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Efficacy, Safety, and Functional Impact of Total Knee Arthroplasty in the Treatment of Unilateral Knee Osteoarthritis: A Systematic Review

[1] Andrei Machado Viegas da Trindade, [2] Mateus Santiago de Souza, [3] Higor Antonio Araujo Brito, [4] Daniel de Castro Silva, [5] Káren Araújo Rodrigues, [6] Camilla da Rocha Rezende, [7] Marco Antônio da Silva Neres, [8] Victor Vilarinho Vieira, [9] Rebecca Gomes Moura Bastos, [10] Marcos Vinícius Amorim Silva, [11] Helder Rocha da Silva Araújo, [12] Fernanda Grazielle da Silva Azevedo Nora

[1] Department of Orthopedics and Traumatology, HMAP - Hospital Municipal de Aparecida de Goiânia, Aparecida de Goiânia, Goiás, Brazil

[2, 3, 4] Department of Orthopedics and Traumatology, HUWC - Hospital Universitário Walter Cantídio, Fortaleza, Ceará, Brazil

[5] Department of Orthopedics and Traumatology, HUGO - Hospital de Urgência de Goiânia, Goiânia, Goiás, Brazil

[6, 7, 8] Department of Orthopedics and Traumatology, Hospital Regional do Gama, Gama, Distrito Federal, Brazil

[9, 10] Department of Orthopedics and Traumatology, IOG - Instituto Ortopédico de Goiânia, Goiânia, Goiás, Brazil

[11] Department of Orthopedics and Traumatology, HC/UFG - Hospital das Clínicas, Universidade Federal de Goiás, Goiânia, Goiás, Brazil

[12] LAM – Movement Architecture Laboratory, UFG - Universidade Federal de Goiás, Goiânia, Goiás, Brazil, Avenida Esperança s/n, Campus Samambaia, Goiânia, Goiás, Brazil

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Abstract

Objective

To conduct a systematic review of the scientific literature to evaluate the efficacy, safety, and functional impact of total knee arthroplasty (TKA) in the treatment of unilateral knee osteoarthritis. The review aims to synthesize evidence on pain reduction, improvements in quality of life, restoration of functional capacity, return to daily activities, and to discuss current surgical indication criteria and clinical implications in patients with isolated joint degeneration.

Methods

This review followed PRISMA guidelines and included studies published between January 2000 and May 2025, identified through searches in PubMed/MEDLINE, Scopus, Web of Science, and Embase. Eligible studies were randomized controlled trials, cohort studies, observational studies, and systematic reviews involving patients undergoing TKA for unilateral knee osteoarthritis. Data extraction was performed using a standardized protocol. Thematic synthesis was organized into three domains: (1) functional outcomes and safety in elderly patients, (2) ligament preservation and biomechanical considerations, and (3) fixation strategies in complex surgical scenarios. Risk of bias was assessed using RoB 2.0, NOS, and AMSTAR 2 tools.

Results

Thirty studies met the inclusion criteria. Evidence indicates that TKA provides significant improvements in pain relief, functional recovery, and quality of life in patients with unilateral knee OA, including those over 75 years of age. Age alone was not associated with increased complication rates. Cementless implants showed promising fixation outcomes in select elderly populations. Ligament-preserving techniques, especially PCL-retaining approaches, were associated with enhanced proprioception and biomechanical integrity. In complex cases, metaphyseal fixation with porous-coated components and patient-specific strategies improved implant stability and long-term outcomes.

Conclusion

Total knee arthroplasty is a safe and effective surgical option for the treatment of unilateral knee osteoarthritis. The procedure yields substantial functional and quality-of-life benefits when applied using individualized surgical planning, appropriate prosthesis selection, and evidence-based rehabilitation. Advanced age should not be considered a contraindication. Future research should aim to standardize fixation criteria and expand data on long-term outcomes in specific subgroups.

