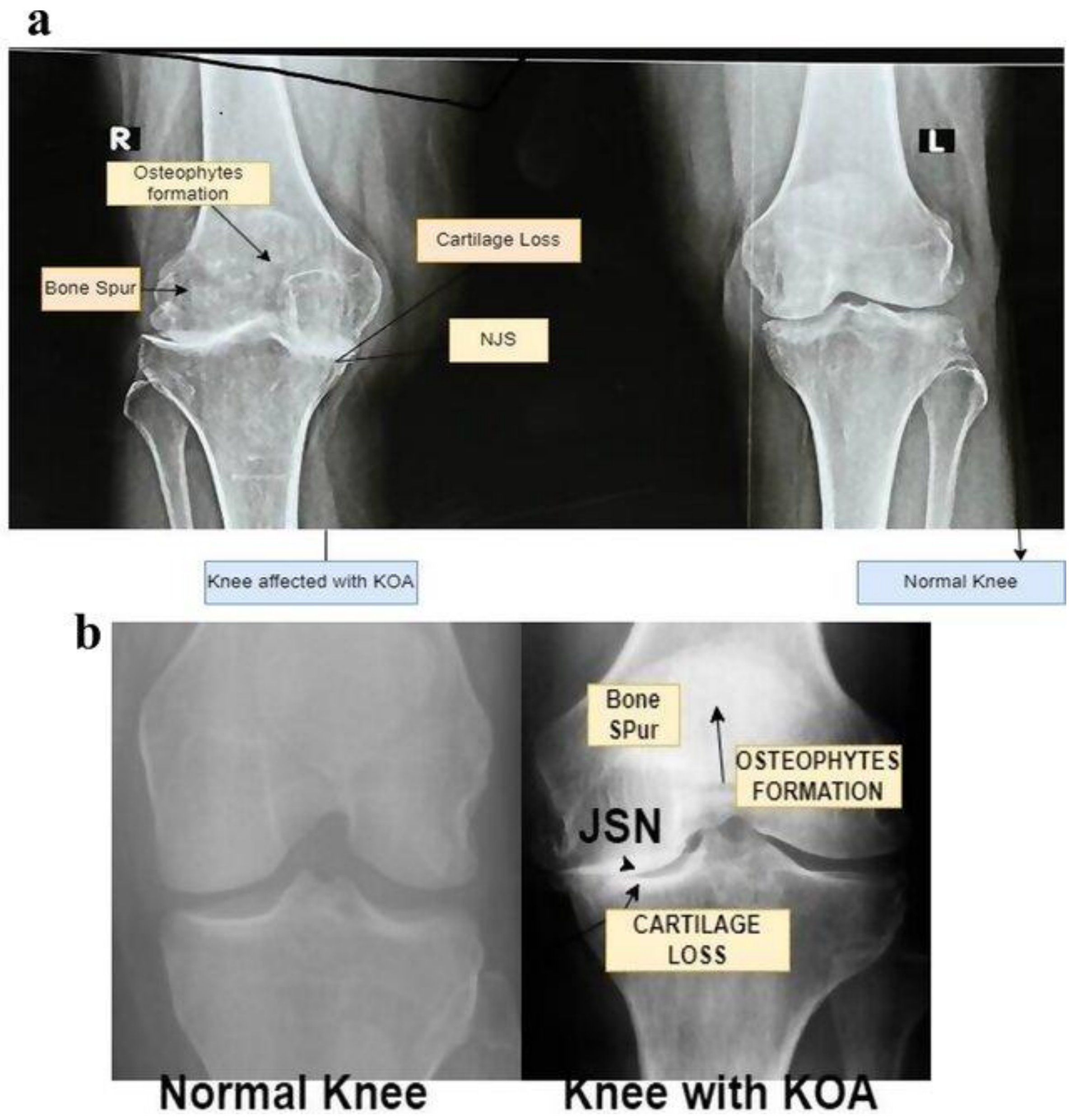


Figure 17: X-ray descriptions of the normal and OA knee.[36]

Risk Factors

The onset and advancement of knee OA are influenced by many risk factors. Age remains the noticeable non-modifiable risk factor, with increasing prevalence observed after the fourth decade of life due to cumulative mechanical stress and biological changes within the joint tissues.[37] Obesity represents a substantial modifiable risk factor, with each unit increase in BMI associated with a 10-15% increase in knee OA risk through both mechanical and metabolic pathways.[38]

Previous joint trauma, particularly meniscal or ligamentous injuries, significantly increases the risk of post-traumatic OA development. Genetic factors contribute approximately 40-65% to the disease susceptibility, with identified polymorphisms in genes regulating cartilage matrix composition and inflammatory responses.[35] Occupational factors, including repetitive knee bending, squatting, and heavy lifting, particularly relevant in rural agricultural settings, accelerate joint degeneration through mechanical stress on articular surfaces.[38]

Pathophysiology of Primary OA

Primary knee OA represents a complex interplay between mechanical, cellular, and biochemical processes. Historically viewed as a "wear and tear" condition, contemporary understanding recognizes OA as an active, inflammatory disease involving multiple joint tissues.[39] The pathophysiological cascade begins with abnormal mechanical loading, which triggers cellular responses in chondrocytes, synoviocytes, and subchondral bone cells.

Cartilage degradation occurs through upregulation of catabolic enzymes, primarily MMPs and aggrecanases, which cleave key structural components of the extracellular matrix.[40] Simultaneously, chondrocytes exhibit reduced anabolic capacity, impairing their ability to synthesize new matrix components. This imbalance between catabolic and anabolic processes drives progressive cartilage deterioration.[41]

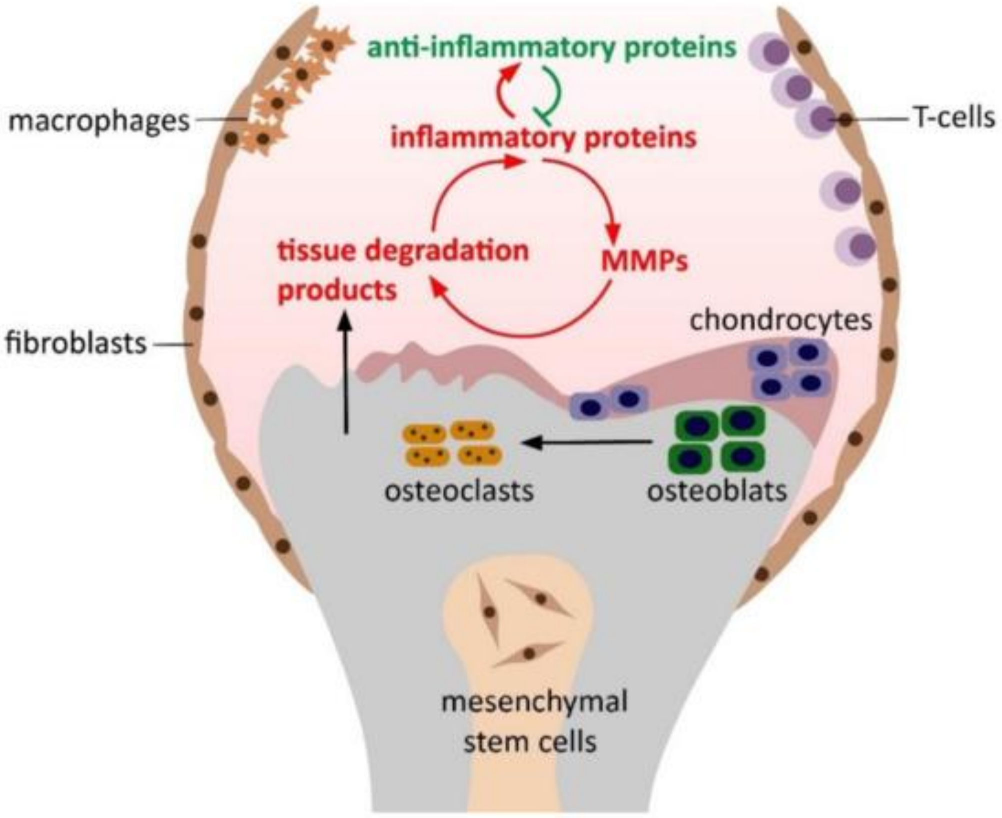


Figure 18: Pathogenesis of OA[42]

Inflammation plays a crucial role in disease progression, with synovial activation and subsequent production of pro-inflammatory cytokines, including IL-1β, TNF-α, and IL-6, which further accelerate cartilage breakdown.[43] Synovial fluid analysis in OA patients demonstrates elevated levels of these cytokines, correlating with disease severity.[44] Subchondral bone remodelling contributes to disease progression through increased bone turnover, resulting in sclerosis and cyst formation.[45]

Clinical Manifestations and Progression

Knee OA always develops with subtle onset of pain, initially activity-related and relieved by rest, progressively becoming more constant and occurring at rest or during the night.[38] Joint stiffness, particularly following periods of inactivity ("gelling phenomenon"), represents another cardinal symptom. Physical examination frequently reveals crepitus, joint line tenderness, reduced ROM, and varying degrees of joint effusion.[37]

Disease progression follows a variable course, with some patients experiencing rapid deterioration while others demonstrate minimal progression over decades. Radiographic progression often occurs at a rate of 0.1-0.3 mm joint space narrowing per year, with clinical symptoms not always correlating with radiographic severity.[35] Advanced disease manifests as joint deformity, muscle atrophy, and significant functional limitation, substantially impacting quality of life and independence.

Classification of Knee OA

Radiographic Classification Systems

KL Grading System

Figure 19: Kellgren–Lawrence (KL) scale[46]

Most of the time, the KL method is used to classify knee OA on x-rays in study settings. On a scale from 0 to 4, this method looks at how many and what kind of subchondral sclerosis, joint space shortening, bone deformation, and osteophytes there are.

This system of grades goes from 0 (no radiography results) to 4 (severe sickness). There is some doubt about the presence of osteophytes and possible lipping of the joint space in Grade I. There are osteophytes and the possibility of narrowing the joint space in Grade II. There are moderately multiple osteophytes with some sclerosis and narrowing of the joint space in Grade III. And there is advanced disease with large osteophytes, severe sclerosis, and clear bone deformity in Grade IV.[45]

Ahlbäck Classification

The Ahlbäck system focuses specifically on joint space narrowing and bone attrition, categorizing OA into five grades based on anteroposterior weight-bearing radiographs:[47]

Grade I: Joint space narrowing (<3 mm)

Grade II: Joint space obliteration

Grade III: Minor bone attrition (<5 mm)

Grade IV: Moderate bone attrition (5-10 mm)

Grade V: Severe bone attrition (>10 mm)

Grade	KL Scale	Ahlbäck Classification	KOGS
Grade 0	No pathological features of osteoarthritis (OA)		
Grade 1	Suspicious narrowing of the joint space and possible osseous lip	Joint space narrowing, with or without subchondral sclerosis. Joint space narrowing is defined by this system as a joint space <3 mm, or less than half of the space in the other compartment, or less than half of the space of the homologous compartment of the other knee	An isolated medial, lateral tibiofemoral, or patella-femoral joint OA with ligament stability and two functionally intact compartments
Grade 2	Clear bone tissue and possible stenosis of the joint space	Obliteration of the joint space	Deteriorating isolated lesion with ligament stability and a correctible coronal subluxation
Grade 3	Moderate multiple bone tissue, clear narrowing of the joint space, slight sclerosis, and possible deformity of the ends of the bones	Bone defect/loss < 5 mm	Includes an isolated medial or lateral tibiofemoral OA and concomitant pathologies such as anterior cruciate ligament deficiency (3A) or grooving of patella-femoral joint or patellectomy (3B)
Grade 4	Large bone tissue, marked narrowing of the joint space, severe sclerosis, and clear deformities of the ends of the bones	Bone defect/loss between 5 mm and 10 mm	Includes cases of bi-compartmental tibiofemoral OA without concomitant ligament instability (4A) and with ligament instability (4B)
Grade 5		Bone defect/loss >10 mm, often with subluxation and arthritis of the other compartment	

Table 1: Comparison of KL scale, Ahlbäck classification, and KOGS[46]

Brandt Classification

The Brandt classification evaluates OA progression based on joint space narrowing measured in the weight-bearing position:

Grade 0: Normal joint space

Grade 1: Possible narrowing with questionable osteophytes

Grade 2: Definite narrowing with definite osteophytes

Grade 3: Severe narrowing with multiple osteophytes

Grade 4: Complete loss of joint space with bone-on-bone contact

Clinical Classification Systems

ACR Criteria[46]

The clinical criteria include:

1. Knee pain on most days of the previous month
2. At least three of the following:

   people with more than 50 years, experiencing morning stiffness for thirty minutes, shows crepitus on movement, painful feel on touch, bony prominence and not feeling hot on examination

These criteria demonstrate 95% sensitivity and 69% specificity for knee OA diagnosis when compared to radiographic standards.

WOMAC Classification

When it comes to knee OA, WOMAC offers a systematic way to evaluate discomfort, rigidity, as well as functionality. [46]This patient-reported outcome measure includes agony, stiffness as well as physical activity.

The WOMAC score serves as both a classification tool and an outcome measure for monitoring disease progression and treatment response.

Anatomical Classification

Anatomical classification categorizes knee OA based on the involved compartments:[48]

Medial compartment OA represents the most common pattern due to the physiological varus alignment and increased load transmission through this region during weight-bearing activities.[48]

Etiological Classification

Etiologically, knee OA is classified as either primary or secondary:[49]

1. **Primary (idiopathic) OA:** Occurring without a clearly identifiable underlying cause, typically involving multiple factors such as aging, genetics, and biomechanical stressors

2. **Secondary OA:** Developing consequent to a specific predisposing condition, including:
    a. Post-traumatic: Following meniscal, ligamentous, or articular surface injuries
    b. Post-infectious: After septic arthritis
    c. Metabolic: Associated with conditions such as hemochromatosis, Wilson's disease, or gout
    d. Developmental: Secondary to congenital or developmental abnormalities
    e. Neuropathic: Associated with neurological disorders affecting joint sensation and protection

This classification informs both prognostication and treatment approaches, particularly regarding addressing underlying causes in secondary OA cases.

Conservative Management of Knee OA

Non-Pharmacological Interventions

Non-pharmacological interventions are essential in the management of knee OA. These include lifestyle modifications, physical therapy, and weight management. Exercise, particularly low-impact aerobics activities and strength training, are some of the interventions. Joint stabilization may be improved by workouts by reinforcing the muscles surrounding the knee. Weight loss is crucial for overweight patients, as it decreases stress on knee joints, alleviating symptoms.[50]

Pharmacological Interventions

Pharmacological treatments for knee OA aim to relieve pain and improve joint function. NSAIDs are commonly prescribed to reduce inflammation and pain. Acetaminophen is often used for pain management, although its efficacy may be limited compared to NSAIDs. Topical analgesics, such as capsaicin, can provide localized pain relief with fewer systemic side effects. While these medications can be effective, they may not address the underlying degenerative changes in the joint.[51]

IA Injections

When non-invasive methods of treating knee OA fail, doctors may resort to injecting the affected joint with medication. By lowering inflammation, steroid injections provide relief from discomfort. Joint lubrication and cushioning may be restored with hyaluronic acid injections, which may lead to improved mobility. Although data for the effectiveness of PRP injections is still emerging, they are being investigated for their restorative qualities. These treatments can be beneficial in delaying the need for surgery, but their effects are often temporary.[52]

Limitations of Conservative Management in Advanced OA

Conservative management faces significant limitations in advanced stages of knee OA, such as Kellgren and Lawrence grade IV. In these cases, the joint degeneration is severe, and the structural damage may not respond sufficiently to conservative treatments. The efficacy of non-pharmacological and pharmacological interventions diminishes as the disease progresses, often necessitating surgical options like KA. Additionally, chronic pain and functional limitations in advanced OA can significantly impair quality of life, making conservative management less effective.[53]

Surgical Management Options for Advanced Knee OA

HTO

Younger, more active individuals suffering with medial compartment knee OA are the main candidates for HTO. In order to realign the knee joint and shift the patient's weight away from the injured cartilage and onto the healthy cartilage, the tibia must be cut and reshaped. By reducing the need for TKA and improving pain and function for years to come, HTO is a great option. However, it requires a lengthy recovery period and meticulous postoperative rehabilitation.[54]

UKA

UKA, or partial knee replacement, is suitable for patients with OA confined to a single compartment of the knee. It involves replacing only the damaged compartment, preserving the unaffected cartilage and ligaments. UKA offers benefits such as shorter recovery time, less postoperative pain, as well as improved ROM compared to TKA. However, patient selection is critical, and the success largely depends on the precise alignment and implantation of the prosthesis.[55]

TKA

TKA is the gold standard for treating advanced knee OA, especially when multiple compartments are affected. To alleviate discomfort and restore function, TKA replaces the whole knee joint with a synthetic implant. It has a high success rate, with significant improvements in pain and mobility. However, TKA is associated with potential complications such as infection, implant loosening, and the need for revision surgery. Patients must undergo extensive rehabilitation to achieve optimal outcomes.[56]

Emerging Minimally Invasive Techniques

Minimally invasive techniques in KA aim to reduce tissue trauma, minimize pain, and speed up recovery. These techniques use smaller incisions and specialized instruments, preserving more of the surrounding soft tissue. Minimally invasive approaches have been applied to both UKA and TKA, showing promising results in terms of reduced hospital stays and faster return to daily activities. However, these techniques require a steep learning curve and are not suitable for all patients, particularly those with complex deformities or severe bone loss.[57]

Historical Perspective and Evolution of TKA[58]

Early Innovations (1890-1960)

The developmental trajectory of total knee replacement (TKR) commenced with rudimentary interpositional arthroplasty, exemplified by the Gluck ivory knee prosthesis in 1890. This pioneering attempt, while revolutionary in concept, exhibited significant limitations in durability and biocompatibility. The field remained relatively dormant until the mid-20th century, when Walldius introduced his hinged knee design circa 1951, representing the first systematic attempt at functional knee joint replacement. Due to their restricted kinematics and poor biomechanical features, these early hinged devices were able to treat only severe deformities; nevertheless, they also exhibited considerable mechanical constraints as well as high complication rates.

