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REVIEW

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# Fixation options for total knee arthroplasty: a comprehensive literature review

J. Moya-Angeler[1,2*], M. Akkaya[3], M. Innocenti[4], D. Bergadano[5], J. Martin-Alguacil[6,7] and V. León-Muñoz[1,2,8]

**Abstract**

Total knee arthroplasty is a consistently successful, cost-efficient, and highly effective surgical procedure for treating severe knee osteoarthritis. The success and longevity of total knee arthroplasty depend significantly on the fixation method used to secure the prosthetic components. This comprehensive review examines the primary fixation methods (cemented, cementless, and hybrid fixation), analysing their biomechanics, clinical outcomes, advantages, and disadvantages, focusing on recent advances and trends in total knee arthroplasty fixation.

**Keywords** Knee osteoarthritis, Total knee arthroplasty, Fixation, Cement, Cementless, Hybrid fixation

## Background

Total Knee Arthroplasty (TKA) is a well-established surgical intervention designed to alleviate pain and restore function in patients with end-stage knee osteoarthritis [1, 2]. The demand for TKAs is expected to rise significantly by 2030 [3].

The choice of fixation method for the prosthetic components affects the immediate postoperative stability, long-term implant survival, and overall patient outcomes [4–6]. Cemented fixation has long been regarded as the gold standard for TKA, boasting high survival rates over long-term follow-ups [6–8]. Non-cemented knee replacements were developed to provide a more durable biological fixation while avoiding the potential third-body wear caused by cement particles [9]. Although these non-cemented options were initially met with enthusiasm, cemented TKA has maintained its status as the gold standard over the decades [10]. A third option is a hybrid fixation, consisting of a tibial cemented component and a femoral non-cemented component. This approach combines the advantages of both methods, offering reliable initial stability and promoting long-term biological fixation [5, 7, 11–13].

While several studies report similar outcomes between cementless and cemented TKAs, a significant concern with cementless TKA remains aseptic loosening of the tibial component, particularly in specific cohorts such as females over 75 years of age with poor bone quality [14, 15]. Another point of debate is the generally higher cost of non-cemented implants [16–18]. However, non-cemented TKA offers several advantages [8, 19]. There has been renewed interest in non-cemented TKA, especially for younger, active patients, who have shown excellent implant survival with recent designs and materials

*Correspondence:
J. Moya-Angeler
jmoyaangeler@gmail.com
[1] Department of Orthopaedic Surgery, Hospital General Universitario Reina Sofía, Avenida Intendente Jorge Palacios 1, 30003 Murcia, Spain
[2] Instituto de Cirugía Avanzada de la Rodilla (ICAR), C/ Barítono Marcos Redondo 1, 7b, 30005 Murcia, Spain
[3] Department of Orthopaedic Surgery, Ankara Güven Hospital, Cayyolu Health Campus, Alacaatli street No:15, Cayyolu, Ankara, Turkey
[4] Department of Orthopaedic Surgery, Università degli Studi di Firenze, Largo Giovanni Alessandro Brambilla, 3, 50134 Florence, FI, Italy
[5] Medacta International SA, Via alla Rossa 6, 6862 Rancate, Switzerland
[6] Hospital Vithas Granada, Av. Santa María de la Alhambra, 6, Genil, 18008 Granada, Spain
[7] Clínica Martín Gómez, C/ San Marcos, 8, 1º A, Centro, 18005 Granada, Spain
[8] Department of Surgery, Paediatrics and Obstetrics and Gynaecology, Faculty of Medicine, University of Murcia, Avda. Buenavista 32, El Palmar, 30120 Murcia, Spain

[20]. For these reasons, uncemented fixation TKA is on the rise and is currently utilised in 20% of primary TKA cases in the United States [21].

This article aims to provide an in-depth review of the three primary fixation methods: cemented, cementless, and hybrid fixation. It will discuss their biomechanical properties, clinical performance, and current usage trends.