Keywords: Total knee Arthroplasty, Unilateral Osteoarthritis, Ligament Preservation, Elderly Patients, Implant Fixation

1. Introduction

Knee osteoarthritis (OA) is a progressive, degenerative joint disorder characterized by articular cartilage degradation, subchondral bone remodeling, osteophyte formation, and synovial inflammation. It is a leading cause of chronic pain and functional decline, particularly in older adults, with unilateral presentation being the most common initial pattern. Unilateral

knee OA poses a significant clinical challenge, often resulting in asymmetric loading, altered gait biomechanics, and a progressive decline in quality of life. As global demographics shift toward an aging population, surgical interventions such as total knee arthroplasty (TKA) have become increasingly integral in managing advanced diseases.

TKA is currently regarded as the gold-standard surgical procedure for patients with end-stage OA refractory to conservative management. Its efficacy in reducing pain, correcting deformity, restoring function, and improving quality of life has been extensively validated across diverse patient populations. Historically, age-related factors such as frailty and comorbidities limited the application of TKA in elderly individuals. However, recent evidence has challenged this paradigm, demonstrating that advanced age alone is not a contraindication to surgery [1].

Leung *et al*. [1], in a prospective study involving patients over 80 years of age undergoing fast-track TKA, reported substantial improvements in postoperative mobility and pain control, with complication rates analogous to those in younger cohorts. These findings support the notion that chronological age, in isolation, should not exclude patients from surgical candidacy, provided that perioperative risk is appropriately managed.

Goh *et al*. [2] investigated the use of cementless TKA in patients older than 75 years, a demographic previously considered unsuitable for uncemented fixation due to presumed poor bone quality. Their findings demonstrated comparable implant survivorship and fixation outcomes relative to cemented alternatives, suggesting that biologic fixation is feasible and safe in select elderly individuals when combined with meticulous surgical technique and appropriate patient selection.

The viability of cementless techniques in older adults is supported by advancements in implant surface technology. Schwabe and Hannon [3] detailed the evolution of porous and hydroxyapatite-coated implants, which facilitate osseointegration and enhance primary and long-term fixation. These innovations are particularly beneficial in cases with preserved metaphyseal bone stock, even among elderly patients, and may reduce the risk of aseptic loosening.

Nonetheless, the decision to perform TKA in elderly patients must account for individualized risk stratification, including comorbidities, physiological reserve, and bone integrity. McInnis *et al*. [4] highlighted that while bilateral TKA in elderly populations is associated with increased perioperative cardiopulmonary risk, it may offer benefits in selected patients when conducted under strict perioperative protocols, reducing cumulative recovery time and overall resource utilization.

Christensen *et al*. [5] emphasized that surgical outcomes in elderly patients are more closely associated with the precision of technique and implant selection than with age itself. Their work supports the use of modern noncemented designs in appropriately indicated cases, demonstrating that technical execution plays a pivotal role in achieving durable clinical outcomes.

Technological advances have further enabled individualized approaches to TKA. Brinkmann and Fitz [6] discussed the clinical application of custom-made implants and patient-specific instrumentation, which enhance component alignment, optimize ligament balance, and reduce intraoperative adjustments. These innovations are particularly valuable in patients with complex anatomical deformities or degenerative alterations of the joint.

From a primary care perspective, accurate timing of referral for TKA is essential to avoid delayed surgical intervention and associated deterioration in joint function. Van Manen *et al*. [7] stressed that TKA should be considered after exhaustion of conservative modalities, including weight management, pharmacologic therapy, and structured rehabilitation. Appropriate timing of surgery is associated with improved outcomes and reduced risk of progression to complex arthroplasty.

Preoperative functional evaluation is crucial for determining surgical suitability and guiding intraoperative strategy. Williams *et al*. [8] argued that functional limitations, ligament integrity, and mechanical alignment are more predictive of postoperative outcomes than chronological age alone. Comprehensive assessment informs implant selection and allows for better anticipation of surgical challenges.

The role of postoperative rehabilitation is central to optimizing recovery, particularly in geriatric patients. Alsayed *et al*. [9] highlighted the importance of standardized rehabilitation protocols, early mobilization, and multidisciplinary management in reducing complication rates and enhancing long-term functional recovery. These principles are fundamental for restoring autonomy and preventing institutionalization in elderly individuals.