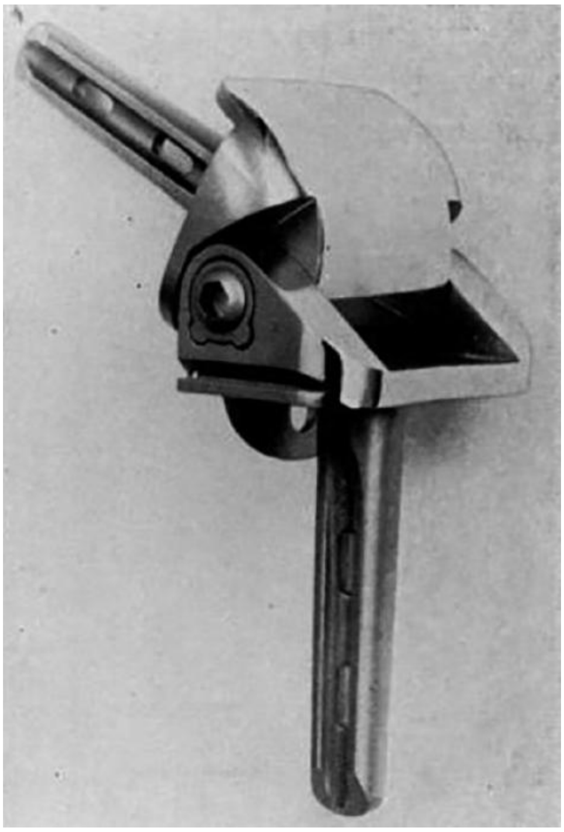


Figure 20: Walldius knee[58]

Fundamental Design Evolution (1960-1975)

In the 1960s, the first condylar prostheses were made, which marked the start of a new era. These methods were set as important design standards that are still used in modern implants. It was a big change from designs that were based on mechanics to ones that took anatomy as well as biomechanics into account at this time. And the Bosquet-Trillat hinge design made mechanical performance better and kept badly broken joints safe at the same time. In the early 1970s, total condylar forms were made to better deal with pan-articular degenerative disease. All joint surfaces were changed to these forms.

How Fixation Technology and Biomechanical Refining Changed Over Time (1975–1990)

From the mid-1970s to the 1980s, there were major improvements to these available designs, with a major focus on cruciate control methods. Insall along with Burstein were the first people to use PS to treat PCL weakness, as well as the Geomedic cruciate-preserving devices kept the original ligamentous structures. In 1978, new ideas about motion were made it possible for mobile bearing platforms in order to improve dynamics as well as lower polyethylene wear. In the early 1980s, porous-coated anatomic uncemented systems were created as an option to traditional cemented methods for biological anchoring. This was a big step forward in fixing implants.

Methods and technology are being updated (1990–present)

The modern TKR age is marked by improvements in technology that aim was to improve the efficiency as well as outcomes of procedures. Computer-assisted tracking systems, which came out in the 1990s, made alignment more accurate and consistent with where parts were placed. Robotic-assisted arthroplasty, introduced around 2005, represents further refinement of computer-assisted techniques, providing haptic feedback and real-time intraoperative assessment. Contemporary challenges in TKR center on improving accuracy and precision, with ongoing refinements in PSI, anatomic implant designs, and advanced biomaterials.

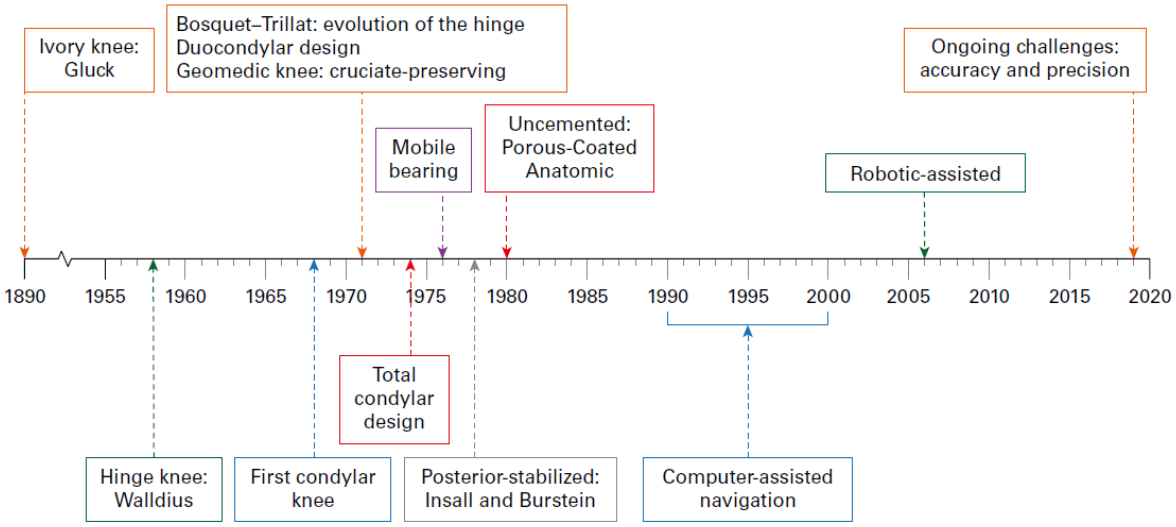


Figure 21: A timeline showing important events in the history of TKA[58]

The evolution of TKR represents a remarkable convergence of biomechanical principles, materials science, and surgical technique, transforming a once experimental procedure into a highly reliable intervention with demonstrable efficacy in addressing end-stage knee arthropathy. Current research focuses on optimizing functional outcomes, enhancing implant longevity, and tailoring solutions to individual patient requirements and expectations.

Referencing Systems and Clinical Implications[59]

Dimensional Considerations for Femoral Component Selection

The determination of appropriate femoral component dimensions in KA is primarily governed by the anteroposterior (AP) measurements of the femur rather than mediolateral parameters. Optimal positioning necessitates precise alignment with the anterior femoral cortex, avoiding both anterior cortical protrusion and notching phenomena. The latter is particularly significant as anterior cortical notching compromises distal femoral structural integrity, potentially precipitating supracondylar femoral fractures through biomechanical stress concentration. Two methodological approaches for femoral sizing warrant consideration: anterior referencing and posterior referencing systems.

Anterior referencing system

In the anterior referencing paradigm, the anterior femoral cortex serves as the primary anatomical landmark, establishing a constant anterior resection plane irrespective of component dimensional variations. This method has a lot of treatment benefits because it lowers the risk of anterior cerebral violation and keeps the anterior cut parameters the same during component shrinking. Still, the methods used in this system to shrink the joint require more posterior condylar removal, which makes the bending gap bigger. But when the femur component is made bigger, there is less posterior condylar removal, so the bending space parameters are smaller.

Posterior referencing system

The posterior reference method is different because it standardizes the posterior condylar resection while letting the anterior resection parameters change based on the size of the component. A posterior condylar resection can be fixed with this method, and the bending gap can be kept stable. The system's different anterior cutting plane, on the other hand, means that if it is shrunk, it could cut the neural tissue in the front of the femur. When measurements taken during surgery show that two measures are almost the same, it is usually best to go with the bigger part to avoid damage to the frontal cortex.

Clinical Decision-Making Implications

These differential referencing systems need careful planning before surgery and review during surgery in order to get the best component selection and location. When the operating surgeon is choosing between anterior as well as posterior referencing systems, the surgeon should look at the patient's unique anatomy, the way of surgery they prefer, and how important it is to keep the anterior brain structure versus the bending gap. Clinicians can make better decisions that improve functional results after KA treatments if they fully understand these physical ideas.

Whiteside's Line[59]

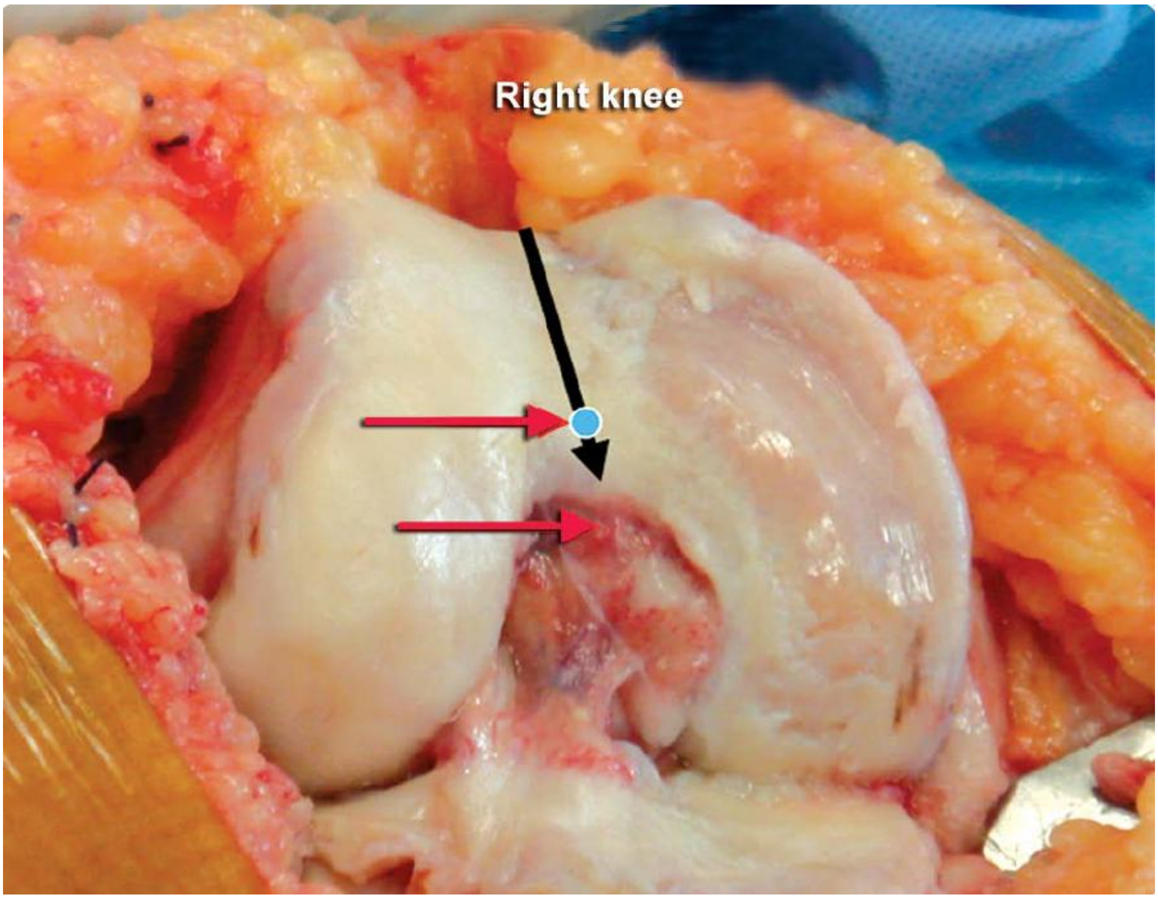


Figure 22: White side's line[59]

Whiteside's line, which goes from the bottom edge of the trochlear groove to the top edge of the intercondylar notch, is an important anteroposterior structural reference for placing the femoral component. The best place to enter the femoral canal is about 1 cm closer to the PCL's origin along this reference line. This needs to be precisely located before an opening hole is made and widened to fit intramedullary positioning tools. An expertly clean medullary canal with special tools is needed for this surgery in order to lower the risk of a fat embolism happening during later steps.

Distal Femoral Cut

The distal femoral resection initiates with femoral entry point identification along Whiteside's line (the anteroposterior axis connecting the intercondylar notch apex and trochlear groove nadir), positioned 1 cm anterior to the proximal PCL insertion. Following portal creation and appropriate reaming, intramedullary instrumentation is introduced. Medullary canal lavage using elongated suction apparatus is recommended to mitigate fat embolization risk.

Contemporary systems predominantly utilize intramedullary referencing instrumentation with resection angles typically configured at 5-7° based on preoperative scanogram analysis, facilitating perpendicular resection relative to the mechanical axis. Instrumentation positioning against the distal femur requires careful attention to condylar contact patterns, which vary according to preexisting deformity orientation. Following cutting block fixation with multiple pins, a oscillating saw resects 9-10 mm of distal femur from the less affected compartment. Optimal saw blade dimensions (1.2-1.25 mm) relative to cutting slot width (1.27 mm) are essential for resection accuracy. Proper saw blade orientation and uninhibited movement during resection enhance precision.

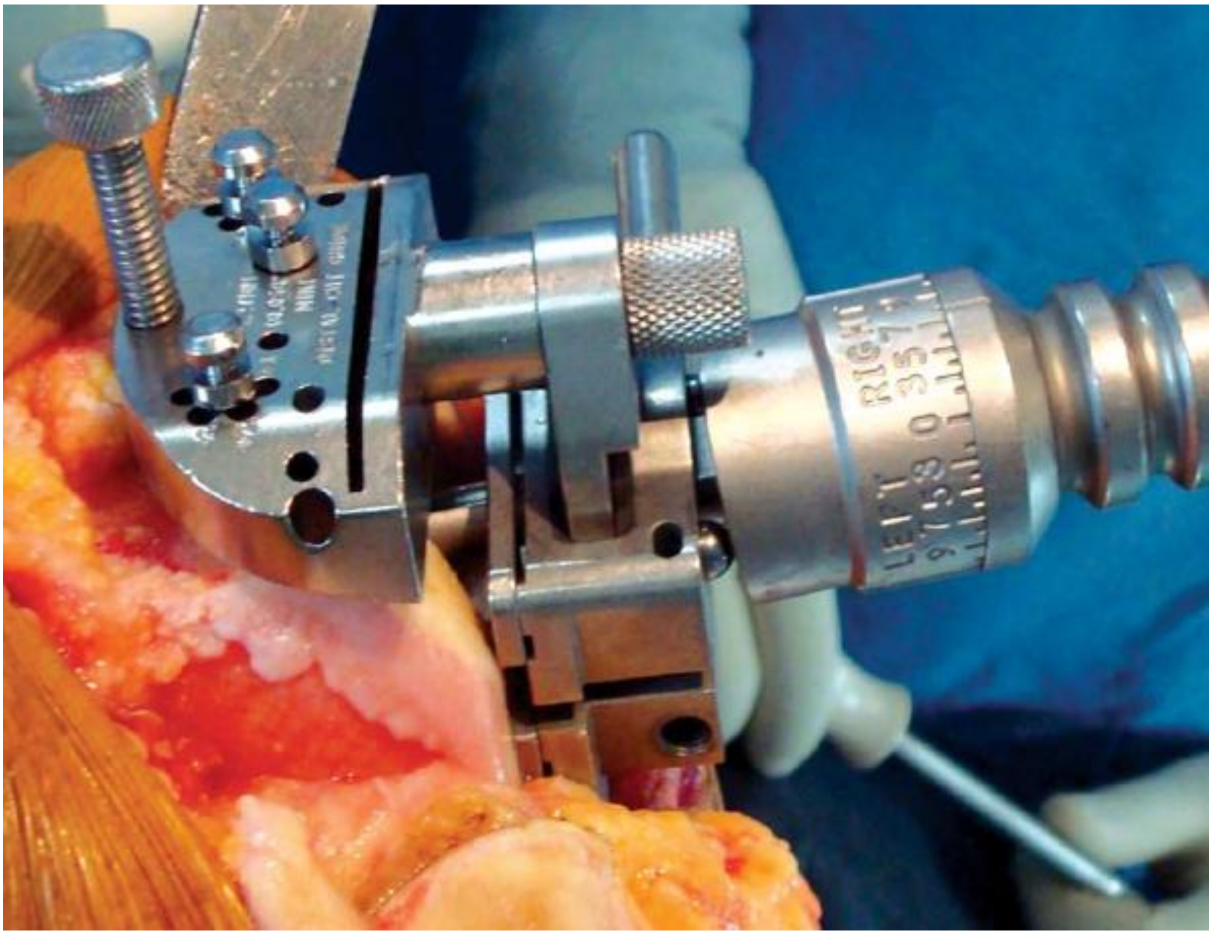


Figure 23: The jig set completely against the distal surface of femur[59]

Proximal Tibial Cut

The proximal tibial resection procedure commences with anterior tibial subluxation and strategic placement of protective retractors. A posteriorly positioned curved Hohmann retractor with blunted tip is introduced anterior to the PCL, resting against the distal femur with soft tissue cushioning. Additional retractors are positioned medially and laterally to facilitate exposure while protecting vital periarticular structures.

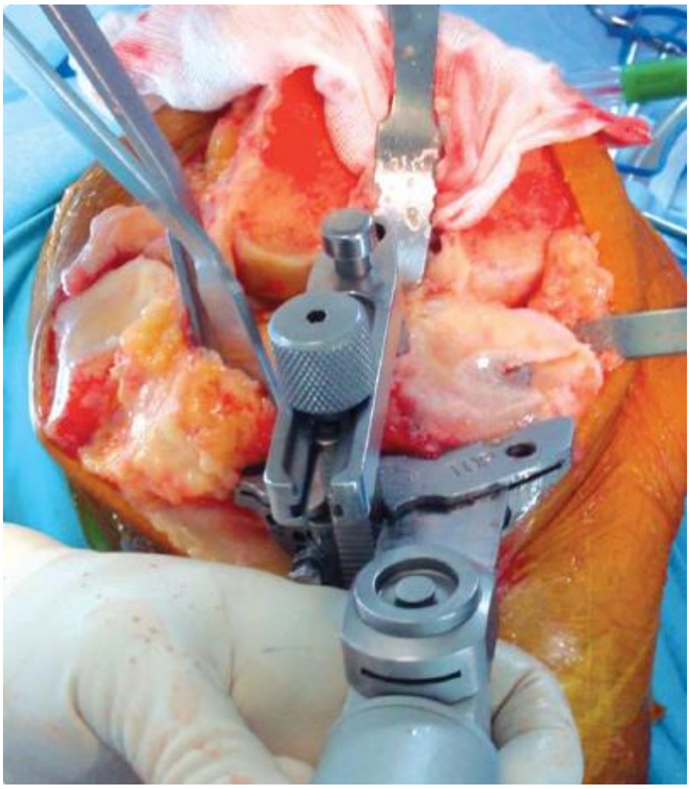


Figure 24: Proximal tibial cut[59]

Contemporary instrumentation systems predominantly employ extramedullary referencing techniques with distal tibial fixation. The alignment jig is initially secured distally with rotational orientation referenced to the tibial tubercle junction (medial third/lateral two-thirds). Proximally, the jig is positioned centrally on the tibial plateau. The posterior slope parameter (0-7°) is configured according to prosthesis-specific requirements, with the anterior arm positioned parallel to the tibial anterior cortex. Distal alignment references include the ankle center, positioned medial to the inter-malleolar midpoint.