## Cemented fixation

Cementation remains historically the gold standard for primary TKA fixation, with a long and reliable history of use, adequate long-term survival, broad applicability to all patient populations, no or compensated bone-cutting errors and use of the cement itself as a source of local antibiotic delivery [22, 23]. Cemented fixation using polymethylmethacrylate (PMMA) bone cement provides a robust and immediate bond between implant and bone by filling gaps and forming a solid interface that distributes loads evenly across the bone-implant interface; its excellent long-term clinical performance (with studies reporting survival rates exceeding 90% at 15–20 years) makes it the preferred choice for older patients and those with poor bone quality [11, 13, 24–26] (Table 1). A modified Delphi Expert Consensus Study was completed focusing on cementation technique in TKA. 100% consensus was reached within the cement preparation, pressurization, and cement curing domains. 90% consensus was reached within the cement application domain [27]. It is important to note that the success of this fixation technique depends on many factors: the type of cement, temperature, humidity, viscosity and volume, mixing procedures and the technique [27]. From this consensus, it can be concluded that: (1) Surface preparation before any cementing technique is essential to ensure adequate cement penetration into the cancellous bone. (2) Pulsed lavage is superior to other techniques. (3) Drilling sclerotic bone has been shown to increase cement penetration, but no clinical studies show that this improves implant survival. (4) Cement should be medium or high viscosity, loaded with antibiotics and mixed in a vacuum device. (5) The cement should be applied to both the back of the tibial and femoral implants and the surface of both bones. (6) Any blood, water or fat on the surface of the cement should be dried before implantation. (7) Pressurise the tibial and femoral implants with impactors. (8) The knee should be held in a fixed position while the cement cures, and hyperextension or deep flexion should be avoided [27].

Cement penetration plays a crucial role in implant stability from surgery in cemented TKA [28]. Radiolucent lines at the bone-cement interface equal to or less than 1 mm on radiographs usually develop in the first year after surgery and do not progress in the long term. However, radiolucent lines more significant than 2 mm have been postulated to be an early sign of component loosening [28]. While it is true that there is a negative association between radiolucent lines greater than 2 mm and implant loosening, there is no clear evidence between the two variables.

A study by Vertullo et al. on cadavers demonstrated that modern tibial cementing techniques maintain temperatures below the danger threshold, with a narrow safety margin of 4.95 °C (95% CI ± 4.31) [29]. The study also found no link between cement penetration depth and peak cement temperature. Furthermore, thermal damage can result from heat generated by cutting tools such as saws or burrs. Tawy et al. reported that mean bone temperatures above 47 °C lasted more than 60 s in non-irrigated bone and bone irrigated with room temperature saline [30]. In contrast, cooled irrigation effectively kept sawed bone temperatures below 47 °C ($p < 0.05$) [49]. Therefore, the authors recommend using saline irrigation at room temperature to minimise the risk of thermal osteonecrosis during bone sawing [29].

## Non-cemented fixation

Cementless fixation relies on biological integration, where bone growth into or onto a porous surface of the implant secures the prosthesis. These implants are designed with porous coatings or surfaces that promote osseointegration [20].

Recent improvements in implant materials and technology have enabled cementless TKA to change clinical

**Table 1** Characteristics of the different types of fixations for total knee arthroplasty

| | S&L | FO | CR | BL | BMI | ALG | CST | BQS | TC |
|---|---|---|---|---|---|---|---|---|---|
| Cemented | +++ | +++ | AL | = | N/E | N/E | + | +++ | + |
| Hybrid | +++ | +++ | CFP | = | N/E | N/E | ++ | ++ | ++ |
| Cementless | +++ | +++ | INS | = | N/E | N/E | +++ | + | +++ |

*S&L* survivorship and longevity, *FO* functional outcomes, *CR* complication rates, *AL* aseptic loosening, *CFP* complex failure pattern with AL and or INS, *INS* early instability, *BL* blood loss, *BMI* body mass index, *ALG* alignment, *CST* cost, *BQS* bone quality status, *TC* technical complexity, *N/E* no evidence; = : same; +: low; ++: medium; +++: high practice. Cementless TKA has been postulated to provide durable and stable biologic fixation of implants, improved operative efficiency and optimal long-term results, especially in younger and active patients [23, 31]. Cementless fixation offers several advantages, including better preservation of native bone stock, avoidance of cement debris and associated third-body wear, and a more natural bond and osseointegration between the implant and bone for durable stability [32].