Epidemiologically, the global demand for primary TKA continues to rise, paralleling increases in life expectancy and the prevalence of OA. Thomsen *et al*. [10] reported a marked growth in primary TKA procedures in Denmark between 1997 and 2013, with projections indicating a commensurate increase in future revision surgeries. These data highlight the necessity for durable, evidence-based primary interventions to mitigate long-term burden.

A growing body of literature has focused on the preservation of native ligamentous structures—particularly the posterior cruciate ligament (PCL) and, in some cases, the anterior cruciate ligament (ACL) to enhance biomechanical fidelity in TKA. Sabatini *et al*. [11] reviewed the potential benefits of bicruciate-retaining prostheses, which aim to maintain natural joint kinematics and proprioception, thereby improving functional outcomes.

Tateishi [12] emphasized that ligament preservation is particularly advantageous in early-stage OA, where native soft tissue structures remain intact. By maintaining PCL function, these techniques reduce the need for mechanical constraint and allow for more physiologic load transfer through the joint. This approach may be especially beneficial in active elderly patients seeking to maintain high levels of mobility.

Saragaglia *et al*. [13] corroborated these findings by demonstrating that unconstrained and semiconstrained prosthetic designs, when combined with preserved ligament function, promote superior rotational stability and flexion-extension balance. Their biomechanical data suggest that ligament-sparing approaches may improve patient satisfaction and long-term joint function.

Technological innovations have facilitated these strategies through tools such as patient-specific instrumentation. Brinkmann and Fitz [14] noted that PSI allows for more accurate ligament balancing and component positioning, leading to better reproducibility and reduced intraoperative variability. Such precision is essential in achieving optimal

outcomes, particularly in patients with complex anatomy or previous deformity.

Beyond biomechanical and clinical considerations, ligament preservation also intersects with broader ethical principles in surgical decision-making. Tsuboi [15], in his address to the World Medical Association, underscored the importance of preserving patient autonomy and maximizing postoperative independence. The maintenance of native anatomy whenever feasible aligns with the ethical

This study aims to conduct a systematic review of scientific literature on the efficacy, safety, and functional outcomes of total knee arthroplasty (TKA) in the treatment of unilateral knee osteoarthritis. Specifically, it seeks to identify the most robust evidence related to pain relief, functional capacity, quality of life improvement, and return to activities of daily living. Furthermore, the review explores current surgical indication criteria and the clinical implications of TKA in patients with isolated joint compromise.

2. Methodology

2.1 Study Design and Objectives

This systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The objective was to synthesize and critically evaluate the scientific evidence on the effectiveness, safety, and functional outcomes of total knee arthroplasty (TKA) in the management of unilateral knee osteoarthritis, particularly among elderly populations and in complex surgical scenarios. Specific focus was given to outcomes such as pain reduction, improvement in functional capacity, return to daily activities, surgical indications, ligament preservation strategies, and fixation methods.

2.2 Eligibility Criteria

To ensure methodological rigor and consistency in the selection of studies, clear inclusion and exclusion criteria were established prior to the literature search. Eligible studies were those published between January 2000 and May 2025, written in either English and peer reviewed. The review considered a wide range of study designs, including randomized controlled trials, prospective or retrospective cohort studies, observational studies, and systematic reviews. Only studies involving patients undergoing total knee arthroplasty (TKA) for the treatment of unilateral knee osteoarthritis were included. Furthermore, studies were required to report at least one of the primary outcomes of interest, namely: Functional recovery, pain reduction, improvements in quality of life, postoperative complications, fixation methods, use of ligament preservation strategies, or criteria for surgical indication.

On the other hand, studies were excluded if they focused solely on bilateral knee osteoarthritis and did not present separate data for unilateral cases. Also excluded were animal studies, *in vitro* experiments, and secondary literature such as narrative reviews, editorials, letters to the editor, case reports, and conference abstracts. Additionally, articles were not considered if the full text was not accessible or if they lacked sufficient methodological detail to allow for quality assessment and data extraction. These criteria ensured that the review focused exclusively on high-quality, clinically relevant, and methodologically sound publications.

2.3 Information Sources and Search Strategy

The literature search for this systematic review was conducted between February and May 2025, encompassing the four major biomedical databases: PubMed/MEDLINE, Scopus, Web of Science, and Embase. These databases were selected due to their broad indexing of clinical, surgical, and orthopedic journals, thereby ensuring comprehensive coverage of the topic.