Following jig stabilization, resection depth is determined using a stylus reference on the less affected tibial compartment, typically targeting 9-10mm resection in standard varus deformities. The resection is performed with appropriate saw blade length to prevent iatrogenic neurovascular injury, with strategic retractor positioning providing comprehensive protection of periarticular soft tissue structures. The procedure concludes with cruciate ligament remnant excision and meticulous hemostasis.

Evolution of Total Knee Replacement Prosthesis[15]

TKA has undergone remarkable evolution since its inception. In 1973, Insall and colleagues introduced the complete condylar prosthesis, a groundbreaking innovation that laid the groundwork for contemporary TKA.

As illustrated in Campbell's Operative Orthopaedics, this seminal design prioritized mechanical considerations over anatomical replication, sacrificing both cruciate ligaments while maintaining stability through sagittal plane articular surface geometry.

The original cemented total condylar prosthesis featured symmetric medial and lateral condyles with a decreasing sagittal radius of curvature posteriorly, individually convex condyles in the coronal plane, and a double-dished tibial polyethylene component with perfect congruence in extension that transitioned to coronal plane congruence in flexion.

Figure 25: Total condylar prosthesis introduced by Insall[15]

Early Design Innovations and Biomechanical Considerations

Concurrent with the total condylar prosthesis development, the duopatellar prosthesis emerged as an alternative design featuring anatomically shaped femoral components that preserved the PCL. This system initially employed separate medial and lateral tibial plateau components before evolving to a unified tibial component with a PCL accommodation cutout. The duopatellar design subsequently evolved into the kinematic condylar prosthesis widely utilized during the 1980s.

Figure 26: Posterior cruciate–retaining total knee designs[15]

Early clinical reviews documented substantial functional limitations with the total condylar design, including restricted flexion (90-100 degrees) and compromised femoral rollback. A centralized cam system on the femoral component contacted a tibial post at around 70 degrees of flexion; this was the result of biomechanical limitations; in 1978, the Insall-Burstein PS design was developed. This innovative mechanism facilitated posterior displacement of the tibiofemoral articulation, effectively simulating femoral rollback and enhancing flexion capacity.

Patellofemoral Considerations and Design Refinement

Patellofemoral problems became major revision indications in the latter part of the 1980 and early 90s, therefore future designs paid more attention to patellofemoral articulation. Contemporary prostheses incorporate expanded patellofemoral contact areas through extended trochlear grooves, asymmetric anterior flanges to resist patellar subluxation, and deeper trochlear geometry achieved through sulcus cuts in the anterior femoral chamfer.

Cruciate Management Strategies

Cruciate-retaining (CR) designs have evolved significantly over three decades, attempting to recreate natural femoral rollback through PCL preservation. These systems theoretically offer reduced constraint and decreased tibial tray forces, though kinematic studies have demonstrated paradoxical roll-forward contact patterns on the medial joint aspect. Some manufacturers have incorporated deep-dish polyethylene inserts or tray options for CR designs to address cases with insufficient PCL support, providing sagittal plane concavity similar to the original total condylar design without requiring intercondylar bone sacrifice.

Constraint Variations and Specialized Designs

The constrained condylar knee (CCK) design emerged as a modification of posterior-substituting systems, featuring an enlarged central post constrained against the medial and lateral walls of a deepened femoral box. This configuration provides controlled varus-valgus stability while permitting flexion-extension and limited rotational movement, offering an intermediate option between PS designs and fully hinged systems for patients with moderate instability. CCK designs have demonstrated particular efficacy in revision arthroplasty, with reported survivorship rates of 97.6% at 10-year follow-up according to contemporary clinical studies (Maynard et al.).

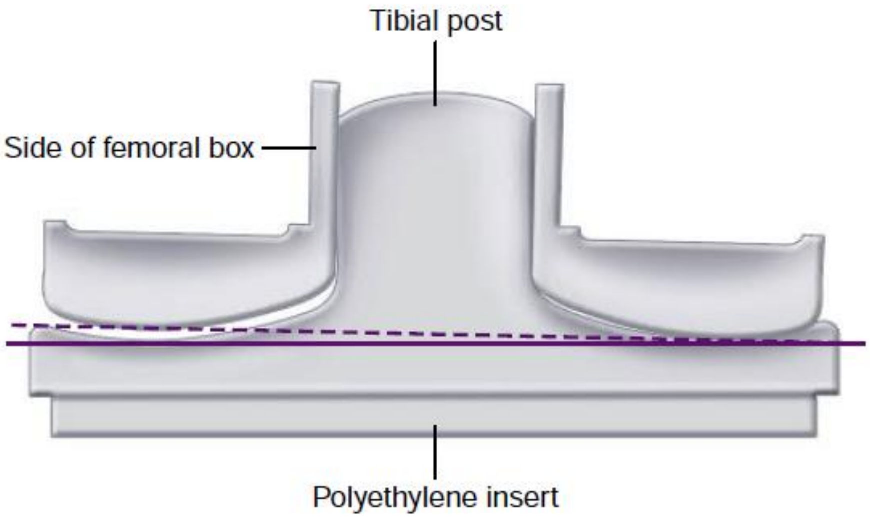


Figure 27: Original constrained condylar knee[15]

Mobile-Bearing Innovations

Plastic meniscal components that link to both femur and tibial components are used in mobile-bearing knee prosthetic designs, such as the LCS system that was developed by Buechel and Pappas. These components are used to enhance the structural function of the knee. Individually curved dovetailed slots are included into the design of these implants, which are located on the tibial baseplate. These slots are designed to limit the movement of the meniscus and to enhance the mechanics of the joint. When the posterior curve radius is decreased in these designs, the extensor mechanism is able to function more effectively when the knee is bent. This is an advance in the physics of total knee arthroplasty.

Unicompartmental and Specialized Prostheses

Figure 28: Fixed and mobile bearing UKA system[15]

UKA has demonstrated efficacy in appropriately selected patients, with contemporary systems available in both fixed-bearing and mobile-bearing configurations. While controversy persists regarding indications, particularly in higher BMI patients, recent literature supports UKA utilization in properly selected candidates, with reported advantages including bone stock preservation, minimized surgical invasiveness, and enhanced rehabilitation potential compared to TKA.

Advanced Constraint Options

For cases with severe instability, the Kinematic Rotating Hinge provides comprehensive constraint in sagittal and coronal planes while permitting rotation in the transverse plane. This design limits force transfer to implant-bone interfaces, offering a salvage option for complex primary and revision scenarios. Recent studies have documented improved outcomes with contemporary rotating hinged designs compared to earlier fixed-axis systems, with reduced complication rates at mid-term follow-up.

The evolution of TKR prosthesis designs reflects progressive refinement in biomechanical understanding, materials science, and surgical technique, transforming a once experimental procedure into a highly reliable intervention for advanced knee pathology. Contemporary research continues to focus on optimizing kinematics, enhancing implant longevity, and tailoring solutions to individual patient requirements and anatomical variations.

Advances in Surgical Techniques of TKA

Surgical techniques in TKA have advanced in parallel with prosthetic innovations. The shift from extensive open surgeries to minimally invasive approaches has been significant.

Minimally invasive TKA techniques, which involve smaller incisions and less soft tissue disruption, have been associated with reduced pain, faster recovery, and shorter hospital stays. Navigation systems and robotic-assisted surgeries have further refined surgical precision, allowing for more accurate alignment and positioning of the implants. These technological advancements have improved the overall success rates of TKA procedures and have contributed to better functional outcomes.[60]

Surgical approaches for TKR

1. Medial Parapatellar Retinacular Approach

The medial parapatellar retinacular approach is commonly preferred skin incision for primary TKA. This standard approach involves a medial parapatellar retinacular approach with the following key technical elements:

A median anterior midline incision is used as the starting point for this surgical procedure; however, this incision structure can be altered depending on the anatomy of the patient. When repositioning subcutaneous tissues laterally as well as medially, the knee must also be flexed to put this incision. When this step is performed, the infrapatellar branch of the saphenous nerve is often and severely injured. This can cause lateral knee pain post surgically. The normal retinal cut starts about 3–4 cm above the kneecap, goes along the medial edge of the patella, as well as finishes on the anteromedial side of the tibia, right next to the patellar tendon. To get to the medial knee compartment for surgery, the anteromedial capsule and deep medial collateral ligament must be raised below the periosteum. To get to the lateral knee compartment for prosthetic installation, the lateral patellofemoral plicae must be released.

This approach provides excellent exposure of the knee joint. [15]

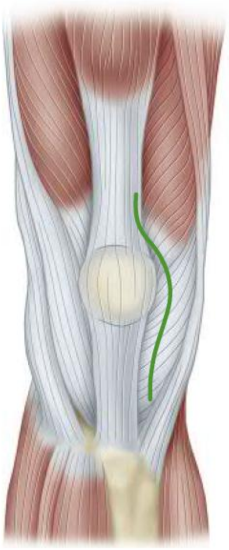


Figure 29: Medial parapatellar retinacular approach[15]

2. Midvastus Approach

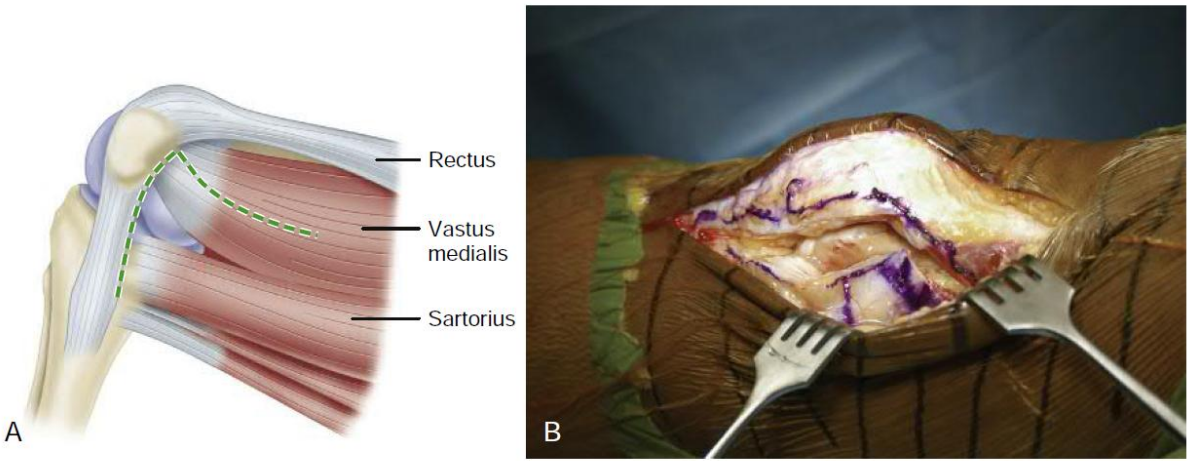


Figure 30: Midvastus approach[15]

Instead of using lateral subluxation, as in the subvastus method, the midvastus approach, which was first proposed by Engh and Parks, is an improvement in knee arthroplasty technique that optimizes the preservation of the extensor mechanism. It does this by separating the vastus medialis along its fiber orientation. This surgical technique preserves vital arterial systems, such as the superior geniculate artery to the patella and quadriceps tendon, by establishing a safe dissection zone that extends 4.5 cm from the patella's superomedial border proximally and medially toward the intermuscular septum. Obesity, a history of total knee arthroplasty, and a knee flexion less than 80 degrees before to surgery are some of the particular contraindications to this technique, despite the fact that it provides better extensor mechanism integrity with sufficient surgical visibility. Shown in Figure, the surgical plane with the knee bent at 90 degrees, the method's anatomical accuracy is shown.

3. Subvastus Approach

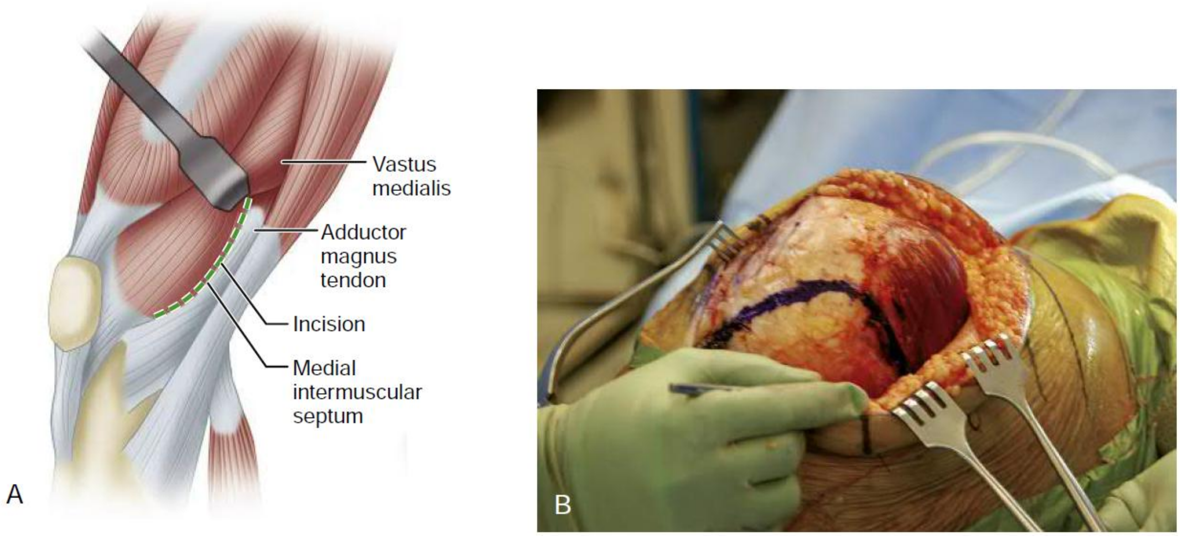


Figure 31: Subvastus approach[15]

The subvastus ("Southern") approach offers an alternative method that aims to reduce patellofemoral complications and expedite the return of quadriceps function postoperatively:

An alternate surgical strategy for TKA known as the subvastus ("Southern") approach is used. This technique preserves patellofemoral integrity with specialist manipulation of the extensor mechanism, while still using the normal anterior midline incision. Delicately separate the muscle's origin from the medial intermuscular septum about 10 cm proximal to the adductor tubercle by cutting the superficial fascia overlying the vastus medialis: then, as shown in figure, fully subluxate the extensor apparatus laterally. Faster quadriceps strength recovery preserved patellar vascularity, higher patient satisfaction ratings, less postoperative discomfort, and fewer lateral release operations are just a few of the clinical benefits that proponents of this method claim Despite these advantages, there are certain technical limitations to the subvastus approach as compared to the medial parapatellar procedure in terms of surgical exposure. This is especially true for patients who are overweight or have had prior knee surgeries.

Advocates of this approach claim several benefits:

- More rapid return of quadriceps strength
- Preserved vascularity to the patella

- Improved patient satisfaction

Each of these approaches has specific indications, technical considerations, and potential advantages/disadvantages that surgeons must consider based on patient-specific factors and their own surgical expertise.

Posterior cruciate-retaining KA

When treating advanced instances of knee OA, specifically those categorized as Kellgren and Lawrence grade IV, the surgical treatment known as PCRKA is used. Maintaining knee stability and natural kinematics is the goal of PCRKA, which is achieved by maintaining the PCL. Indications, surgical method, and possible consequences of PCRKA are discussed in this article.

Indications for PCRKA

Extreme OA of the knee, with severely damaged joint surfaces and no improvement with conservative therapy, is the main reason for PCRKA. This operation may help patients whose pain, mobility, and quality of life are severely compromised even after non-surgical treatments have been tried and failed. Since the effectiveness of the operation depends on characteristics including enough bone stock and undamaged PCLs, PCRKA is best suited for patients who meet these criteria.[61]

Assuming their PCL is operational, PCR KA may be beneficial for patients suffering with OA, RA, or post-injury arthritis. Most people who have knee replacement surgery are younger, more active people who will need their knees to be very stable and functional following the procedure. [62]

Surgical Technique and Rationale

After the damaged cartilage and bones are removed from the femur and tibia, the surfaces are rebuilt with metal and plastic components in PCR KA. Since it has remained uninjured, the PCL can keep the knee stable and guide its natural movement. [63]

Proper alignment of the prosthetic components and delicate balancing of the knee ligaments are essential steps in the surgical procedure to achieve the best possible joint performance. Surgeons need to check the PCL's integrity during the operation to make sure it's OK to keep. If the PCL is defective or not strong enough, surgeons may choose to use a prosthetic that stabilizes from the back instead.[64]

The PCL should be maintained because it improves knee proprioception and makes walking more natural. The goal of PCR KA is to increase ROM and patient satisfaction after surgery by maintaining the ligament.[65]

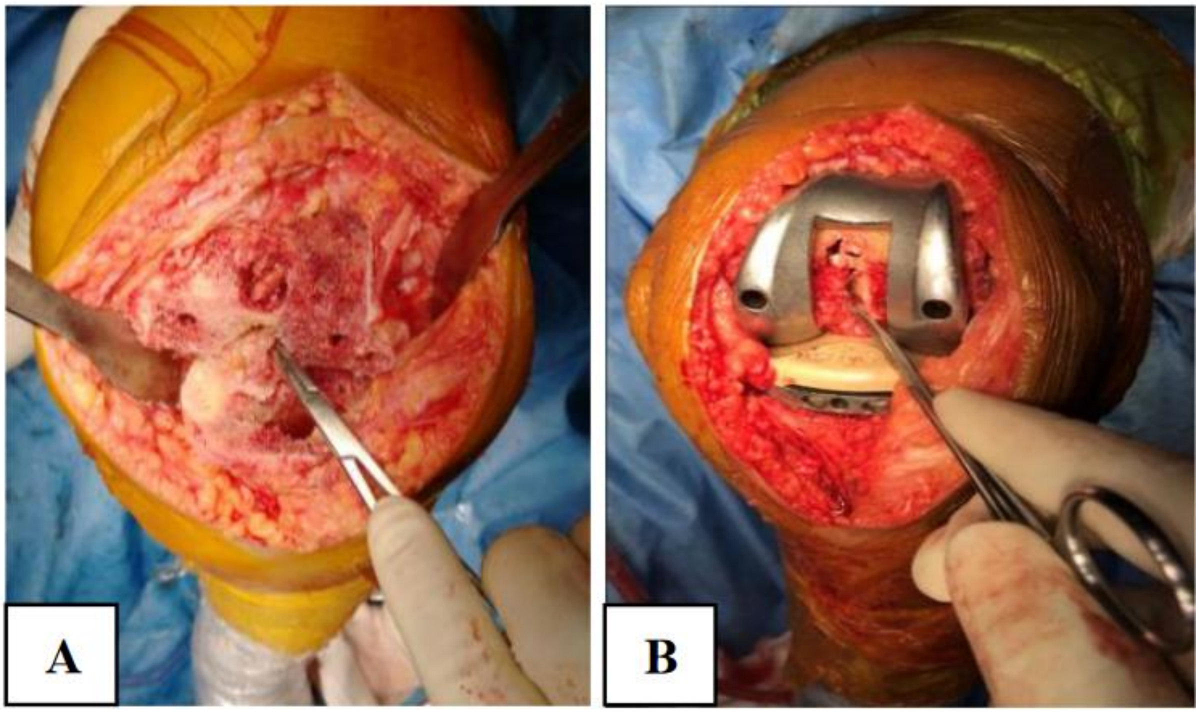


Figure 32: Parts A and B show intact PCL in femoral and tibial cuts, while part B shows intact PCL in trail implants[11]

Complications of PCRKA

While PCRKA is generally considered a safe and effective procedure, it is not without potential complications. Infections, DVTs, and implant loosening are among the most common problems. Nonetheless, these dangers are not dissimilar from those of other KAs. [64]

A specific concern in PCRKA is the potential for PCL insufficiency or rupture, which can lead to instability and impaired knee function. In such cases, revision surgery may be necessary to convert to a posterior-stabilized design. Additionally, improper balancing of the knee ligaments during surgery can result in residual pain or stiffness, necessitating further intervention.[66]

Long-term studies have shown that PCRKA offers satisfactory prosthesis survivorship and functional outcomes. However, patient selection and surgical expertise are critical factors in minimizing complications and maximizing the benefit of surgery.[67]

Posterior-stabilized TKA

Indications for PS-TKA

PS-TKA is predominantly indicated for patients with severe knee OA, classified as Kellgren and Lawrence grade IV, where there is extensive cartilage loss and significant joint deformity. It is also suitable for patients with rheumatoid arthritis, post-traumatic arthritis, and those with previous knee surgeries that may have affected the PCL.[61]

In clinical practice, PS-TKA is preferred when the PCL is non-functional or absent, as it includes a mechanical cam and post system that substitutes for the PCL. This design helps maintain knee stability and ensures proper kinematics during flexion and extension.[68] Patients who want to be somewhat active after surgery and who need a high level of stability generally opt for PS-TKA.