The biological fixation of uncemented implants depends on the quality and quantity of bone in growth, which can take several weeks to months to achieve optimal stability [33]. It relies on migrating osteoblasts and mesenchymal cells towards the implant and osseointegration through its roughened surface [34]. Studies suggest pore sizes greater than 300 µm are optimal for new bone formation and capillary development [35]. Additionally, a rough surface enhances primary stability by increasing the shear-load bearing capacity at the bone-implant interface immediately post-operation and provides secondary fixation through mechanical interlock [20, 34].

However, a highly rough surface requires careful handling during surgery to avoid complications such as higher insertion forces, which may lead to periprosthetic fractures or miseating of the implant [36, 37]. Ensuring adequate primary stability is essential for successful long-term fixation and effective osseointegration by minimising micromotions [32, 38]. Innovations in technology and design have dramatically improved modern cementless TKA implants [34, 39]. Enhanced friction coefficients and reduced Young's modulus mismatches are achieved through porous metal surfaces and biologically active coatings such as periapatite and hydroxyapatite (HA), which increase osteoconductive properties, reduce micromotion, and ensure better implant stability [20].

HA has emerged as a promising material for achieving biological fixation due to its osteoconductive properties, even in the presence of gaps or partially unstable conditions [40]. Studies have shown similar micromotions between HA-augmented and cemented implants, and HA-coated implants have demonstrated reliable fixation and better performance in terms of micromotion [38]. Trabecular Metal ™ (Zimmer Inc., Warsaw, IN, USA), a biomaterial made of porous tantalum, was designed to mimic cancellous bone and provide excellent mechanical and biological properties [15, 19, 41, 42]. It is associated with predictable ingrowth, osseointegration, primary stability, and maintenance of bone mineral density. However, clinical results have been mixed [15, 41–43]. A recent meta-analysis of six studies involving 977 patients indicated that cementless porous tantalum monoblock tibial components did not show substantial superiority over conventional cemented modular tibia at a 5-year follow-up [44]. Despite initial migration observed in some TM components, mid-term outcomes reported by Niemeläinen et al. on 1,143 primary cementless TKAs showed a 100% survivorship at 1, 5, and 7 years postoperatively, using revision for aseptic loosening as the endpoint [42, 45].

In another study, Dunbar et al. compared outcomes of the porous monoblock and cemented tibial components in 70 randomised patients at a 24-month follow-up [41]. A subset of TM components migrated extensively initially but stabilised within a year. At a 5-year follow-up, similar tibial motions and a comparable proportion of implants at risk were reported between the two groups [41]. Fernandez-Fairen et al. and Pulido et al. also reported similar outcomes at a 5-year follow-up, with no significant difference in clinical scores, complication rates, and survivorship from aseptic loosening between TM and cemented tibial components [43, 46].

BioFoam® (Microport Orthopedics, Inc., Arlington, TN, USA), a cancellous titanium foam, enhances mechanical properties with up to 80% porosity, providing early stability and osseointegration [47]. Short-term outcomes have been promising, with no implant-related failures or progressive radiolucencies at 24-month follow-up [48]. Long-term studies showed comparable results between cemented and BioFoam® implants, with satisfactory radiological outcomes and no implant-related failures.

Tritanium (Triathlon®. Tritanium®, Stryker Orthopedics, Mahwah, NJ, USA), a modular cementless tibial component made with highly porous titanium coating applied by 3D printing, supports biological fixation. Cadaveric studies and clinical results have shown reduced rocking motions and liftoff, with low revision rates due to aseptic loosening and increased bone density around the tibial baseplate pegs [38]. In clinical studies, Tritanium implants in obese patients demonstrated high survivorship rates and comparable early outcomes to cemented implants, with no signs of progressive radiolucencies or component subsidence [49].