To optimize the retrieval of relevant studies, the search strategy combined controlled vocabulary terms (MeSH terms) with free-text keywords, tailored to the indexing system of each database. The primary search syntax included the following terms: *("Total Knee Arthroplasty" OR "TKA" OR "Knee Replacement") AND ("Unilateral" OR "One-sided") AND ("Osteoarthritis" OR "Gonarthrosis") AND ("Functional Outcomes" OR "Pain" OR "Quality of Life" OR "Fixation" OR "Implant" OR "Ligament Preservation")*. Boolean operators were used to structure the search logic and maximize sensitivity without compromising specificity.

In addition to database searches, the reference lists of all studies selected for full-text review were manually examined to identify further relevant publications that might have been missed by the electronic search strategy. This snowballing technique helped ensure that no key evidence was inadvertently excluded due to indexing limitations or differences in terminology. All retrieved references were managed using a reference manager to facilitate duplicate removal and screening workflow.

2.4 Study Selection Process

All search results obtained from the selected databases were exported to a reference management software, where duplicates were automatically identified and removed. Following this step, two independent reviewers (R1 and R2) conducted a systematic screening of the remaining records by evaluating the titles and abstracts based on the predefined eligibility criteria. Studies that appeared to meet the inclusion parameters or whose relevance was uncertain proceeded to full-text assessment.

The full texts of potentially eligible articles were read in detail by the same reviewers. Any disagreements regarding study inclusion were resolved through discussion and consensus. In cases where consensus could not be reached, a third reviewer (R3) was consulted to arbitrate and make the final decision.

From an initial pool of 1,132 records, and after the removal of duplicates and non-relevant entries, a total of 30 studies fulfilled all eligibility criteria and were included in the final qualitative synthesis. The complete study selection workflow was documented according to PRISMA guidelines and is summarized in a flow diagram (not included in this document but available upon request).

2.5 Data Extraction

Data extraction was conducted independently by two reviewers using a standardized form specifically developed for this review. This instrument ensured uniformity and completeness in the collection of relevant study characteristics and outcomes. For each included study, the following variables were systematically recorded: Name(s) of the author(s), year of publication, and country of origin; study design and sample size; population demographics

including age, sex distribution, comorbidity profiles, and clinical indication for surgery.

In addition, specific information related to the surgical procedure was extracted, including the type of total knee arthroplasty (TKA) implant used, the fixation method employed (cemented or cementless), and whether ligament preservation strategies were applied, such as posterior cruciate ligament (PCL)-retaining or bicruciate-retaining (BCR) techniques. Postoperative outcomes were documented with emphasis on pain relief, functional recovery, and quality of life indicators—measured through standardized instruments such as the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Knee injury and Osteoarthritis Outcome Score (KOOS), and the Short Form-36 (SF-36).

Additional data were collected regarding the incidence of complications and adverse events, such as infection, implant loosening, or need for revision surgery. The duration of follow-up and the main conclusions drawn by the authors were also recorded. All extracted data were subsequently cross verified between reviewers to ensure accuracy and consistency, with discrepancies resolved by consensus.

2.6 Data Synthesis and Analysis

Given the significant heterogeneity among the included studies—particularly in terms of methodological design, patient populations, types of surgical interventions, and outcome measures—a quantitative meta-analysis was deemed inappropriate. Instead, a narrative synthesis approach was adopted to systematically organize and interpret the evidence.

The analysis was structured thematically, following the core objectives of the review. The first domain focused on the functional outcomes and safety of TKA in elderly patients, synthesizing data related to perioperative risk, recovery trajectories, and age-related surgical considerations. The second domain addressed ligament preservation strategies, exploring their impact on joint biomechanics, proprioception, and long-term functional performance. The third domain analyzed fixation techniques in complex TKA, particularly in revision procedures or cases involving substantial bone loss, incorporating insights from implant design and material science.

Each thematic category integrated findings from multiple studies and contextualized them within current clinical practice, evolving surgical protocols, and advancements in implant technology. This analytical framework allowed for a comprehensive and nuanced interpretation of the literature, highlighting both areas of consensus and points of divergence across the evidence base.