Method and Reasoning Behind Surgery

The PS-TKA process begins with the femur and tibia having their damaged bone and cartilage removed, and then the joint surfaces are replaced with metal and plastic components. One unique aspect of posterior-stabilized total knee arthroplasty (PS-TKA) is the presence of a cam and post that, when engaged during knee flexion, stabilize the knee and stop the posterior tibial translation.[69]

In order to guarantee the best possible performance and durability of the implant, the PS-TKA surgical procedure places an emphasis on exact alignment and balance of the knee joint. To create proper flexion and extension gaps, surgeons must carefully evaluate the architecture of soft tissues and execute the necessary releases. Surgical precision and results may be greatly improved with the use of PSI, or computer-assisted navigation.[61]

The advantage of a posterior-stabilized design is that it may increase knee flexion and enhance anteroposterior stability, much as the PCL. Patients having revision surgery or those with severe abnormalities benefit greatly from this design since it compensates for the loss of the natural ligamentous stabilizers.[64]

Issues with PS-TKA

In most cases, PS-TKA is able to restore function and reduce discomfort, although treatment is not risk-free. Deep vein thrombosis, infection, and implant loosening are common problems. The changed knee kinematics also increases the likelihood of patellofemoral problems including patellar maltracking or instability.[70]

When the synovial tissue becomes stuck in the posterior-stabilized mechanism, it may cause discomfort and restricted mobility; this is another prominent consequence. In such a case, arthroscopic surgery to free the trapped tissue may be necessary.[71]

In spite of these worries, PS-TKA outperforms other KA designs in terms of long-term survival, and patients report less pain, more satisfaction, and less loss of function in several trials. Minimizing problems and attaining optimum outcomes need surgical competence and proper patient selection.[67]

PCR versus PS TKA

The two most common methods, PCR and PS TKA, are based on different biomechanical concepts and have their own set of benefits and drawbacks

Biomechanical Principles

The treatment of the PCL is the major differentiator between PCR and PS TKA. In order to keep the knee's normal kinematics and proprioceptive input intact, PCR TKA keeps the PCL. For stability and a more organic femoral roll-back action on the tibia during flexion, this method depends on the intact PCL.[72]

Conversely, PS TKA involves the removal of the PCL and uses a cam and post mechanism to mimic the stabilizing role of the PCL, offering stability during knee flexion and extension.

Figure 33: MRI scans of the PCL[17]

Advantages and Disadvantages of PCL Retention

Several benefits may be gained by keeping the PCL in TKA. Because normal knee biomechanics are preserved, it has the potential to contribute to more natural knee mobility, preservation of proprioception, and higher patient satisfaction. But there are obstacles that, if not handled correctly, might cause problems, such as the technical difficulties of maintaining knee balance when the PCL is intact.

Keeping the PCL in place can also affect the prosthesis' stability and durability if it's already weak or broken. Thorough evaluation of the PCL's integrity and the patient's unique requirements should lead to the decision of keeping or sacrificing the ligament. [73]

Factors Influencing PCL Retention Decisions

Age, activity level, and PCL condition are three of the many variables that go into deciding whether or not to keep the PCL during TKA. The possibility for more natural knee function makes PCR TKA a good option for younger, active patients with a healthy PCL.

Evaluating PCL integrity is an important part of preoperative preparation, which includes imaging and physical examination. Surgeons should think about the patient's expectations and way of life in addition to their own familiarity and comfort level with the procedure. [74]

Contraindications for PCL Retention

Keep in mind that PCL retention in total knee arthroplasty has some limitations. Severe PCL degeneration or injury, major abnormalities requiring substantial repair, and situations where establishing adequate balance with the PCL is not conceivable are all examples of what is considered severe. The stability it gives without the PCL makes a PS TKA a potential better choice in these cases.

Furthermore, PCR TKA may not be the best option for people who have had prior knee operations or who have health issues that have impaired the PCL's ability to do its job.[75]

Outcomes of PCR TKA

The pros and cons of PCR TKA affect how well it works, how happy the patient is, and how long they can live.

Functional Outcomes: ROM, Stability, Proprioception

Because the PCL is kept, the goal of PCR TKA is to keep the knee's normal function. Keeping the PCL in place may help with motion and stability because it helps the knee's normal roll-back movement when it's bent. PCR TKA has been shown in many studies to help people get enough range of motion (ROM) and keep their knees stable, which are important for everyday tasks and sports. Keeping the PCL in place may also help with proprioception, which tells patients more about where their joints are and how much they can move.[76]

Patient-Reported Outcomes: Pain Relief, Satisfaction

Patient-reported results are very important for figuring out if TKA worked. After PCR TKA, patients say they are much less in pain and happier generally. The protection of the PCL helps keep the knee's biomechanics as close to normal as possible after surgery. This makes the knee more useful and the patient happier. Standardized tests, like the KSS and the WOMAC score, show that patients' pain and ability to do things have gotten a lot better.[77]

Survivorship and Complications

A lot of studies have shown that PCR TKA works well in the long term. After 10 years, 90% of people who get it still have it. Implant wear and loosening are rare problems that can happen if the PCL isn't strong or balanced after surgery. The choice to keep the ligament should be based on a full review of the PCL's stability and the patient's whole knee position.[78]

Studies Comparing PCR vs. PS Designs

When you compare PCR and PS TKA methods, systematic reviews and meta-analyses may teach you a lot about which one is better. The therapeutic effects of both systems are about the same in terms of general performance and pain relief. On the other hand, PCR TKA might not be able to improve knee mechanics and proprioception. Which is better, PCR or PS TKA? It depends on the surgeon's skill, the patient's structure, and their real needs.[65]

PCL Retaining TKA in Specific Patient Populations

PCL has unique advantages and disadvantages to different patient populations. Particular issues for rural communities, effects in patients with severe varus deformity and flexion contractures, and factors connected to age will all be thoroughly investigated.

Age-Related Considerations

When deciding if PCL retaining TKA is right for you and what results to anticipate, age is a major consideration. As people become older, their bone density and muscle mass naturally decline, which might make joint replacement treatments more challenging for them. The durability and steadiness of the implant may be impacted by these factors. Nevertheless, PCL retention may be more advantageous for younger patients because of the higher quality of their tissues and the possibility of more natural knee kinematics. Before deciding to keep the cruciate, it is important to check for age-related changes, including degeneration, in the PCL to make sure it is still intact. [79]

Outcomes with Significant VD

One special difficulty with TKA is dealing with patients who have substantial VD. Because of their superior stability in extreme deformity instances, PS designs have traditionally been used. Recent research, however, has shown that individuals with varus deformity may have PCL retaining TKA done successfully with meticulous preoperative planning and surgical technique, leading to alignment and function results that are acceptable. Making ensuring the retained PCL doesn't cause more instability while also achieving the right balance of soft tissues is crucial.[80]

Outcomes with Flexion Contractures

Due to their impact on range of motion and alignment, flexion contractures may make TKA a lot more difficult to perform. Because the knee's mechanics are changed when flexion contractures are present, PCL retention may be difficult. Despite this, research has shown that PCL maintaining TKA is still a possibility with the right surgical procedures, such as the right soft tissue releases. These patients may experience improved postoperative outcomes, provided the contractures are addressed adequately during surgery.[81]

Rural Populations and Special Considerations

When it concerns healthcare, particularly TKA, rural communities have distinct obstacles. Factors such as distance from healthcare facilities, socioeconomic status, and availability of specialized care can influence the outcomes of joint replacement surgeries. For rural patients, PCL retaining TKA offers the advantage of potentially quicker recovery times and fewer follow-up visits, which are beneficial given the logistical challenges they face. Tailored rehabilitation programs that consider the rural context can further enhance recovery and patient satisfaction.[82]

Figure 34: Anteroposterior radiographs of knees with the Genesis II PCR implant (left) and posterior cruciate-substituting implant (right)[83]

Outcome Measurement Tools for TKA

In evaluating the functional outcomes of PCR TKA in advanced-stage OA, several validated outcome measurement tools are essential. These instruments not only help in comparing study outcomes, but they also provide light on how successful the surgical intervention was.

KSS

One common method for gauging KA's efficacy is the KSS. The KSS has been revised to make it more accurate and useful. It was originally established by the Knee Society.

A patient satisfaction component is now a part of the updated KSS, making it more thorough. It is a strong instrument for research and clinical use, since validation tests proved its responsiveness and dependability..[84]

WOMAC Index

The WOMAC index consists of 24 questions in total, with three subscales that measure activity level, stiffness, and discomfort. Because of its temporal sensitivity, the WOMAC is a great instrument for evaluating the efficacy of OA treatments. Multiple studies have shown its reliability and validity, and it is often used in conjunction with other metrics to provide a whole picture of patient outcomes. [85]

Other Relevant Outcome Measures

- **SF-36:** An overall well-being questionnaires, SF-36 evaluates eight aspects of QOL, including both physical as well as mental wellness. It is useful in capturing the broader impact of KA on a patient's overall health.
- **OKS**: The OKS is a 12-question assessment tool that was created with KA patients in mind; its primary foci are pain and physical function. Validation across several populations has been conducted, and it is easy to administer.
- **VAS**: One simple method of pain quantification is the visual analog scale (VAS), which lets patients rate their discomfort on a scale from 0 to 100. It is often used in conjunction with other tools to provide a quick assessment of pain levels.[86]

Correlation between Different Outcome Measures

Correlations between these outcome measures can provide insights into their interrelationships and the comprehensive assessment of patient outcomes. For instance, studies have shown correlations between the KSS and WOMAC scores, indicating that improvements in clinical measures often align with patient-reported outcomes. The SF-36, while broader in scope, can correlate with disease-specific measures like the WOMAC and OKS, highlighting the interconnectedness between general health and disease-specific impacts.[87]

Perioperative Management and Rehabilitation in TKA

Preoperative Assessment and Optimization

Preoperative assessment is crucial for identifying and optimizing modifiable risk factors that could impact surgical outcomes. A comprehensive evaluation includes assessing comorbidities, nutritional status, and psychosocial factors. Optimization protocols focus on controlling diabetes, managing hypertension, and addressing obesity, as these conditions can affect recovery and increase complication risks. Getting patients ready for surgery and getting them to follow through with their plans after surgery both need preoperative education, which includes setting realistic goals.[88]

Surgical Approach and Technique for PCL Retention

During TKA, the PCL is carefully kept in place so that the knee can keep moving naturally. Careful planning of the tibial cut and PCL balance are two important methods. Because the PCL is so important for the support and function of the joint, surgeons must be extra careful not to damage it during the procedure. Because of improvements in surgery, like the use of specialized tools and supports, PCL retention is now more accurate, which leads to better results for patients.[89]

Postoperative Care Protocols

Effective postpartum care plans aim to reduce problems as much as possible and speed up the mending process. Pain relief, preventing venous thromboembolism, and getting people moving again quickly are all standard parts of these kinds of programs. A lot of people use acetaminophen, NSAIDs, and local anaesthetics together. This is called multimodal analgesia. The goals of early movement are to lower the risk of pain and improve functional healing. Physical therapy may help with these goals. Patients and their families should get a lot of information about what to expect after surgery and any problems that might come up.[90]

Rehabilitation Strategies and Their Impact on Outcomes

Rehabilitation is a very important part of figuring out how well a total knee surgery will work. The goals of some of these workouts are to improve efficiency, restore ROM, and build muscle. Getting better after surgery can begin right away and last for months. It is very important to do balance skills, walking training, and other physical exercises. Individualized therapy programs that are tailored to each patient's needs and goals lead to higher levels of patient happiness and better functional outcomes. Getting psychological help can help you get better faster and may improve things like your drive and resilience.[91]

Complications of PCR TKA

Early problems often show up as instability, especially if the PCL isn't properly tightened or gets hurt during surgery. This could make you feel bad and make it hard to do things in the days after surgery.

If PCL retention changes the biomechanics, it could lead to late problems like polyethylene wearing out and becoming loose. PCL avulsion fractures that happen during surgery could also cause weakness and the need for more surgery.[92]

Management of Complications

To deal with problems in PCR TKA, you need to take a broad method. Things will not get worse if you catch them early and do something about it. Physical therapy and support might be the first things that are used to help movement problems. If the patient has a lot of mechanical failure or instability, the surgeon may need to change the form of the implant or make changes to the patient. If you have PCL avulsion, you may need surgery to reattach the ligament or make it bigger.[93]

Revision Rates and Causes

PCR TKA correction rates are usually pretty low, but they can go up in a number of situations. Surgery is often needed because of problems like infection, broken parts, or weakness. When it comes to valgus abnormalities, the PCL might not be stable enough. Studies show that the correction rate for PCR TKA designs is a bit higher than for PS designs. Long-term follow-up studies show that about 0.4% of cases are changed every year. [84]The main reason for this is uncertainty

Strategies to Improve Outcomes and Reduce Complications

The main things that need to be looked at to improve the effects of PCR TKA are the surgical method and the choice of patient. By making sure the patient is properly centered and balanced, you can cut down on problems that could happen during surgery. During surgery, the doctors should know how to check the PCL's stability and put the right amount of stress on it.[94]

Recent Advances and Future Directions in PCR TKA

CAS and Navigation

CAS in TKA provides enhanced precision in implant positioning and alignment. By utilizing real-time feedback and three-dimensional imaging, CAS helps surgeons achieve optimal component placement, potentially reducing the risk of malalignment and improving functional outcomes. Although the initial cost of CAS is higher, studies indicate that the prolonged benefits concerning alignment accuracy and reduced revision rates justify its use in complex cases. The integration of robotic systems further advances the precision of TKA, offering personalized surgical plans based on the patient's anatomy.[95]

PSI

PSI entails making individual surgical instructions that are tailored to each patient's specific framework. This approach aims to improve alignment accuracy and reduce surgical time. PSI uses preoperative imaging to develop cutting blocks tailored to the individual, potentially increasing implant longevity and patient satisfaction. However, despite its promise, some studies suggest that PSI does not significantly outperform traditional methods in terms of alignment and functional outcomes. Future research may focus on refining PSI techniques to enhance their efficacy.[96]

Advanced Bearing Surfaces

Advancements in bearing surfaces aim to reduce wear and extend the lifespan of knee implants. New materials are polyethylene and oxidized zirconium, offer improved resistance to wear compared to traditional materials. These innovations are crucial for younger, more active patients who place greater demands on their implants. By minimizing wear, advanced bearing surfaces contribute to lower revision rates and enhanced long-term outcomes. [97]

Emerging Research on PCL Retention Techniques

These days, researchers are trying to come up with novel approaches to retaining the PCL after TKA. A more stable and also effective preserved PCL is achieved by using the balanced gap approach, and it also entails meticulously adjusting the gaps for bending and extension. The possibility that preserving both the ACL and PCL can enhance knee mechanics and patient satisfaction is also being considered by specialists. These revisions demonstrate the ongoing effort to improve PCL retention strategies to accommodate all TKA patients.[98]

Relevant articles assessing the management of primary OA by PCR KA

1. This study compared CR with PS TKA over a brief period of time. The study included 60 patients with advanced OA, each randomly assigned to one of two groups: CR (n=30) and PS (n=30). The KSS and WOMAC ratings were used to evaluate the outcomes at three and six months postoperatively in this study. The results revealed that both groups improved significantly; however, the PS group exhibited higher scores on flexion and KSS, whereas the CR group showed marginally higher scores on WOMAC. Researchers finally discovered that both designs had excellent results after a short follow-up period, with just minor differences in terms of medical outcomes..[99]
2. This study conducted a prospective, randomized trial by comparing PS versus PCR TKA. The study included patients with advanced OA receiving either CR or PS implants. Outcome measures included knee flexion and patient satisfaction scores. Results showed PS implants achieved better flexion (average 7° improvement) than CR implants, but surprisingly, this did not translate to improved patient satisfaction scores between groups. Researchers concluded that despite technical advantages in flexion with PS designs, patient satisfaction remains comparable between both implant types.[100]