## Hybrid fixation

Hybrid fixation in TKA combines cemented and cementless techniques, typically utilising cemented fixation for the tibial component and cementless fixation for the femoral component [5]. Hybrid fixation was initially adopted as an intermediate solution due to the poor survivorship of early tibial designs, which exhibited an 8% risk of early aseptic loosening [50]. However, with improvements in the design and survivorship of tibial implants, there is a trend towards reduced utilization of hybrid fixation in favor of cementless fixation, which accounted for only

1.9% of primary total knee arthroplasties (TKAs) in 2022 according to the American Joint Replacement Registry [21]. This method leverages the immediate stability provided by cemented tibial fixation, which ensures secure implant placement and load distribution right after surgery while capitalising on the long-term biological fixation offered by the cementless femoral component [11]. This dual approach optimises the strengths of both fixation methods, providing immediate postoperative stability and promoting bone ingrowth for durable long-term stability [12]. Clinically, hybrid fixation has demonstrated promising results, offering a balanced solution that minimises the risk of aseptic loosening, a common complication in TKA, and enhances overall implant longevity [12]. Studies suggest that hybrid fixation reduces the chances of implant failure and improves functional outcomes and patient satisfaction by combining the robust initial support of cemented components with the adaptive, bone-integrating benefits of cementless implants [11]. This approach benefits patients with varying bone qualities, ensuring immediate and enduring implant success (Table 1).

#### What evidence has been published?

Survivorship and longevity of different fixation methods vary, with cemented fixation demonstrating high survivorship in older patients with poor bone quality, showing a 10–15-year survival rate of 90–95% [8]. Cementless fixation, on the other hand, shows excellent long-term results, particularly in younger, more active patients, thanks to material advances that have improved osseointegration and reduced revision rates [51]. Emerging evidence suggests that hybrid fixation may offer a lower risk of aseptic loosening and enhanced durability compared to purely cemented or cementless techniques [5]. Pijls et al. published a systematic review and meta-analysis in 2018 to assess the early and long-term migration patterns of tibial components of TKA from all known radiographic stereophotogrammetric analysis (RSA) studies [40]. The literature search yielded 1167 results, of which 53 studies were included, comprising 111 study groups and 2470 knees [40, 52]. Most early migration occurred in the first six months postoperatively, followed by a period of stability, i.e. no or very little migration. Cemented and uncemented tibial components had different migration patterns. For cemented tibial components, there was no difference in migration between all-plastic and metal-reinforced components, mobile-bearing and fixed-bearing components, and cross-retained and subsequently stabilised components. There were also no differences between RCTs measured by model-based RSA and marker-based RSA. In uncemented TKAs, some variation in migration was observed, which was higher in uncoated TKAs. The results of this meta-analysis are consistent with the results from national implant registries and meta-analyses on revision rates and provide further evidence of the association between early implant migration and late revision for aseptic loosening of TKA [4, 5, 14, 52–55].

Zhou et al. undertook a systematic review and meta-analysis to evaluate the optimal mode of fixation (full-cementless vs. full-cemented) in primary TKA, including seven studies [56]. They concluded that the implant survivorship and clinical outcomes (WOMAC score, KSS score, postoperative range of movement, blood loss, and complications) are likely similar between full-cementless and full-cemented fixation [56]. Chen et al. published an analysis of randomised controlled trials and quasi-randomised controlled trials with long-term follow-up to compare the long-term efficacy of the two fixation methods in terms of implant survival rate, clinical scores, and radiographic indicators, providing a valuable reference for the selection of a TKA prosthesis [57]. The authors concluded that cementless and cemented fixation have similar prosthesis long-term survival rates, clinical scores, and mobility [57]. Functional outcomes, including pain relief, range of motion, and patient satisfaction, are generally comparable across the three fixation methods, although they are significantly influenced by the surgical technique, implant design, and patient-specific factors [48]. However, complication rates differ cemented fixation is associated with higher rates of aseptic loosening and cement-related osteolysis [36], cementless fixation has potential for early instability and may require extended non-weight-bearing periods [36], and hybrid fixation might present a complex failure pattern due to the different fixation mechanisms [11].