2.7 Ethical Considerations

As this study involved the synthesis of data exclusively from previously published, peer-reviewed sources, without the collection or handling of individual patient data, submission to a research ethics committee was not required. The review was conducted in strict accordance with principles of academic integrity, methodological transparency, and responsible reporting. All included studies were properly cited, and their respective ethical approvals, when applicable, were respected. No new interventions, personal data, or confidential information were generated or accessed during this review.

3. Results and Discussion

Total knee arthroplasty (TKA) is widely recognized as one of the most successful orthopedic procedures for alleviating pain and restoring function in patients with advanced osteoarthritis. Its indications have progressively expanded beyond younger or middle-aged populations to include elderly and even very elderly individuals, reflecting both demographic shifts and evolving surgical techniques. The increasing longevity and functional demands of aging populations have prompted growing interest in the safety, efficacy, and long-term outcomes of TKA in patients aged 75 years and older. In parallel, advances in perioperative care, anesthetic protocols, and implant design have challenged the traditional view that age alone should limit surgical candidacy. These changes have generated an important body of literature aimed at clarifying the real risks and benefits of TKA in the geriatric population.

As clinical experience and scientific data accumulate, it has become increasingly clear that outcomes in elderly patients are influenced less by chronological age than by preoperative functional status, comorbidities, and surgical precision. This section explores the functional results and safety profiles of TKA in elderly patients, synthesizing recent evidence from prospective studies, registry analyses, and clinical trials. Key issues such as fixation method, postoperative rehabilitation, and complication management are critically examined, providing a comprehensive understanding of how modern TKA performs in this growing and clinically diverse group of patients. The discussion aims to inform surgical decision-making and contribute to the development of evidence-based protocols tailored to the needs of older adults with knee osteoarthritis.

3.1 Functional Outcomes and Safety in Elderly Patients

Total knee arthroplasty (TKA) has long been established as an effective intervention for managing end-stage osteoarthritis. In recent years, increasing attention has been directed toward evaluating its safety and efficacy in elderly populations, including octogenarians. Contrary to historical apprehensions about performing major joint replacement surgery in older adults due to presumed increased risk of complications and limited functional recovery, accumulating evidence demonstrates that age alone should not be a contraindication. Leung *et al*. [1], in a prospective cohort of patients aged over 80 years undergoing fast-track TKA, reported significant improvements in mobility and pain reduction, with postoperative complication rates comparable to those seen in younger populations.

Challenging traditional implant philosophies, Goh *et al*. [2] evaluated the outcomes of cementless TKA in patients aged over 75, a group typically considered for cemented fixation due to concerns about bone quality. Their findings revealed favorable implant survivorship, stable fixation, and no increase in revision rates, reinforcing that, with appropriate surgical technique and implant design, cementless options can be successfully applied to select elderly patients.

The biological plausibility of these findings is supported by advancements in prosthetic materials and surface coatings. Schwabe and Hannon [3] discussed the role of hydroxyapatite layers, porous titanium, and trabecular metal surfaces in promoting osseointegration, which is essential for long-term implant stability. These technologies have been particularly beneficial in elderly patients with preserved bone stock, challenging prior assumptions that aging bone cannot support biologic fixation.

Nonetheless, the potential risks of TKA in the elderly must be carefully considered, especially in bilateral procedures. McInnis *et al*. [4] highlighted that simultaneous bilateral TKA may carry increased perioperative risk—particularly for thromboembolic events and cardiopulmonary complications—yet also noted that, when performed in carefully selected patients with optimized perioperative protocols, outcomes can be highly satisfactory with reduced hospitalization times and improved cost-effectiveness.

Christensen *et al*. [5] emphasized that outcomes in elderly patients are more dependent on surgical accuracy and technique than chronological age. They demonstrated that when noncemented implants are selected appropriately and positioned precisely, the risks of aseptic loosening and early failure are minimal. This underscores the critical importance of surgical expertise and individualized implant selection in this age group.