3. The study carried out this match-pair comparative study and investigated CR versus PS TKA in OA samples. The researchers matched patients based on demographics and deformity severity. Outcomes were measured using KSS, OKS, and ROM assessments. Results demonstrated comparable functional outcomes between CR and PS groups at short follow-up. The study concluded that CR implants can be effectively used even in cases of severe varus deformity in Asian populations, challenging the conventional preference for PS implants in severe deformities.[9]
4. The study compared PCR TKA versus PS TKA specifically in OA patients. The CR group contained 45 knees, whereas the PS group had 42. The results were evaluated by using radiographic measures, KSS, and WOMAC. With no statistically noteworthy distinctions between groups, both groups demonstrated considerable gains in functional ratings at the mean 52-month follow-up. Researchers concluded that CR prostheses provide comparable results to PS designs even in severe varus deformity cases.[101]
5. This study conducted intermediate-term comparison study and evaluated CR versus PS TKA. The study included 76 knees (39 CR, 37 PS) followed for a minimum of 5 years. Outcomes assessed included knee function scores, ROM, and radiographic outcomes. Both clinical ratings and client happiness were not significantly different among groups. The PS group demonstrated slightly better deep flexion capabilities. The researchers

concluded that both implant designs provide comparable functional outcomes with OA patients.[4]

6. Study carried out this prospective study and examined early outcomes of PCR primary TKA in Indian OA patients. 32 patients with OA underwent CR TKA. Outcomes were assessed using KSS and WOMAC. Results showed significant improvement in both score systems, with mean KSS improving from 32.5 to 82.9 at 6 months. Researchers concluded that CR TKA provides excellent early functional outcomes in Indian patients with OA.[11]
7. The study carried out this prospective, randomized study and compared functional outcome and ROM between high-flexion posterior cruciate-retaining and high-flexion posterior cruciate-substituting total knee prostheses. The study included 138 patients (250 knees) with advanced OA randomized to either CR or PS high-flexion designs. Outcomes were measured using KSS, WOMAC, and ROM assessments. Results showed comparable improvements in KSS and WOMAC scores between groups, but PS knees achieved better mean flexion. The researchers concluded both designs provide excellent functional outcomes at short-term follow-up.[7]
8. This study did a review and examined the outcomes and indications for PCR TKA. The authors conducted a comprehensive literature review incorporating numerous studies comparing CR and PS designs. The review highlighted that CR designs demonstrate comparable functional outcomes

to PS designs using KSS and WOMAC metrics. The authors emphasized that CR designs provide advantages including preservation of proprioception, more natural kinematics, and bone conservation. They concluded that CR TKA remains an excellent option for most patients with primary OA who have functional PCL.[5]

9. This study investigated outcomes of PCL-retaining primary TKA. The prospective study included 70 knees with advanced OA treated with CR TKA. Outcomes were assessed using KSS and WOMAC scores at preoperative, 3 months, and 6 months postoperatively. Results demonstrated significant improvement in functional scores, with mean KSS improving from 34.7 to 85.2 at 6 months. The researchers concluded that CR TKA provides excellent short-term functional outcomes and is a reliable option for treating advanced OA.[102]
10. This study compared PCR versus PS prostheses for primary TKA in OA. The analysis included 28 randomized controlled trials with 4,121 participants. Outcome measures included KSS, WOMAC, ROM, and complications. Results showed PS implants provided marginally better flexion and KSS scores, while CR implants demonstrated slightly better WOMAC scores and lower complication rates. The authors concluded that while minor differences exist, both implant types provide good functional outcomes for OA patients.[12]

11. Study conducted in chapter of "Primary TKA" reviewed PCR TKA outcomes. The authors analysed numerous studies comparing CR TKA outcomes using standardized metrics including KSS and WOMAC. The review emphasized that CR designs maintain proprioception and stability while demonstrating excellent functional outcomes in appropriate candidates. ROM typically improves from preoperative values of 90-100° to postoperative values of 110-115°. The authors concluded that CR TKA remains an excellent option for patients with intact PCL and provides functional outcomes comparable to PS designs in most OA cases.[8]
12. This study compared PS versus PCR for TKA. The analysis included 12 systematic reviews with over 5,000 TKA procedures. Outcome measures included KSS, WOMAC, ROM, and complications. Results indicated PS implants provided marginally better ROM (2-3°) than CR designs, but similar functional scores. The authors identified moderate methodological quality across reviews and concluded that while PS designs may offer slight advantages in flexion, both implant types provide comparable functional outcomes for most OA patients.[13]
13. This study conducted a three-armed, blinded, RCT comparing PCR, anterior-stabilized, and PS TKA designs in 146 patients with 2-year follow-up. Using comprehensive assessment including KOOS, OKS, Forgotten Joint Score, and radiographic evaluation, they documented no significant differences in any patient-reported outcome measures between

designs. All groups showed substantial improvements from baseline in pain, function, and satisfaction metrics. The investigators concluded that all three design philosophies provide equivalent short-term patient-reported outcomes, challenging the presumed functional advantages of specific stabilization strategies. This methodologically rigorous randomized trial provided high-quality comparative effectiveness evidence regarding PCL management options, incorporating contemporary patient-centered outcome measures most relevant to clinical decision-making.[77]

14. This study evaluated benefits of PCR TKA specifically in 46 OA knee with severe varus deformity (>10°). With mean follow-up of 11.5 years, they documented significant improvements in KSS (from W42.3 to 90.1) and functional scores (from 48.5 to 87.2). ROM improved from 119.7° to 124.3°, with excellent deformity correction (mean HKA angle improvement from 169.4° to 179.3°). The investigators noticed PCR TKA provides excellent long-term functional outcomes and durability in severe varus deformity when appropriate surgical technique ensures adequate soft tissue balancing. This focused long-term study directly addressed the controversial application of PCR designs in significant varus deformity, providing compelling evidence supporting their efficacy in this challenging scenario.[80]
15. This study conducted a systematic review and meta-analysis comparing long-term survival of PCR versus PS TKA across 14 studies with 3,448

TKAs. Their analysis demonstrated superior 10-year survival rates for PCR designs (94.7%) compared to PS designs (91.8%), with relative risk of 0.50 favoring PCR (p=0.0004). While functional outcomes showed no significant differences, PCR designs demonstrated fewer revision surgeries, particularly for aseptic loosening and polyethylene wear. The investigators attributed these findings to reduced bone resection, lower polyethylene stresses, and more physiologic kinematics with PCR designs. They concluded that PCR TKA offers superior long-term durability with equivalent functional outcomes, supporting its preferential utilization when anatomically appropriate. This comprehensive evidence synthesis provided important long-term comparative effectiveness data regarding PCL management strategies.[78]

16. This study evaluated short-term outcomes of bicruciate-retaining TKA with personalized alignment in 33 patients. Using this novel technique designed to preserve both cruciate ligaments with PSI, they documented significant improvements in KSS (from 52.9 to 93.9) and functional scores (from 52.5 to 90.3). ROM improved from 123° to 131°, with no instances of postoperative instability. Radiographic analysis confirmed appropriate restoration of native knee geometry and alignment. The investigators concluded that this advanced PCL preservation strategy combined with personalized alignment offers excellent short-term functional outcomes with enhanced physiologic kinematics. This study represented an evolution

in PCL preservation techniques beyond conventional PCR TKA approaches.[103]

17. The study compared 230 TKAs (115 PCR vs. 115 PS) using OKS and ROM with mean follow-up of 32 months. Their results demonstrated no significant differences in postoperative OKS between designs (38.2 PCR vs. 38.0 PS). While PS knees showed marginally greater flexion (118.7° vs. 115.4°), this difference fell below clinical significance thresholds. Radiographic analysis revealed equivalent component positioning and alignment. The investigators concluded that both designs offer comparable medium-term functional outcomes, suggesting implant selection should prioritize individual patient factors and surgeon experience rather than presumed functional advantages of either design. This well-matched comparative study with substantial sample size provided relevant outcomes data using validated patient-reported measures.[76]
18. The study specifically in OA knee with VD. With mean follow-up of 51.2 months, they documented comparable improvements in KSS (PCR: 40.1 to 84.7; PS: 38.3 to 86.2) and WOMAC scores between groups. Both designs achieved similar correction of mechanical alignment and showed equivalent ROM improvements. Complication and revision rates showed no significant differences. The investigators concluded that PCR designs, when properly executed, provide equivalent functional outcomes to PS designs in severe varus deformity, challenging conventional assumptions

about PCR limitations in significant deformity. This focused comparative study addressed an important clinical scenario where PCL management remains particularly controversial, providing evidence supporting PCR viability in carefully selected severe varus cases.[101]

19. This study investigated PCL preservation techniques during tibial preparation in 25 PCR TKAs. Using modified surgical techniques including conservative tibial resection, sloped tibial cuts, and PCL recession when necessary, they documented complete PCL preservation in all cases with no instances of postoperative PCL insufficiency at minimum 2-year follow-up. Mean postoperative flexion achieved was 118°, with excellent functional scores and stability testing. Radiographic analysis confirmed appropriate component positioning despite the modified techniques. The researchers thought about it for a long time and decided that protecting the PCL during tibial preparation is very important for a good PCR TKA. They also gave specific technology instructions on how to help protect PCL. This technical study looked at important surgical issues for surgeons using PCR designs in order to improve PCL performance.[89]

MATERIALS AND METHODS

Study Design and Study Setting

This investigation employed a prospective observational study design and it was conducted at R.L. Jalappa Hospital and Research Centre.

Study Period

From May 2023 to October 2024

Inclusion Criteria

(1) Diagnosis of primary OA of the knee with varus deformity.

(2) Age greater than 50 years

(3) Radiographic evidence of KL grade 3 or 4 OA

(4) Fixed flexion deformity not exceeding 20 degrees

(5) Intact posterior cruciate and collateral ligaments confirmed during preoperative assessment.

Exclusion Criteria

(1) Evidence of active joint sepsis

(2) Valgus knee deformity

(3) Previous HTO

(4) Ipsilateral old fracture altering mechanical axis

(5) Secondary OA

(6) Inflammatory OA

(7) Neuromuscular disorders affecting lower extremity function.

(8) Charcot's joint.

Sample Size Estimation

This sample size was calculated using cochrane’s estimatiob of proportion formula. Based on the prevalence of successful functional outcomes following PCR TKA reported by Dash et al. (2018) in their study of 66 Indian patients (p=0.85), and employing an absolute precision of 15%, the minimum required sample size was calculated as 19.55 patients, rounded to 20 participants.[11] This calculation is consistent with similar methodological approaches in comparable studies, including those by A GB et al. (2017), who utilized a sample size of 42 patients, and Benbarka et al. (2024), whose meta-analysis included randomized controlled trials with comparable per-arm sample sizes.[12,102]

Sampling Method

Consecutive sampling technique was employed, wherein all patients presenting to the orthopaedic outpatient department with advanced knee OA during the study period were screened against the inclusion and exclusion criteria. This non-probability sampling method was selected for its practicality in the clinical setting while minimizing selection bias through systematic patient screening.

Data Collection Procedure

Comprehensive demographic data was collected preoperatively, including age, sex, occupation, height, weight, and body mass index (BMI). Clinical assessment documented symptomatology (pain, stiffness, difficulty squatting, cross-legged sitting), presence of varus deformity, fixed flexion deformity, and ROM. Radiographic evaluation included anteroposterior, lateral, and skyline views, with OA severity classified according to the KL grading system. Preoperative laboratory investigations encompassed complete blood count, erythrocyte sedimentation rate, coagulation profile, blood urea, serum creatinine, random blood sugar, and serological testing for HIV and hepatitis B, supplemented by electrocardiography for surgical risk stratification.

All patients underwent PCR TKA utilizing a medial parapatellar approach under combined spinal and epidural anesthesia. Surgical parameters recorded included operative duration, anesthetic technique, intraoperative findings, and implant characteristics. Postoperative radiographs were obtained from 3rd to 5th day , and all patients initiated full weight-bearing mobilization with walker assistance according to a standardized rehabilitation protocol. Wound inspection and dressing changes were performed on the third postoperative day, with standardized antibiotic prophylaxis (intravenous for 5 days, followed by oral antibiotics for 7 days). Hospitalization duration was documented for all participants.

Follow-up assessments were conducted at 1, 3, and 6 months postoperatively, documenting ROM, KSS, and WOMAC scores at each interval. Radiographic evaluation at these time points included anteroposterior and lateral views to assess component positioning and alignment. Any complications or adverse events were systematically recorded throughout the follow-up period.

Assessment Tools

The Knee Society Score:

It was utilized as the primary objective outcome measure, evaluating both knee-specific parameters (pain, stability, ROM) and functional capabilities (walking, stair climbing). This validated instrument has demonstrated excellent reliability and validity in TKA outcome assessment across diverse populations. The KSS incorporates both clinician-measured parameters and functional assessment, providing comprehensive evaluation of postoperative recovery.[4,83]

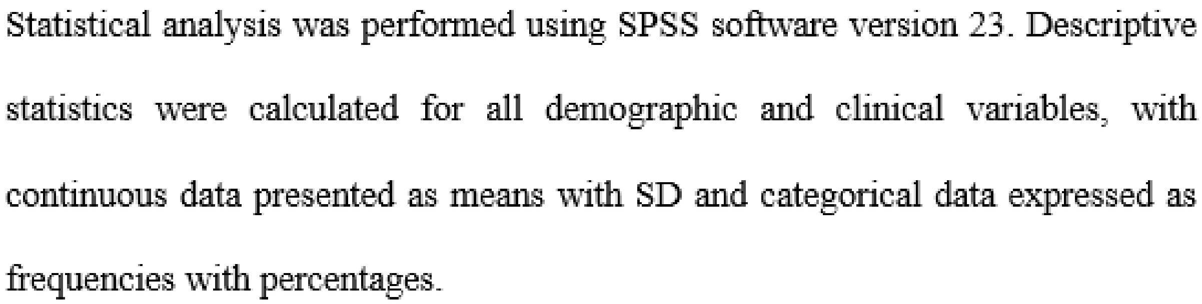
WOMAC

It was employed as the primary patient-reported outcome measure, assessing pain, stiffness, and physical function from the patient's perspective. This extensively validated instrument has demonstrated robust psychometric properties in OA research, with established minimal clinically important difference thresholds.[77,87] The WOMAC's focus on activities of daily living makes it particularly relevant for evaluating functional improvements in rural populations with specific occupational demands.

ROM:

The measurement was performed using standard goniometric technique following established protocols to ensure measurement reliability. The KL grading system was utilized for radiographic classification of OA severity, representing the gold standard for radiological assessment in knee OA.[9,80]

Data Analysis



Statistical analysis was performed using SPSS software version 23. Descriptive statistics were calculated for all demographic and clinical variables, with continuous data presented as means with SD and categorical data expressed as frequencies with percentages.

Longitudinal analysis of KSS and WOMAC scores employed paired t-tests to evaluate changes between sequential assessment intervals and between baseline and final follow-up (baseline to 6 months). To ensure statistical rigor and account of several comparisons, the threshold of statistically significant differences was established at $p<0.001$. The mean differences in KSS and WOMAC scores between assessment intervals were calculated with corresponding t-statistics and p-values.

RESULTS

Table 2: Age distribution

Age in years		
Mean		66.00
Median		66.50
Std. Deviation		6.966
Percentiles	25	63.25
	50	66.50
	75	70.00

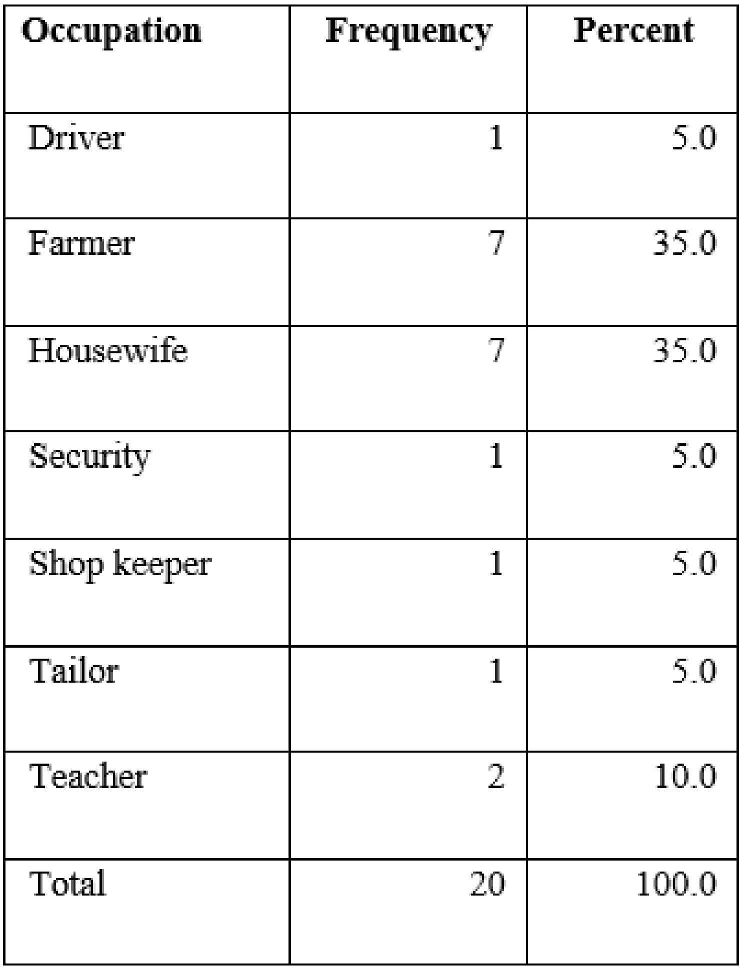
The demographic analysis revealed a mean age of 66.00 years (SD ±6.97) with a median of 66.50 years. The 25th and 75th percentiles were 63.25 and 70.00 years, respectively, indicating a predominantly elderly cohort.

***Table 3:* BMI distribution**

Body Mass Index		
Mean		24.80
Median		24.50
Std. Deviation		1.881
Percentiles	25	23.25
	50	24.50
	75	26.00

The body mass index (BMI) assessment demonstrated a mean of 24.80 kg/m² (SD ±1.88) with a median of 24.50 kg/m². The 25th and 75th percentile values for BMI were 23.25 and 26.00 kg/m², respectively, suggesting most patients were within the normal to overweight range.