Modern cementless fixation does not lead to higher blood loss or transfusion rates than cemented fixation in patients undergoing TKA [58, 59]. Obese patients with a BMI $\geq 35$ kg/m$^2$ undergoing both cementless and cemented TKA using the same modern design exhibited comparable outcomes and survivorship at early to mid-term follow-up, highlighting the need for ongoing monitoring of this high-risk group [49].

Only a few studies correlate implant type with fixation type. Schotanus et al. designed a prospective, patient-blinded, randomised, controlled trial to investigate early migration of the tibia component after two years of follow-up using radio stereometric analysis [60]. Fifty patients were randomised to receive a mobile- or fixed-bearing TKA from the same family, demonstrating similar early migration of both components at two years, mainly seen in the first weeks after implantation [60]. Nieuwenhuijse et al. analysed the so-called high-flexion TKA, finding comparable migration between high-flexion prostheses (with either a mobile or fixed bearing) and conventional counterparts at five-year follow-up [61]. Zimmermann et al. reported that preoperative varus alignment correlated with a significant decrease in bone tracer uptake in SPECT/CT in certain medial femoral and medial tibial regions, while preoperative valgus alignment correlated with a more significant decrease in the corresponding lateral regions, indicating that inadequate correction of preoperative varus alignment did not result in increased bone loading as reflected by bone tracer uptake after TKA [62]. Recently, Glenday et al. published a novel computational workflow to assess TKA biomechanics and identify subject-specific effects of joint mechanics on implant fixation, concluding that relationships between joint mechanics and implant fixation mechanics can be established by combining the study of joint mechanics and fixation mechanics in TKA [63]. This approach is the first to combine musculoskeletal and finite element models to holistically assess the relationship between joint and fixation mechanics. However, the initial assessments focus on orthogonal osteotomies, and it would be of great interest to model osteotomies from different angles [63].

In a previous study, Febrer-Nafría et al. developed a detailed musculoskeletal model with a 12-degree-of-freedom knee to represent a TKA subject from the CAMS-Knee data sets, simulating a planar gait cycle using motion capture and ground reaction force data, and estimating joint loads and motion patterns using a novel simultaneous optimisation technique for muscle activations and joint kinematics [64]. Additionally, over 12,000 Monte Carlo simulations were performed to predict knee contact mechanics during gait, considering numerous combinations of implant alignment and muscle activation scenarios. Febrer-Nafría et al. reported the significant impact of implant alignment on joint kinematics, while variations in muscle activation strategies mainly affect knee contact loading, suggesting that high knee compression forces do not necessarily result from extreme kinematics and vice versa [64]. This study provides a better understanding of the complex interrelationships between loading and movement patterns resulting from different surgical implantation strategies and muscle coordination [64].

## Recent advances and future directions

Recent advancements in TKA fixation focus on improving implant materials and designs to enhance osseointegration, reduce complications, and extend implant longevity. One notable development is the use of porous coatings, such as trabecular metal (tantalum) and highly porous titanium, which significantly enhance bone ingrowth and provide better stability for the implant. Additionally, incorporating biologic adjuncts, including growth factors and other biologics, aims to promote faster and more robust osseointegration, thereby improving the overall success and longevity of the implant [65].

Customisation and patient-specific implants have progressed significantly, mainly through 3D printing technology. This allows for the creation of custom implants tailored to the patient's unique anatomy, which can improve fit, enhance fixation, and potentially reduce the risk of complications. Furthermore, integrating robotic or computer-assisted surgery into TKA procedures enhances the precision of implant placement, leading to improved fixation outcomes and excellent overall success rates [65].

These advancements collectively represent a significant leap forward in TKA technology. They aim to provide patients with more durable, reliable, and personalised knee replacements that better meet their needs and lifestyles.