Technological advancements have also facilitated better outcomes in the elderly with patient-specific implants. Brinkmann *et al*. [6] noted that custom-cutting guides and 3D-printed components allow for more precise alignment and soft tissue balance, particularly in patients with anatomical variations due to degenerative changes. These tools reduce the need for intraoperative adjustments and may contribute to better early function and reduced postoperative pain.

In parallel, the growing prevalence of knee osteoarthritis among aging populations demands a thoughtful approach to surgical indication. Van Manen *et al*. [7] argued that TKA in the elderly should follow the exhaustion of nonoperative management strategies, including weight management, pharmacologic therapy, and physical rehabilitation. Careful assessment of the patient's functional status and quality of life is fundamental in determining the appropriate timing for surgical intervention.

Preoperative evaluation must be comprehensive. Williams *et al*. [8] emphasized the importance of assessing gait, lower limb alignment, and ligamentous integrity, as these factors directly influence implant selection, surgical approach, and the likelihood of functional recovery. Their findings suggest that functional capacity and comorbidity burden—not age per se—are more accurate predictors of surgical success.

Postoperative care is equally important to maximize the benefits of TKA in elderly individuals. Alsayed *et al*. [9] recommended the implementation of standardized, multidisciplinary rehabilitation protocols tailored to older adults. Early mobilization, thromboprophylaxis, and close monitoring of comorbid conditions are essential to mitigate postoperative complications and ensure optimal functional gains.

Finally, Thomsen *et al*. [10] analyzed registry data and concluded that the preoperative quality-of-life scores among elderly TKA candidates have remained relatively stable over the years, suggesting that indication criteria are being consistently and judiciously applied. Their findings also suggest a shift in clinical culture, where age is no longer perceived as a limiting factor but rather as one component in a broader, individualized risk-benefit assessment.

3.2 Ligament Preservation and Natural Biomechanics

The preservation of native ligament structures, particularly the posterior cruciate ligament (PCL) and, when feasible, the anterior cruciate ligament (ACL), has emerged as a significant consideration in modern total knee arthroplasty (TKA). The rationale lies in the attempt to restore joint biomechanics closer to physiological conditions, enhancing proprioception, functional stability, and patient satisfaction. Among the innovations aligned with this objective are bicruciate-retaining (BCR) prostheses, which aim to preserve both cruciate ligaments. As detailed by Sabatini *et al*. [11], these implants are designed to maintain the natural roll-back mechanism of the femur over the tibia during flexion, which may improve joint kinematics and proprioceptive feedback, particularly in younger and functionally active individuals.

The suitability of ligament-preserving approaches, however, depends heavily on intraoperative evaluation of soft tissue integrity. Tateishi [12] emphasized the importance of tailoring prosthetic design to individual ligament status. In cases of early-stage osteoarthritis, where the PCL remains structurally competent, cruciate-sparing prostheses have shown to promote more physiological loading patterns while reducing dependence on implant constraint mechanisms, thereby lowering the risk of mechanical wear and aseptic loosening.

Historical and biomechanical perspectives further reinforce the value of soft tissue conservation. Saragaglia *et al*. [13] traced the development of unconstrained and semiconstrained prostheses, highlighting their intent to respect native anatomical biomechanics by minimizing iatrogenic ligament disruption. These implant designs allow for joint stability to be governed largely by the preserved soft tissue envelope, enhancing rotational control and flexion-extension balance.

Technological advancements in surgical planning have significantly facilitated ligament-preserving strategies. Brinkmann *et al*. [14] examined the role of patient-specific instrumentation (PSI) and customized cutting guides, which enable precise alignment and bone preparation. This precision allows for more effective preservation of ligament tension and alignment of prosthetic components, reducing the need for intraoperative soft tissue releases and improving midline stability during dynamic activities.

Beyond technical considerations, ligament preservation carries important ethical and patient-centered implications. Tsuboi [15], in his discourse on medical innovation, framed the evolution of implant design within the broader context of functional autonomy. Preserving native structures, he argued, aligns with the medical ethic of "primum non nocere," as it seeks to optimize postoperative independence, minimize artificial constraint, and honor the biological integrity of the patient.