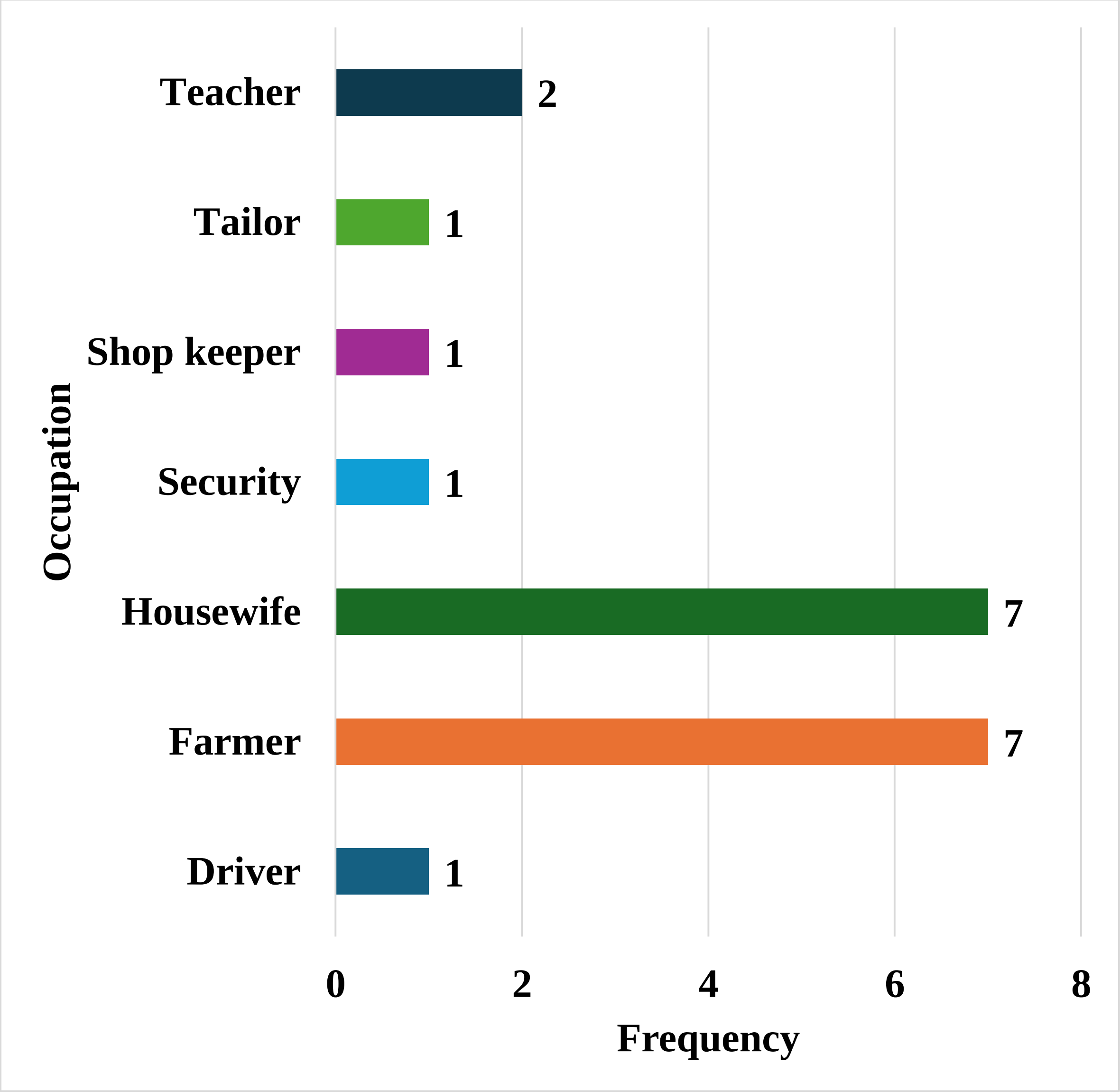
Table 4: Occupational Distribution of Patients



Occupation	Frequency	Percent
Driver	1	5.0
Farmer	7	35.0
Housewife	7	35.0
Security	1	5.0
Shop keeper	1	5.0
Tailor	1	5.0
Teacher	2	10.0
Total	20	100.0

The occupational distribution demonstrated that farmers and housewives constituted the majority of the study population, each accounting for 7 patients (35.0%). Teachers represented 2 patients (10.0%), while occupations including driver, security personnel, shopkeeper, and tailor each contributed 1 patient (5.0%) to the study cohort.

Figure 35: Occupational Distribution of Patients



With respect to symptoms, all 20 patients had pain, stiffness, difficulty to squat and sitting cross leg.

***Table 5:* Distribution of KL Grading of OA**

KL severity grading	Frequency	Percent
Grade 3	7	35.0
Grade 4	13	65.0
Total	20	100.0

The majority, 13 patients (65.0%), were classified as grade 4, representing the most severe radiographic manifestation of OA. The remaining 7 patients (35.0%) were classified as grade 3, indicating moderate to severe disease.

Figure 36: Distribution of KL Grading of OA

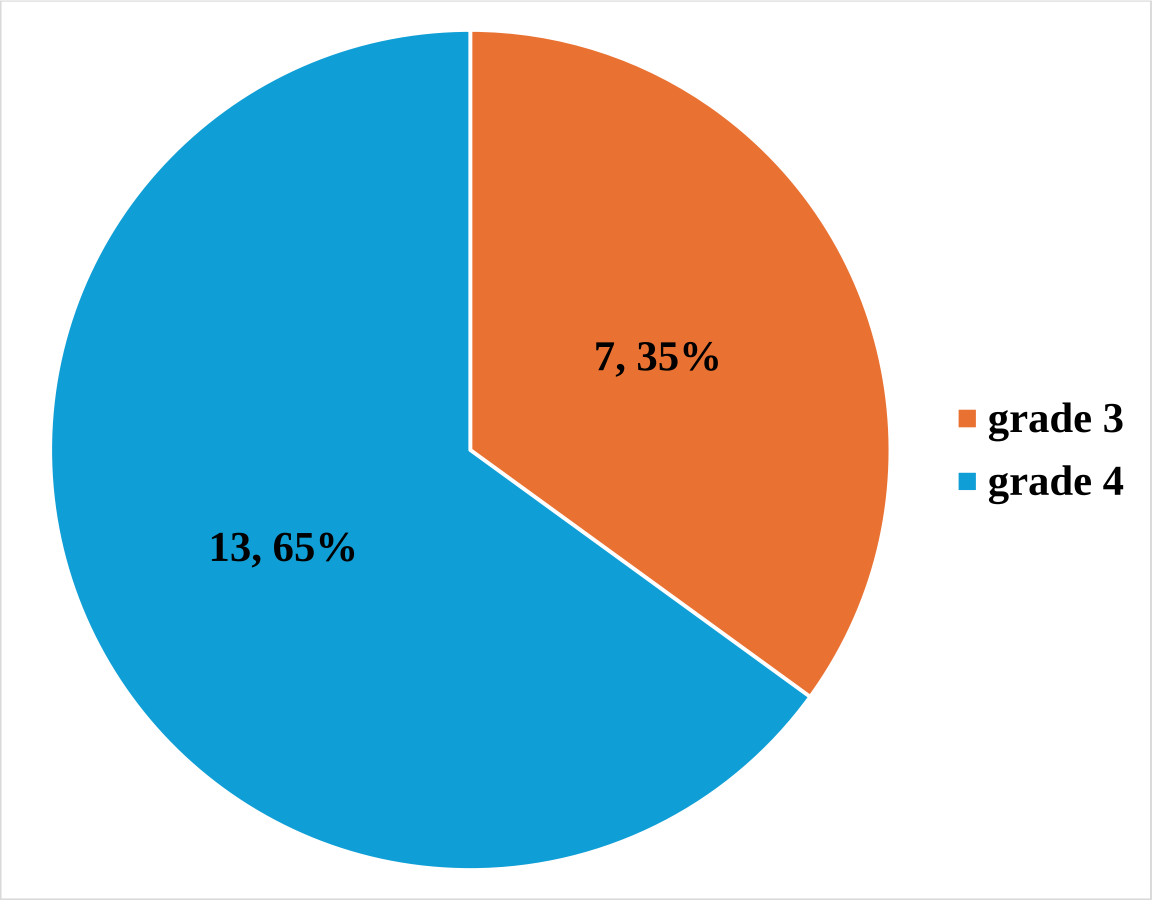


***Table 6:* Prevalence of Varus Deformity**

Varus deformity	**Frequency**	**Percent**
Absent	0	0.0
Present	20	100.0
Total	20	100.0

Varus deformity was present in 20 patients (100.0%), demonstrating the high prevalence of this deformity in advanced OA.

Figure 37: Prevalence of Varus Deformity

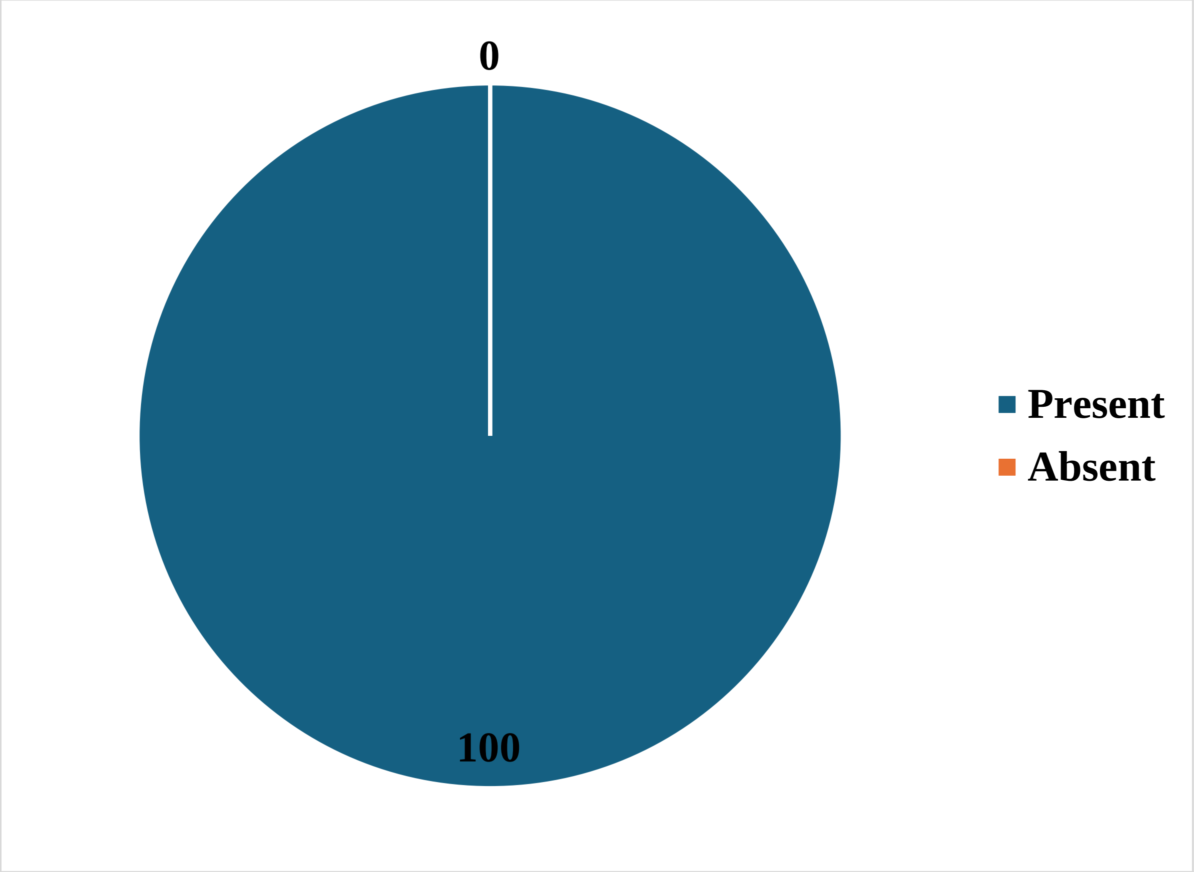


Table 7: Prevalence of Varus Fixed Flexion Deformity

Fixed flexion deformity	Frequency	Percent
Absent	16	80.0
Present	4	20.0
Total	20	100.0

Fixed flexion deformity was less common, present in only 4 patients (20.0%) and absent in 16 patients (80.0%).

Figure 38: Prevalence of Varus Fixed Flexion Deformity

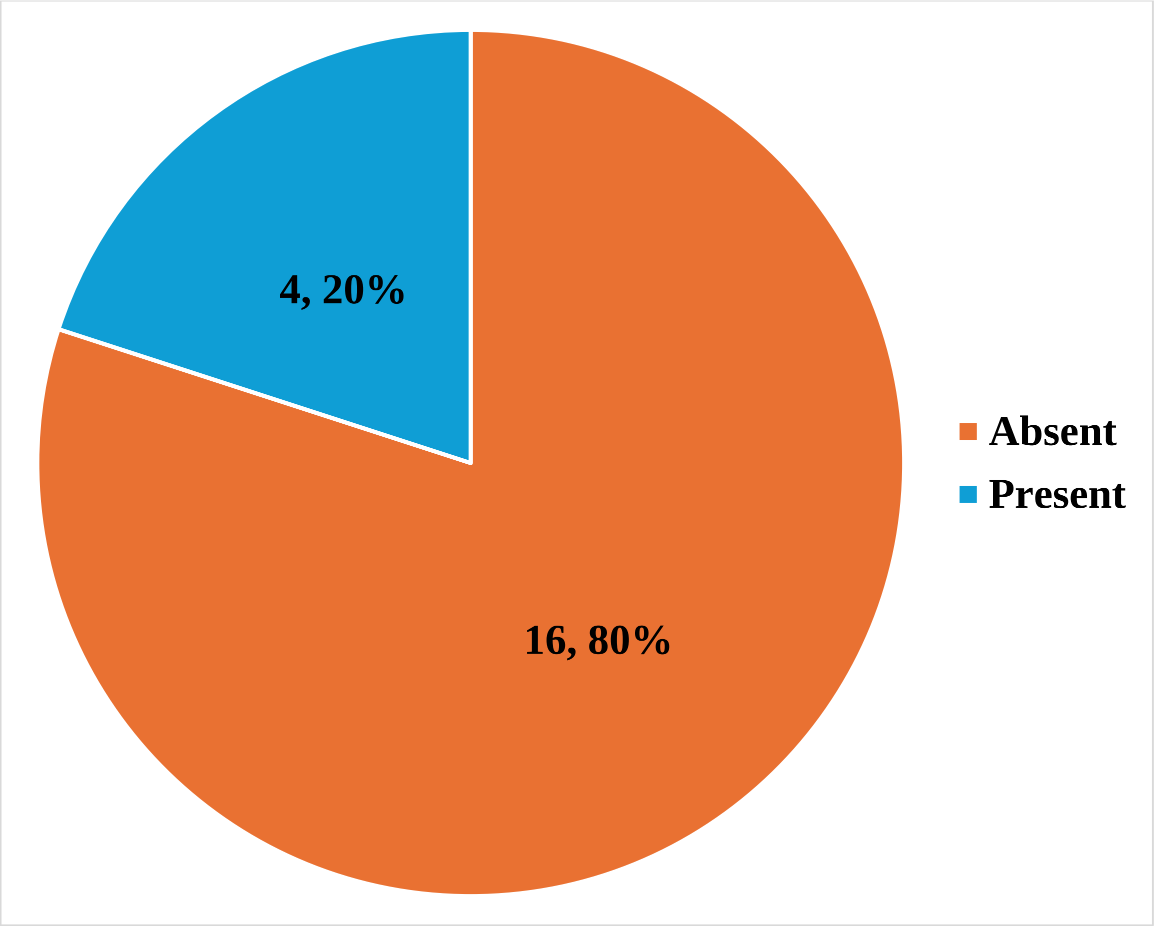


*Table 8: **Measures of duration of surgery***

Duration of surgery in minutes		
Mean		177.00
Median		180.00
Std. Deviation		17.577
Percentiles	25	170.00
	50	180.00
	75	187.50

Surgical procedures lasted for a mean duration of 177.00 minutes (SD ±17.58) with a median of 180.00 minutes. The interquartile range spanned from 170.00 minutes (25th percentile) to 187.50 minutes (75th percentile), reflecting relatively consistent operative times.

With respect to surgical intervention characteristics,

- All patients had PCR KA with Medial parapatellar approach.
- Everyone had SA + Epidural anesthesia during surgery.
- All patients had Intact posterior cruciate and collateral ligaments.
- Nil complications were noted in all 20 patients.

Table 9: Measures of duration of hospitalization

Duration of hospital stay		
Mean		10.25
Median		10.00
Std. Deviation		3.447
Percentiles	25	7.00
	50	10.00
	75	14.00

The mean hospital stay was 10.25 days (SD ±3.45) with a median of 10.00 days. The 25th and 75th percentiles for hospitalization duration were 7.00 and 14.00 days, respectively, indicating some variability in post-operative recovery time.

Table 10: ROM at Baseline and Follow-up Periods

Baseline ROM	**Frequency**	**Percent**
0-100	3	15.0
0-105	1	5.0
0-110	5	25.0
0-120	1	5.0
0-70	3	15.0
0-90	4	20.0
15-80	1	5.0
20-100	1	5.0
20-70	1	5.0
Total	20	100.0

The ROM was evaluated at baseline and during follow-up visits at 1, 3, and 6 months post-operatively. At baseline, patients exhibited variable ROM patterns, with the most common being 0-110° in 5 patients (25.0%), followed by 0-90° in 4 patients (20.0%). Other baseline ROM measurements included 0-70° in 3 patients (15.0%), 0-100° in 3 patients (15.0%), 0-120° in 1 patient (5.0%), 0-105°

in 1 patient (5.0%), 15-80° in 1 patient (5.0%), 20-100° in 1 patient (5.0%), and 20-70° in 1 patient (5.0%).

Table 11: ***ROM at 1 month post-operatively***

1 month ROM	**Frequency**	**Percent**
0-100	8	40.0
0-105	2	10.0
0-110	4	20.0
0-115	2	10.0
0-90	4	20.0
Total	20	100.0

At 1-month follow-up, improvements in ROM were observed with 8 patients (40.0%) achieving 0-100°, 4 patients (20.0%) achieving 0-110°, 4 patients (20.0%) achieving 0-90°, 2 patients (10.0%) achieving 0-105°, and 2 patients (10.0%) achieving 0-115°.