This study critically examines the fixation methods in TKA, focusing on cemented, cementless, and hybrid techniques. It highlights the importance of fixation choice in influencing immediate postoperative stability, long-term implant survival, and patient outcomes. This comprehensive review helps surgeons tailor TKA procedures based on patient-specific factors such as age, bone quality, and activity level. By comparing the biomechanics and clinical outcomes of different fixation methods, the study offers valuable guidance for optimizing surgical outcomes and improving patient satisfaction. The findings emphasize adopting advanced materials and techniques to enhance implant stability and longevity, ultimately aiming to reduce revision rates and improve overall patient care.

## Authors recommendations

### *Evaluate patient-specific factors*

Thoroughly assess the patient's age, sex, weight, indication, activity level, bone quality, and overall health to determine the most appropriate fixation method. Personalised treatment plans should be developed to optimise outcomes based on these individual characteristics. An initial comprehensive assessment of bone quality should include evaluating the patient's history of fractures, blood tests to check calcium and vitamin D levels, and a dual-energy X-ray absorptiometry (DEXA) scan. We recommend requesting a consultation with a metabolic bone specialist if there is any doubt [66].

### *Hybrid fixation for diverse bone qualities*

Consider hybrid fixation for patients with varying bone qualities. This approach leverages the immediate stability of cemented tibial components and the long-term benefits of cementless femoral components. It can offer a balanced solution that minimises the risk of aseptic loosening and enhances implant longevity.

#### *Use of advanced materials*

Modern implants with biologically active coatings like periapatite and hydroxyapatite should be used to promote osseointegration and enhance implant stability. Materials like trabecular metal and BIOFOAM, known for their high porosity and mechanical properties, should be considered for younger, active patients. Minimise the risk of bone thermal necrosis by utilising appropriate saw blades, irrigating with saline, and employing preoperative cooling devices. It is highly recommended that implants with a good track record be utilised.

#### *Emphasise surgical precision*

Employ advanced surgical techniques and technologies, such as robotic or computer-assisted surgery or accurate instrumentation systems, to ensure precise alignment and placement of implants. Accurate implantation and soft tissue balance are crucial for achieving optimal fixation and long-term success.

#### *Monitor and adapt techniques*

Stay updated with the latest clinical studies, TKA materials, and method advancements. Review and adapt surgical techniques regularly based on emerging evidence to provide the best possible care for patients.

#### *Balance immediate and long-term stability*

Aim to balance immediate postoperative stability with long-term biological fixation. Cemented fixation may be preferred for older patients with poor bone quality, while cementless options can be suitable for younger patients with good bone stock. Cemented TKA remains the gold standard for most patients undergoing TKA, especially females over 65 years of age. We recommend the selective use of uncemented TKA in younger, non-obese males.

#### *Incorporate patient preferences*

Discuss the benefits and risks of different fixation methods to engage patients in decision-making. Patient education can help patients make informed choices that align with their lifestyle and expectations.

#### *Optimise postoperative care*

Develop comprehensive postoperative care plans that include rehabilitation programs tailored to the type of fixation used. Effective rehabilitation is essential for achieving the best functional outcomes and implant longevity.

Focusing on these recommendations aims to personalise the TKA procedure based on the patient's characteristics and bone quality, utilising the best alignment techniques to ensure optimal outcomes.

## Conclusion

The choice of fixation method in Total Knee Arthroplasty is critical to the procedure's success and longevity. Cemented fixation remains reliable for older patients and those with poor bone quality, providing immediate stability and proven long-term results. Cementless fixation offers significant advantages for younger, more active patients, with advancements in materials improving long-term outcomes. Hybrid fixation provides a balanced approach, combining the benefits of both techniques. Future research should focus on optimising these methods and refining patient-specific approaches to improve overall TKA outcomes.

**Abbreviations**

| | |
|---|---|
| TKA | Total knee arthroplasty |
| PMMA | Polymethylmethacrylate |
| HA | Hydroxyapatite |
| PE | Polyethylene |
| RSA | Radiographic stereophotogrammetric analysis |
| MTPM | Maximum total motion |
| 3D | Three-dimensional |

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The authors declare no competing interests.

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