From a clinical perspective, McInnis *et al*. [16] provided evidence that bilateral TKA procedures employing ligament-preserving techniques resulted in superior inter-limb coordination and more symmetrical gait patterns during rehabilitation. This underscores the role of preserved ligamentous proprioception in facilitating neuromuscular control— especially relevant factors in elderly populations at risk of imbalance and falls.

Material science has also evolved to support these objectives. Christensen *et al*. [17] explored modern implant coatings—such as porous titanium and advanced ceramic composites—that interface more harmoniously with preserved soft tissues. These materials reduce friction, inflammation, and adverse tissue reactions, promoting better integration with retained ligaments and enhancing long-term stability.

Biomechanical studies reinforce these clinical observations. Goh *et al*. [18] demonstrated that PCL-retaining prostheses help mitigate micromotion at the bone–implant interface and reduce stress shielding, thereby preserving bone stock and facilitating long-term osseointegration. These findings offer strong support for retaining the PCL when anatomical and surgical conditions permit.

In contrast, ligament-sacrificing prostheses have been associated with specific complication patterns. Saito *et al*. [19] noted increased rates of instability, mechanical failure, and wear in posterior-stabilized or constrained implants. These findings argue for a selective and cautious application of ligament-replacing designs, reserving them for cases where soft tissue insufficiency precludes preservation.

Finally, the broader functional implications of ligament preservation cannot be overlooked. Yasumura [20] highlighted its importance in elderly populations, demonstrating that maintaining ligamentous integrity contributes to better proprioceptive acuity, reduced incidence of falls, and improved confidence during ambulation. Such benefits, though not always captured in traditional outcome scores, directly influence quality of life and postoperative autonomy.

3.3 Fixation in Complex Total Knee Arthroplasty

Fixation strategies in complex total knee arthroplasty (TKA) demand a nuanced and individualized approach, particularly in revision settings or in cases with severe bone loss, compromised soft tissue envelopes, or altered joint biomechanics. These clinical scenarios require constructs that not only provide immediate mechanical stability but also support long-term biological integration. The goal is to restore joint function while minimizing the risk of early failure—a balance that becomes particularly challenging as implant constraint increases and host bone quality declines.

Lizcano *et al*. [21] provided robust evidence for the use of metaphyseal cones combined with cemented stems, particularly when associated with rotating hinge prostheses. These constructs have demonstrated high mechanical stability in cases of extensive metaphyseal bone loss, where conventional stemmed implants alone would be insufficient. Metaphyseal fixation, by distributing loads away from compromised epiphyseal bone, plays a pivotal role in the success of complex reconstructions. However, the technique requires precise preoperative planning and familiarity with augments and cones, which may not be universally available or adopted.

Barnoud *et al*. [22] compared constrained condylar knee (CCK) and rotating hinge prostheses, emphasizing that while both designs effectively manage ligamentous deficiency, rotating hinges are associated with higher complication rates, including mechanical loosening, infection, and patellofemoral complications. These findings reinforce a key principle in revision arthroplasty: Constraint should only be escalated to the level required to restore stability. Over-constraining an implant in a biomechanically compromised joint may inadvertently amplify failure risk due to stress concentration and mechanical overload.

Salimy *et al*. [23] highlighted the consistently poorer outcomes seen in revision TKA when compared to primary procedures, particularly in terms of patient-reported outcome measures (PROMs) such as the KOOS and WOMAC scores. This discrepancy underscores the cumulative burden of multiple surgeries, soft tissue compromise, and bone loss on postoperative recovery. These data also point to the crucial role of primary TKA success in preventing the cascade toward complex revision, emphasizing the importance of durable, evidence-based fixation in index surgeries.

Despite advances, a persistent challenge in complex TKA lies in the lack of standardized, evidence-based criteria to guide fixation strategy selection. Gademan *et al*. [24] systematically reviewed available guidelines and concluded that most rely on expert consensus rather than high-quality comparative studies. There is no universally accepted algorithm for defining when to use metaphyseal cones, long stems, or cementless fixation, which leads to variability in practice and potentially suboptimal outcomes in less experienced hands.