*Table 12: **ROM at 3 months post-operatively***

3 months ROM	**Frequency**	**Percent**
0-100	7	35.0
0-105	3	15.0
0-110	6	30.0
0-115	4	20.0
Total	20	100.0

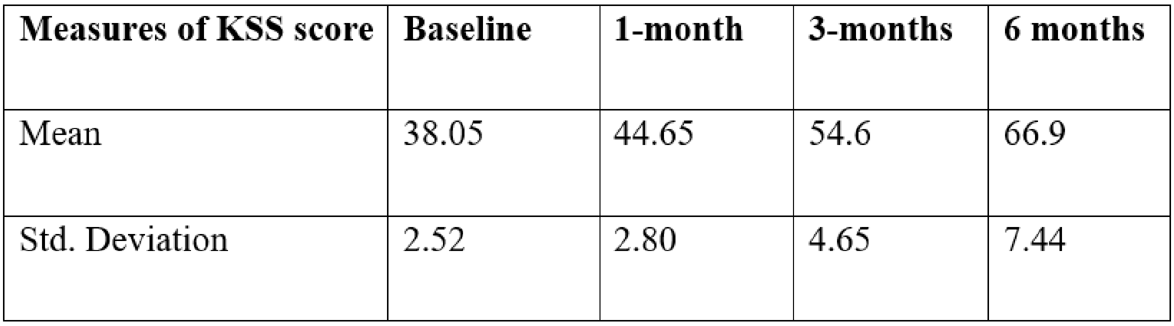
By the 3-month follow-up, further improvement was noted with 7 patients (35.0%) achieving 0-100°, 6 patients (30.0%) achieving 0-110°, 4 patients (20.0%) achieving 0-115°, and 3 patients (15.0%) achieving 0-105°.

***Table 13:* ROM at 6 months post-operatively**

6 months ROM	**Frequency**	**Percent**
0-110	1	5.0
0-115	5	25.0
0-120	8	40.0
0-125	6	30.0
Total	20	100.0

The 6-month follow-up demonstrated the most substantial improvements in ROM, with 8 patients (40.0%) achieving 0-120°, 6 patients (30.0%) achieving 0-125°, 5 patients (25.0%) achieving 0-115°, and 1 patient (5.0%) achieving 0-110°. This progressive improvement in ROM across follow-up intervals indicates the functional success of the surgical intervention.

Table 14: KSS Evaluation at Baseline and Follow-up Periods



Measures of KSS score	**Baseline**	**1-month**	**3-months**	**6 months**
Mean	38.05	44.65	54.6	66.9
Std. Deviation	2.52	2.80	4.65	7.44

In the long-term study using the KSS, functional status improved. The average scores went up from 38.05 (SD ±2.52) at the start of the study to 66.9 (SD ±7.44) after six months, showing a 75.8% increase in function. For one month (44.65, SD ±2.80) and three months (54.6, SD ±4.65), the results showed a steady rise in healing. But as the follow-up time went on, the standard deviation numbers went up, which meant that the results for each patient were less consistent.

Figure 39: KSS Evaluation at Baseline and Follow-up Periods

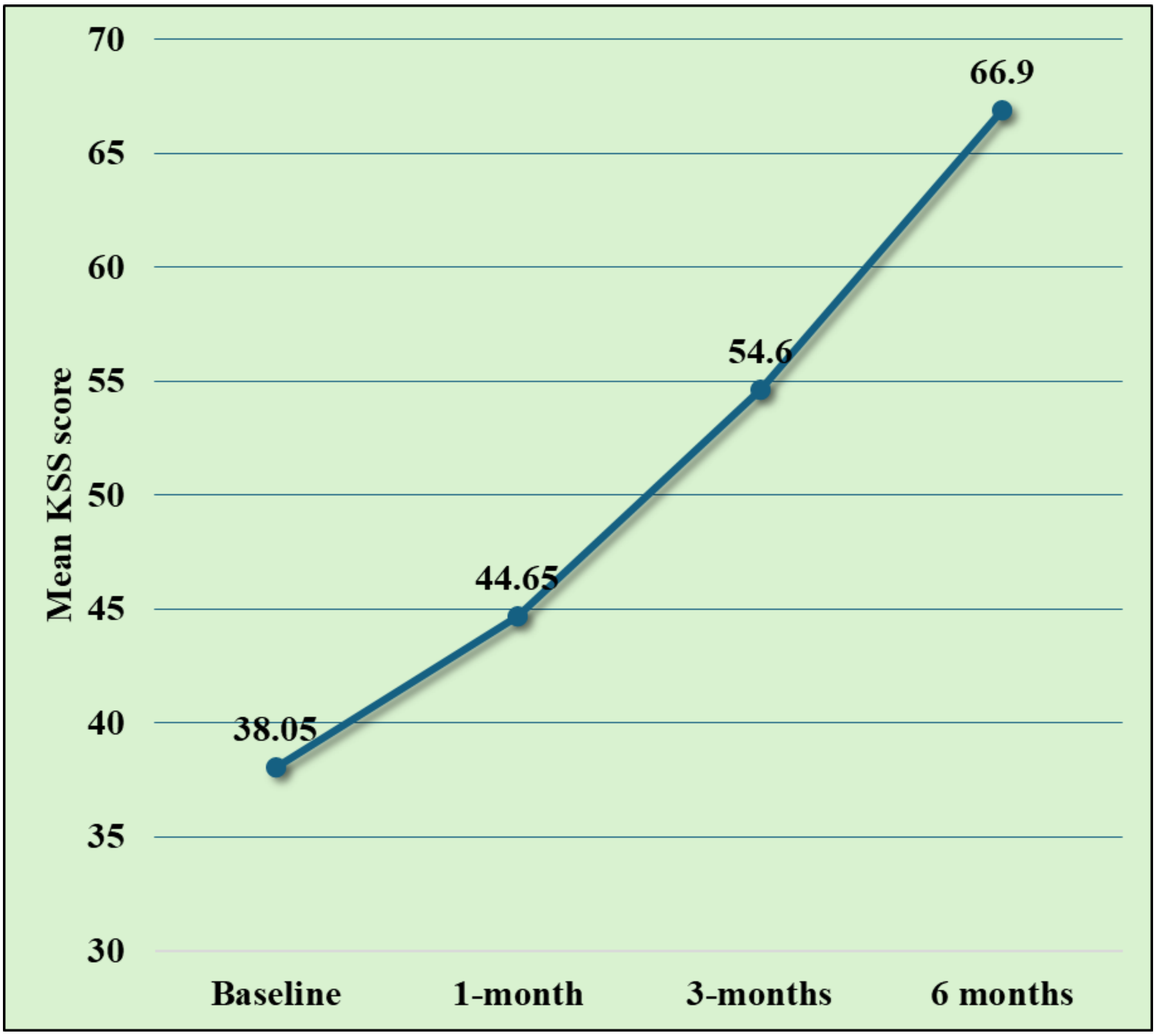
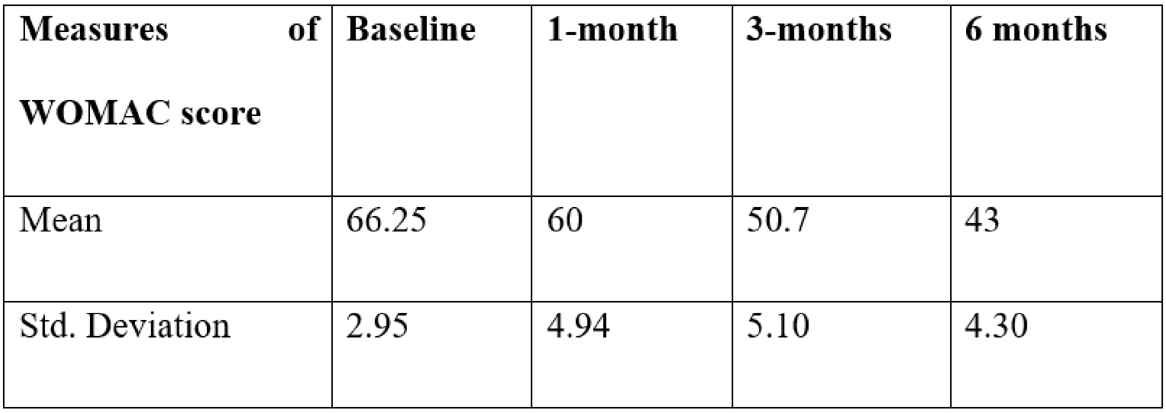


Table 15: WOMAC at Baseline and Follow-up visits



Measures of WOMAC score	Baseline	1-month	3-months	6 months
Mean	66.25	60	50.7	43
Std. Deviation	2.95	4.94	5.10	4.30

The mean baseline WOMAC score was 66.25 (SD ±2.95), indicating substantial symptom burden and functional limitation. A consistent reduction in WOMAC scores was observed throughout the follow-up period, with means of 60.00 (SD ±4.94) at 1-month, 50.70 (SD ±5.10) at 3-months, and 43.00 (SD ±4.30) at 6-months post-operatively. This decreasing trend in WOMAC scores corroborates the functional benefits derived from the surgical intervention.

Figure 40: WOMAC at Baseline and Follow-up Periods

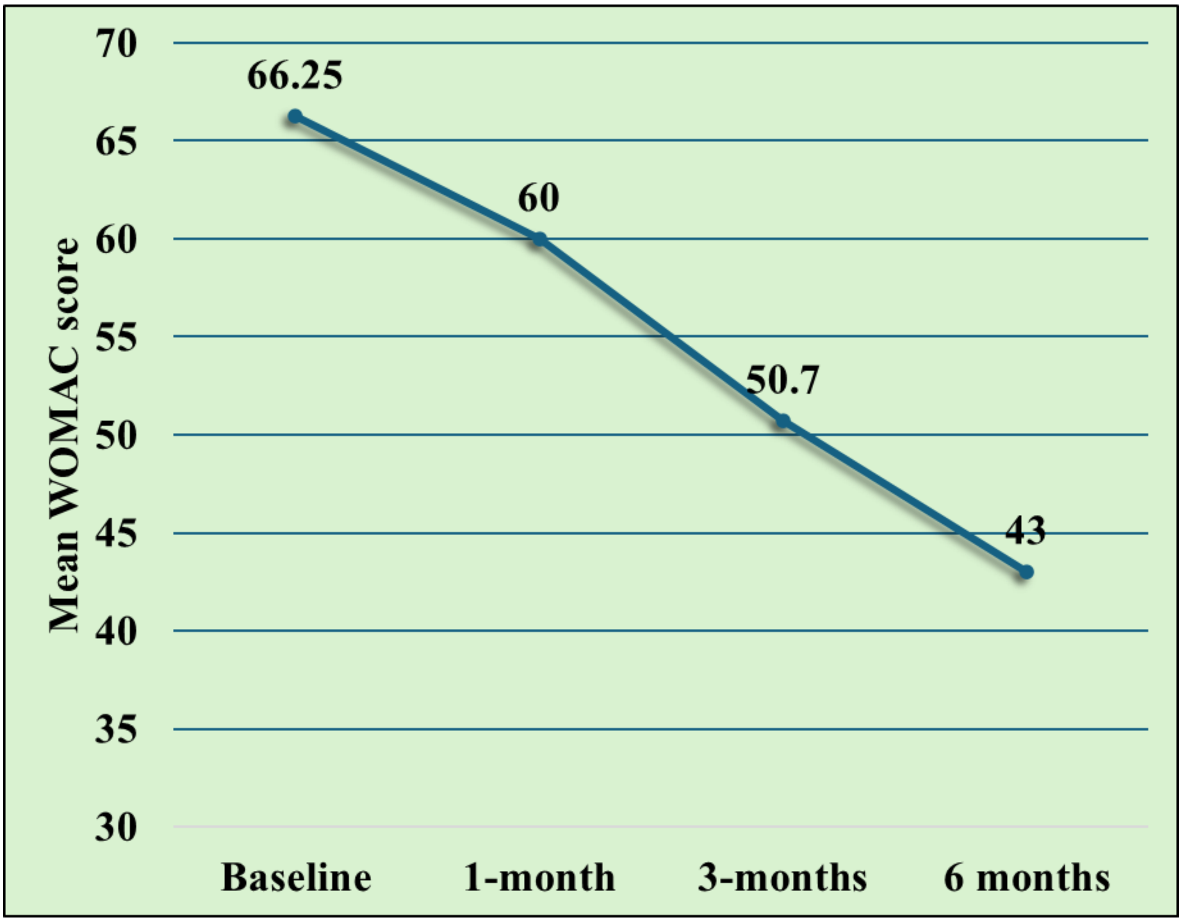
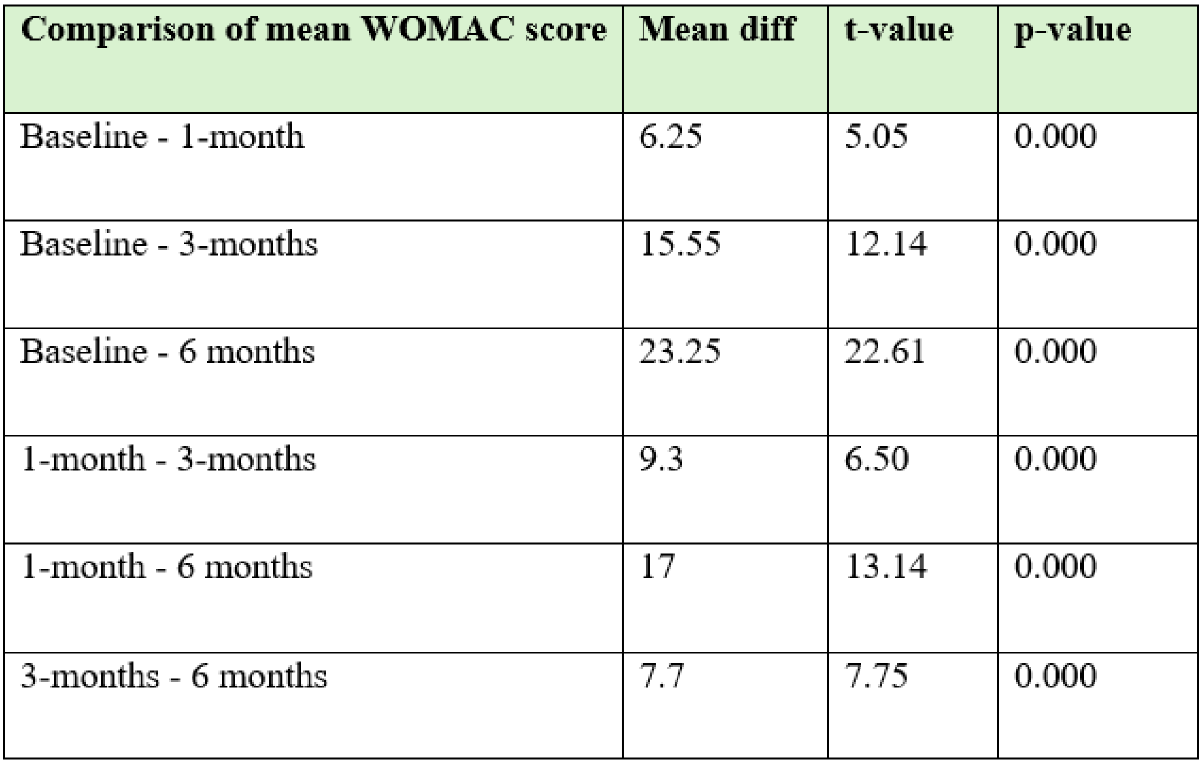


Table 16: Statistical Analysis of Knee Society Score Changes Between Follow-up Periods

Comparison of mean KSS score	**Mean diff**	**t-value**	**p-value**
Baseline - 1-month	-6.600	-10.619	0.000
Baseline - 3-months	-16.550	-14.898	0.000
Baseline - 6 months	-28.850	-16.164	0.000
1-month - 3-months	-9.950	-8.103	0.000
1-month - 6 months	-22.250	-11.104	0.000
3-months - 6 months	-12.300	-10.077	0.000

The mean difference between baseline and 1-month follow-up was -6.600 (t=-10.619, p<0.001). Between baseline and 3-months, the mean difference increased to -16.550 (t=-14.898, p<0.001), and between baseline and 6-months, the difference further increased to -28.850 (t=-16.164, p<0.001). Significant improvements were also observed between successive follow-up intervals: 1-month to 3-months (-9.950, t=-8.103, p<0.001), 1-month to 6-months (-22.250, t=-11.104, p<0.001), and 3-months to 6-months (-12.300, t=-10.077, p<0.001). These findings demonstrate progressive, statistically significant functional improvement throughout the post-operative period.

Table 17: Statistical Analysis of WOMAC Score Changes Between Follow-up visits



Comparison of mean WOMAC score	**Mean diff**	**t-value**	**p-value**
Baseline - 1-month	6.25	5.05	0.000
Baseline - 3-months	15.55	12.14	0.000
Baseline - 6 months	23.25	22.61	0.000
1-month - 3-months	9.3	6.50	0.000
1-month - 6 months	17	13.14	0.000
3-months - 6 months	7.7	7.75	0.000

Significant improvements were also observed between successive follow-up intervals: 1-month to 3-months (9.30, t=6.50, $p<0.001$), 1-month to 6-months (17.00, t=13.14, $p<0.001$), and 3-months to 6-months (7.70, t=7.75, $p<0.001$). These results confirm the progressive symptomatic and functional improvement as reported by patients themselves following PCR KA.

DISCUSSION

The current prospective observational study looked at how well PCR KA worked for people in rural areas who had severe OA. According to the KSS and WOMAC tests, there were statistically significant increases in both quantitative and subjective functional measures at all follow-up times. These results give us important information about how well PCR TKA works for treating severe OA, especially in a rural Indian community

Demographic and Clinical Characteristics

The demographics of our group showed that the average age was 66.0 ± 6.97 years, which is about the same as what other studies have found. Dash et al. (2018) looked at 66 Indian patients who were getting PCR TKA and found that the average age was 65.3 years. Girisha B. et al. (2017) looked at 42 patients and found that the average age was 64.1 years. The average BMI in our study was 24.80 ± 1.88 kg/m², which means that most of the patients were in the normal to overweight range. This is a little different from Western countries, where TKA candidates are more likely to be overweight.[11,102] Farmers and women made up 70% of our group, which shows that most of the people in the study came from rural areas. This adds a new demographic factor that isn't usually found in previous research.