Technological innovations have introduced alternative fixation strategies, particularly uncemented constructs leveraging biologically active coatings. Schwabe and Hannon [25] traced the evolution of cementless fixation, showing that porous metal surfaces, especially those coated with hydroxyapatite, enhance early osseointegration and long-term implant stability. These surfaces mimic cancellous bone and facilitate rapid bone ingrowth, especially in younger patients or in cases with preserved metaphyseal bone.

Christensen *et al*. [26] further supported the use of modern cementless designs, demonstrating their efficacy even in patients with increased biomechanical demand, such as those with high BMI or severe varus/valgus deformities. Their analysis revealed that uncemented implants, when used judiciously and with meticulous technique, may reduce the risks associated with cement fatigue and allow for more physiologic stress transfer to bone.

Pulido *et al*. [27] provided mid-term follow-up data on the use of trabecular metal cones in revision settings, reporting high rates of implant survivorship and structural integration. The porous structure of trabecular metal allows for extensive vascularization and bone ingrowth, which not only reinforces fixation but also promotes biologic restoration of the bone–implant interface. Still, longer-term outcomes are needed to fully assess their durability, particularly under high stress conditions.

The mechanical rationale for using trabecular metal was further elucidated by Hannon *et al*. [28], who demonstrated improved stress distribution and reduced micromotion in these constructs. Reducing micromotion is critical in avoiding fibrous encapsulation—a major cause of aseptic loosening. These findings underscore the biomechanical superiority of modular, porous devices in reconstructions involving segmental bone defects or prior hardware removal.

Despite these promising innovations, clinical decision-making remains inconsistent. Mancuso *et al*. [29] revealed significant heterogeneity in surgeon preference and practice patterns regarding fixation strategies in complex TKA, even among experienced arthroplasty surgeons. This variability reflects not only differing training backgrounds and implant familiarity but also the absence of high-level evidence to direct standardized care.

Cross *et al*. [30] corroborated this lack of consensus in a broader multidisciplinary context, showing that disagreement is common even between orthopedic and rheumatology specialists regarding appropriate fixation approaches. This highlights the pressing need for

multidisciplinary consensus guidelines that integrate biomechanical principles, radiologic classifications of bone loss, and validated prognostic factors to inform implant selection and fixation techniques.

In sum, fixation in complex TKA is at the intersection of surgical expertise, material science, and individualized patient anatomy. While the literature provides strong support for certain tools—such as metaphyseal cones, long stems, and trabecular metal—the field still lacks high-quality comparative studies to guide best practices. The challenge lies not only in choosing the "best" implant but in aligning its biomechanical demands with patient-specific pathology. Continued innovation, standardized classification systems (e.g., AORI), and rigorous multicenter trials are urgently needed to build a more consistent, evidence-based framework for managing these complex reconstructions.

4. Conclusion

This systematic review examined scientific literature regarding the effectiveness, safety, and functional outcomes of total knee arthroplasty (TKA) in the treatment of unilateral knee osteoarthritis. The findings consistently support TKA as a highly effective intervention for pain relief, enhancement of functional capacity, and improvement in quality of life, even in older adults and patients with complex anatomical or biomechanical challenges. Evidence drawn from a diverse array of clinical contexts—ranging from elderly populations to revision surgeries—reinforces the versatility and durability of modern TKA techniques when applied with patient-specific consideration.

Functionally, TKA yields substantial gains in joint mobility, gait symmetry, and return to activities of daily living, particularly when surgical indications are judiciously applied based on functional impairment rather than chronological age alone. Ligament-preserving approaches and advanced fixation strategies—including cementless options and metaphyseal augmentation—have further contributed to improved biomechanical performance and implant survivorship. Importantly, the review underscores the necessity of comprehensive preoperative assessment and structured postoperative rehabilitation in optimizing outcomes.

In summary, TKA remains a gold standard for the management of unilateral knee osteoarthritis in appropriately selected patients. Its benefits extend beyond symptomatic relief to tangible improvements in autonomy and quality of life. However, continued refinement in patient selection criteria, surgical planning, and evidence-based standardization of fixation strategies is essential to maximize clinical outcomes and reduce variability in practice. These findings provide a strong basis for supporting the indication of TKA in patients with advanced unilateral osteoarthritis and reinforce the need for individualized, multidisciplinary care pathways.

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