Radiologically, 65% of our patients were classified as KL grade 4, representing the most severe radiographic manifestation of OA. The preponderance of advanced OA in our cohort aligns with findings by Noh et al. (2023), who studied 46 patients with severe varus deformity, noting that most patients in rural settings typically present at advanced stages due to limited healthcare access.[80] Varus deformity was present in 100% of our patients, which is consistent with the typical pattern of knee degeneration in primary OA. This percentage is slightly higher than the 86% reported by Ünkar et al. (2017) in their study of 93 patients with severe varus deformity undergoing PCR TKA, possibly reflecting regional variations in disease presentation or patient selection criteria.[101]

The presence of fixed flexion deformity in only 20% of our patients differs from findings by Yang et al. (2023), who reported fixed flexion deformities in approximately 35% of their 124 patients.[5] This discrepancy might be attributed to variations in patient selection criteria, as our study specifically included patients with fixed flexion deformity of up to 20 degrees as per the inclusion criteria. All patients in our study exhibited common symptoms of advanced OA, including pain, stiffness, and difficulty in squatting and sitting cross-legged—functional limitations particularly relevant in the Indian cultural context, which requires these postures for many activities of daily living.

Functional Outcomes

ROM

The fact that ROM got better over time in our study is an important practical result. At the start, patients had different ranges of motion (ROM), with 0-110° being the most common in 25% of patients. At the 6-month follow-up, 40% of patients had reached 0-120° ROM and 30% had reached 0-125° ROM, which shows that they had made a lot of progress. These results are similar to those from Kim et al. (2009), who did an RCT with 50 patients who had high-flexion PCR TKA and found that their mean ROM improved from 123° before surgery to 136° at the end of the follow-up period.[7] Similarly, Kawakami et al. (2015) found that ROM improved in 76 patients who had PCR TKA, going from an average of 114° before surgery to 122° after surgery.[4]

The gradual increase in ROM seen at each follow-up visit in our study—from the first month to the third month to the sixth month—indicates a step-by-step recovery process. Cinotti and their colleagues about how important it is to protect the PCL to keep knee mechanics as well as proprioception normal. This may help explain why our group was able to achieve acceptable range of motion. [89]Their study of 25 patients showed that using the right surgery method to protect the PCL during tibial cuts led to better stable and functional results.

Knee Society Score

During the follow-up time, there were statistically significant increases in the KSS, which is an objective measure of knee function. The mean KSS at the start of the study was 38.05 ± 2.52, but it went up to 44.65 ± 2.80 after one month, 54.6 ± 4.65 after three months, and 66.9 ± 7.44 after six months. These changes are similar to what Sando et al. (2015) found in their study of 430 TKAs (215 PCR and 215 posterior-stabilized). [83]They found that the average KSS went from 42 before surgery to 85 at the end of the follow-up period. The size of the gain seen in our study shows that PCR TKA works well in this group of people.

In their 2016 study of 128 patients, Graff et al. stressed how important objective outcome measures like KSS are for judging the success of TKA. They also pointed out that these numbers often show how satisfied the patient is with the procedure.[87] In 2015, Thippanna et al. looked at PCR and PS TKA in 85 patients (40 PCR and 45 PS). They found that both designs improved KSS significantly, but PCR designs had better proprioception and "forgotten joint" scores, which suggests they were better at integrating function.[73] Our results back up these findings; the fact that the KSS got better over time shows that the functional return was better.

WOMAC Score

During the follow-up time, the WOMAC score, which is a patient-reported outcome measure, kept getting better. The mean baseline WOMAC score of

66.25 ± 2.95 decreased to 60.00 ± 4.94 at 1-month, 50.70 ± 5.10 at 3-months, and 43.00 ± 4.30 at 6-months post-operatively, with lower scores indicating reduced symptom burden and improved function. These improvements were statistically significant across all intervals ($p<0.001$). Similar trends were reported by Dash et al. (2018), who documented WOMAC score improvements from 76.84 preoperatively to 43.24 postoperatively in their cohort of 66 Indian patients.[11]

The progressive improvement in WOMAC scores reflects the patient-perceived benefits of PCR TKA. Rehman et al. (2023), in their three-armed randomized study of 146 patients comparing cruciate-retaining, anterior-stabilized, and posterior-stabilized designs, found no significant differences in patient-reported outcomes between designs, suggesting that PCR TKA can achieve comparable subjective improvements to alternative designs.[77] Our findings support this observation, with substantial WOMAC score improvements across all follow-up intervals.

Surgical Considerations and Technical Aspects

All patients in our study underwent PCR TKA using a medial parapatellar approach under spinal and epidural anaesthesia. The mean surgical duration was 177.00 ± 17.58 minutes, slightly longer than the 145 minutes reported by Bonutti et al. (2004) in their study of minimally invasive TKA in 104 patients.[57] This difference may be attributed to variations in surgical technique, surgeon experience, or the specific challenges presented by our patient population.

The mean hospital stay of 10.25 ± 3.45 days in our cohort is longer than contemporary reports from Western centres but comparable to other Indian studies. Dash et al. (2018) reported a mean hospital stay of 9.4 days in their Indian cohort, suggesting that regional healthcare practices and rehabilitation protocols influence hospitalization duration.[11] Notably, all patients in our study had intact posterior cruciate and collateral ligaments, which is a prerequisite for PCR TKA. Totlis et al. (2017) highlighted the importance of this factor in their study of 37 PCR TKAs, finding that despite careful technique, only 57% of the PCL was retained after standard tibial cuts, emphasizing the need for meticulous surgical execution.[93]

The absence of complications in our cohort contrasts with the literature, which typically reports complication rates of 1-3%. Waslewski et al. (1998) documented early instability in 2% of 179 PCR TKAs, while Scott and Volatile (1986) reported a 1.6% revision rate in 811 PCR TKAs over twelve years.[92] Our zero-complication rate, while encouraging, should be interpreted in the context of our relatively small sample size (n=20) and short follow-up period (6 months).

Comparative Analysis with Existing Literature

Abdel et al. (2011) conducted a large retrospective study of 8,117 TKAs (4,743 PCR vs. 3,374 PS) and reported superior 15-year survival rates for PCR designs (90% vs. 77%).[3] More recently, Kanna et al. (2023) performed a review of 14 studies (3,448 TKAs) and concluded that PCR TKA had better 10-year survival than PS TKA.[78] While our 6-month follow-up cannot address long-term durability, the excellent short-term functional outcomes observed in our cohort are consistent with these reports.

In terms of functional outcomes, our results corroborate findings from multiple comparative studies. Li et al. (2014) conducted a meta-analysis of 1,114 TKAs across 14 randomized controlled trials and found no significant differences in KSS between PCR and PS designs, suggesting that PCR TKA can achieve comparable functional improvements to alternative designs.[65] Similarly, Verra et al. (2013) in their Cochrane review of 1,257 patients across 17 studies found no clinically relevant differences in functional outcomes between PCR and PS designs, supporting the viability of PCR TKA as a treatment option.[2]

The applicability of PCR TKA in specific clinical scenarios, such as severe varus deformity, remains debated in the literature. Ünkar et al. (2017) evaluated 93 knees with severe varus deformity and found no significant differences in functional outcomes between PCR and PS designs, while Noh et al. (2023) reported satisfactory outcomes in 46 patients with severe VD undergoing PCR TKA.[80,101] Our findings support these conclusions, as 100% of our patients presented with varus deformity and demonstrated significant functional improvements.

The suitability of PCR TKA for specific patient populations has also been explored. Archibeck et al. (2001) evaluated 531 PCR TKAs in patients with rheumatoid arthritis and reported 91% survivorship at 10 years, while Schai et al. (1999) documented good functional outcomes in 65 RA patients undergoing PCR TKA.[104,105] More recently, Bhattacharjee et al. (2025) reported favourable outcomes in patients with systemic rheumatoid arthritis undergoing PCR TKA.[106] While our study focused exclusively on primary OA, these findings suggest the broader applicability of PCR TKA across various patient populations.

Recent innovations in PCR TKA design and technique have further expanded its applications. Budhiparama et al. (2023) conducted a RCT of 100 patients comparing PCR and PS designs in medial pivot TKA and found that PCR designs were safe and effective in this context.[94] Inui et al. (2023) evaluated bicruciate-retaining TKA using personalized alignment in 33 patients and reported promising short-term results.[103] These developments suggest a continuing evolution in PCR TKA applications, with our study contributing to the evidence base for its efficacy in conventional settings.

Clinical Significance

The statistically significant improvements in objective and subjective functional parameters observed in our study have substantial clinical implications for the management of advanced OA in rural populations. The progressive enhancement in ROM, with 70% of patients achieving ROM of 0-120° or better by 6 months, directly translates to improved functional capacity for activities of daily living. This is particularly relevant in rural Indian settings, where squatting and sitting cross-legged are essential for many routine activities, including cooking, toileting, and religious practices.

The marked improvement in KSS scores, from a baseline mean of 38.05 to 66.9 at 6 months ($p<0.001$), represents a clinically meaningful enhancement in knee function. As emphasized by Graff et al. (2016) in their study of 128 TKA patients, such objective improvements often correlate with increased patient satisfaction and quality of life.[87] Similarly, the reduction in WOMAC scores from 66.25 at baseline to 43.00 at 6 months ($p<0.001$) indicates substantial alleviation of pain and functional limitations from the patient's perspective. Thippanna et al. (2015) noted in their comparative study of 85 patients that such improvements contribute to the "forgotten joint" phenomenon, where patients no longer consciously perceive limitations from their prosthetic joint.[73]

Our findings have particular relevance for surgical decision-making in resource-limited settings. The debate between PCR and PS designs often includes considerations of cost, with PS components typically being more expensive. Benbarka et al. (2024) did a review of RCTs of 2,089 patients across 16 randomized controlled trials and found no clinically significant differences in functional outcomes between designs, suggesting that the more cost-effective PCR option may be preferable in resource-constrained environments. This aligns with our observation of excellent outcomes with PCR TKA in a rural setting.[12]

The demonstrated efficacy of PCR TKA in patients with varus deformity (100% of our cohort) addresses a common clinical presentation in primary OA. Soong et al. (2021) compared 72 knees with severe varus deformity undergoing either PCR or PS TKA and found comparable functional outcomes, supporting our finding that PCR TKA is a viable option for this patient subgroup.[9] This is particularly significant in rural populations where advanced deformities are common due to delayed presentation.

From the point of view of therapy, the care given after surgery may be greatly affected by how much the patient has improved over time. The ROM, KSS, and WOMAC scores can be used to predict how long it will take to recover and plan therapy based on the small improvements seen at 1, 3, and 6 months. Wang et al. (2015) stressed these kinds of slow but steady improvements when they looked at new surgery methods for TKA.[107]

The zero-complication rate observed in our study, while potentially influenced by sample size and follow-up duration, suggests that PCR TKA can be safely performed in rural healthcare settings with appropriate surgical expertise and facilities. According to Sherif et al. (2013), who did a full study of surgeries, this is different from what people thought about how hard PCR TKA would be. [75]We can see that PCR TKA is a good choice for people with serious OA who live in rural places, as long as the patients are carefully picked and the surgery is done with great care.

Finally, PCR TKA is still used in primary TKA because it has been shown to be successful at keeping the knee's natural shape, as shown by the great functional outcomes in our group. Wünschel et al. (2013) documented differences in knee joint kinematics and forces between PCR and PS designs in their biomechanical study of 12 cadaveric specimens, finding that PCR designs more closely replicated natural knee mechanics.[72] This biomechanical advantage may contribute to the positive functional outcomes observed in our study and supports the continued clinical application of PCR TKA in appropriate candidates.

CONCLUSION

This prospective observational study provides compelling evidence supporting the efficacy of PCR TKA in managing advanced OA within a rural demographic context. The statistically significant improvements observed in objective functional parameters (KSS improved from 38.05 to 66.9, p<0.001) and patient-reported outcomes (WOMAC decreased from 66.25 to 43.00, p<0.001) demonstrate meaningful clinical benefits across all follow-up intervals. The progressive enhancement in ROM, with 70% of patients achieving 0-120° or better by 6 months, is particularly relevant for the rural population's functional requirements. These findings align with contemporary literature while addressing an important research gap regarding TKA outcomes in rural populations with unique occupational demands.

The absence of postoperative complications, while potentially influenced by sample size and follow-up duration, suggests procedural safety when appropriate patient selection criteria and surgical techniques are implemented. The demographic profile—characterized by a mean age of 66.0 years, predominantly normal-to-overweight BMI distribution, and occupational predominance of farming and household duties—provides valuable context for interpreting the functional outcomes. These results support the continued utilization of PCR TKA as a viable, effective intervention for advanced OA in rural populations.

STRENGTH OF THE STUDY

There are several things about this prospective observational study method that make it more reliable and useful. Objective (Knee Society Score) and subjective (WOMAC) result data are put together to make a complete functional rating system. This makes it possible to record both factors that were reviewed by a doctor and events that the patient described. The prospective form of the study lets researchers look closely at how functional recovery changes over time after PCR TKA, with checkpoints set at 1, 3, and 6 months. The results are also more accurate because of the strict statistical method that was used. This method includes paired t-test tests with appropriate significance limits ($p<0.001$). So that confusing factors are kept to a minimum, the study group is uniform. This is possible because patients were carefully chosen based on clear standards for admission and rejection. The study population's rural demographic description fills in a big information gap because most of the literature on PCR TKA is about people living in cities, who have different job and healthcare access needs. It might be easier to use the same study method in similar clinical settings if the surgery process, pre-operative treatment plans, and post-operative recovery plans are carefully documented.

RECOMMENDATIONS

Future research should incorporate larger sample sizes with multicentred recruitment to enhance statistical power and generalizability. Extended follow-up protocols (minimum 2-5 years) would permit evaluation of mid-term to long-term outcomes, including implant survivorship and maintenance of functional improvements. Implementation of randomized controlled trial methodologies comparing PCR TKA with alternative designs (posterior-stabilized, medial-pivot) within similar demographic contexts would provide higher-level evidence regarding comparative efficacy. Incorporation of additional outcome measures—including quality of life assessments, patient satisfaction indices, and advanced biomechanical analyses—would provide more comprehensive evaluation frameworks. Development of rural-specific rehabilitation protocols addressing unique occupational demands of agricultural workers is warranted based on the demographic profile identified. Future studies should also implement independent, blinded outcome assessments to mitigate observer bias. Finally, cost-effectiveness analyses comparing PCR TKA with alternative designs in resource-constrained rural healthcare settings would provide valuable information for healthcare policy formulation and resource allocation, particularly in developing economies with significant rural populations requiring TKA interventions.

SUMMARY

This prospective observational study evaluated the functional outcomes of PCR TKA in 20 patients with advanced OA from rural backgrounds. The cohort comprised predominantly elderly individuals (mean age 66.0 ± 6.97 years) with normal-to-overweight BMI distribution (mean 24.80 ± 1.88 kg/m^2). Occupationally, farmers and housewives constituted 70% of the study population, reflecting the rural demographic context. Radiologically, 65% of patients were classified as KL grade 4, representing severe OA, while 35% presented with grade 3 disease. Varus deformity was observed in 100% of patients, and fixed flexion deformity in 20%.

All patients underwent PCR TKA via medial parapatellar approach under spinal and epidural anesthesia. The mean surgical duration was 177.00 ± 17.58 minutes, with an average hospital stay of 10.25 ± 3.45 days. All patients had intact posterior cruciate and collateral ligaments preoperatively, and no complications were reported during the 6-month follow-up period.

Functional outcomes were assessed using objective (KSS) and subjective (WOMAC) measures at 1, 3, and 6 months postoperatively. ROM exhibited progressive improvement, with baseline measurements showing variability (most common being 0-110° in 25% of patients). By 6 months postoperatively, 40% of patients achieved 0-120° ROM, and 30% achieved 0-125° ROM, demonstrating substantial functional recovery.

The KSS demonstrated statistically significant improvements across all time points. The mean baseline score of 38.05 ± 2.52 improved to 44.65 ± 2.80 at 1 month, 54.6 ± 4.65 at 3 months, and 66.9 ± 7.44 at 6 months postoperatively. Paired t-test analysis revealed statistically significant differences between all assessment intervals ($p<0.001$), with progressive improvement throughout the follow-up period. The mean difference between baseline and 6-month KSS was substantial at 28.85 points ($t=-16.164$, $p<0.001$).

Similarly, WOMAC scores showed consistent improvement, with decreasing values indicating reduced symptom burden and enhanced function. The mean baseline WOMAC of 66.25 ± 2.95 decreased to 60.00 ± 4.94 at 1 month, 50.70 ± 5.10 at 3 months, and 43.00 ± 4.30 at 6 months. Paired t-test analysis demonstrated statistically significant improvements between all assessment intervals ($p<0.001$). The mean difference between baseline and 6-month WOMAC was 23.25 points ($t=22.61$, $p<0.001$).

These findings align with existing literature supporting PCR TKA efficacy while addressing a research gap regarding outcomes in rural populations. The substantial improvements in both objective and subjective functional parameters demonstrate the clinical effectiveness of PCR TKA in managing advanced OA within this demographic context. The progressive nature of functional recovery across follow-up intervals provides valuable insights into expected rehabilitation trajectories.

The results have particular relevance for resource-constrained healthcare settings, as PCR TKA generally represents a more cost-effective option compared to alternative designs while achieving comparable functional improvements. The demonstrated efficacy in patients with varus deformity (100% of the cohort) addresses a common clinical presentation in primary OA, especially in rural populations where advanced deformities are prevalent due to delayed healthcare access.

The absence of complications, while potentially influenced by sample size and follow-up duration, suggests that PCR TKA can be safely performed in rural healthcare settings with appropriate surgical expertise. The excellent functional outcomes observed, particularly the ROM improvements facilitating activities requiring deep flexion (common in rural daily activities), support the continued utilization of PCR TKA as a viable intervention for advanced OA in rural populations when appropriate patient selection criteria and surgical techniques are implemented.

LIMITATION

Several methodological constraints warrant consideration when interpreting the study findings. The relatively modest sample size limits statistical power and increases the potential for type II errors, particularly in subgroup analyses. The follow-up duration of six months, while sufficient for assessing early functional recovery, precludes evaluation of mid-term to long-term outcomes, including implant survivorship, which typically requires minimum 2 to 5 year follow-up. The single-centre design may introduce institutional bias, potentially limiting the generalizability of findings to other healthcare settings with different surgical expertise, perioperative protocols, or rehabilitation resources. The absence of a comparison group (such as posterior-stabilized TKA) prevents direct comparative efficacy assessment between implant designs. Additionally, the zero-complication rate observed is potentially attributable to the limited sample size and follow-up duration rather than inherent procedural safety. The study's focus on clinical and radiological outcomes without corresponding analysis of patient satisfaction metrics or quality of life measures represents another limitation. Finally, the potential for observer bias exists, as the postoperative assessments were not explicitly described as being conducted by independent evaluators blinded to preoperative status, which could potentially influence objective outcome measurements, particularly in the KSS assessments.

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