As the number of younger and more active patients treated with total knee arthroplasty (TKA) continues to increase, consideration of better fixation as a means of improving implant longevity is required. Cemented TKA remains the reference standard with the largest body of evidence and the longest follow-up to support its use. However, cementless TKA, may offer the opportunity of a more bone-sparing procedure with long lasting biological fixation to the bone. We undertook a review of the literature examining advances of cementless TKA and the reported results.

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Total knee arthroplasty (TKA) is a proven treatment for advanced arthritis of the knee. Knee replacements reliably relieve pain and restore function.1,2 Multiple authors report successful outcomes for 90% of patients 20 years after surgery.3-6 Fixation in TKA may use cementless, cemented, or hybrid fixation. Cemented fixation is widely reported and is the reference standard, and this appears to be supported by registry data.7-10 However, interest in cementless fixation in TKA has increased for a number of reasons. In many parts of the world, total hip arthroplasty has moved successfully toward cementless fixation. In addition, advancements have been made in implant design and bone preparation for cementless fixation, which has given confidence in adapting this technology for TKA. The purpose of this article is to review the current state of cementless TKA.

Cementless TKA

The theoretical advantages of cementless TKA include the potential to preserve bone stock and avoid cement debris, but most importantly, the potential to achieve lasting, biological fixation of the implant to the bone. Once osseointegration has occurred, it is highly unlikely that loosening will present except due to lysis or sepsis. With an increasing number of younger and more active patients seeking TKA,11 surgeons are looking for a more physiological bond.

Cementless implants rely on a porous or roughened surface to facilitate bone formation, as osteoblasts and mesenchymal cells migrate toward the implant.12,13 The porous surface provides a mechanical interlock, which limits micromotion. The initial stability obtained at surgery influences eventual long-term fixation,14 which is important as the presence of micromotion compromises the chance of achieving osseointegration.15,16

Hydroxyapatite (HA) coating. HA is one of various bioactive coatings that can be added to the metal substrate of cementless TKA to enhance fixation and convert fibrous tissue to bone.17 HA has been shown to decrease micromotion of the tibial component18,19 and increase fixation of the femoral and tibial components.20-22 In 2005, Cross and Parish20 reported a series of 1000 patients treated with an HA-coated cementless TKA with a follow-up of nine years. At final review, they found a 0.5% revision rate for aseptic loosening and calculated the ten-year survivorship of these devices to be 99.14% (95% confidence interval (CI) 92.5 to 99.8). Epinette and Manley23 found a survivorship of 98.14% at a mean follow-up of 11.2 years, using mechanical failure as an end-point in a group of patients (146 primary TKA) treated with an HA-coated cementless device. Voigt and Mosier24 performed a meta-analysis of 926 arthroplasties, concluding that HA-coated implants may provide better durability than other forms of fixation, including cemented TKA.

HA has also been shown to decrease the incidence of radiolucent lines around cementless TKAs.17,18 There is controversy regarding the importance of radiolucent lines. In the absence of implant migration or circumferential radiolucent lines around an implant, most would not consider an implant to be loose.
simply on the basis of radiolucent lines. Further study is needed to ascertain the importance of radiolucent lines around cementless TKA implants.

**Trabecular metal.** Trabecular metal (Zimmer, Warsaw, Indiana) is a novel biomaterial made of tantalum with porosity and mechanical properties resembling native trabecular bone. Predictable ingrowth into the surfaces of a trabecular metal implant has been described, as well as maintenance of bone mineral density (BMD) after ingrowth occurs. Meneghini and de Beaubien, among others, showed a higher early failure rate in a trabecular metal monoblock tibia, but other authors have reported excellent results, including a randomised controlled trial by Pulido et al, in which 389 patients were followed until death, revision, or for a minimum of two years (mean five years; two to nine); 128 of whom were allocated to the cemented highly porous metal tibia. They concluded that trabecular metal provides excellent bone ingrowth.

Other, newer concepts are slowly being introduced to uncemented implants. BIOFOAM (Microport Orthopedics, Inc., Arlington, Tennessee) is one of several titanium foams created by various manufacturers. These foams can be manufactured to vary the porosity and strength of the constructs to be compatible with bone (up to 80% porosity).

BIOFOAM (Microport Orthopedics, Inc.), as well as other titanium foams, has a very high coefficient of friction compared with bead or spray coatings, giving it the potential to improve early bone ingrowth. Waddell et al compared with bead or spray coatings, giving it the potential to improve early bone ingrowth. Waddell et al compared with bead or spray coatings, giving it the potential to improve early bone ingrowth.

Additive manufacturing using electron beam melting (EBM), sometimes referred to as "3D implants," is also coming to orthopaedic implants. This technique enables precise manufacturing of porous metal implants. The ability to vary pore size and density has the potential to improve the biocompatibility of these metal constructs. This technology is in its infancy and, to date, there are no clinical reports available.

**Long-term survivorship.** Multiple studies have reported successful long-term results of various cementless devices (Table I), which rival those of cemented TKA. Ritter and Meneghini reported the 20-year survivorship of 73 Anatomic Graduated Component (AGC, Biomet Inc., Warsaw, Indiana) knees with a ten-year minimum follow-up, and no patients lost to follow-up. They found that, excluding patellar failures, survivorship rates were 96.8% for the cementless tibial component and 100% for the cementless femoral component. Hofmann et al reported a series of 300 consecutive knees in 238 patients with a mean 12-year follow-up after cementless TKA. There were 176 knees in 141 patients available for review. At final follow-up implant survival was 93.4% (95% CI 90.1 to 96.7), including infection and polyethylene liner changes. In this series, the patellar component survivorship was 95.1% (95% CI 92.3 to 98.0). Buechel reported 169 patients treated with a rotating platform device. Survivorship with an end-point of revision for any reason was 98.3% at both ten years and 18 years, with a 99.4% survivorship of the cementless patellar component at final follow-up. Whiteside reported 255 cementless cruciate-retaining TKAs with unresurfaced patellae. These patients were followed for 15 to 18 years, and he reported excellent Knee Society Scores at final follow-up. Watanabe et al performed a prospective study of 76 knees in 54 patients who received cementless TKAs. They reported 100% implant survivorship at ten years and 96.7% at 13 years.

Radiographic follow-up can be difficult in cementless TKA. Interfaces between implants and bone can be difficult to visualise because of rotation, and subtle movements of the implant are often hard to evaluate. Radiostereometric analysis (RSA) has revealed continued motion at two years.
is predictive of late loosening.\textsuperscript{50,51} Nelissen et al\textsuperscript{52} have commented on the value of combining the results of RSA studies with national joint registries as an effective means of decreasing the number of revision TKAs.

**Disadvantages.** Despite increased interest in cementless fixation, many questions remain regarding issues such as optimal implant design, as well as appropriate patient selection and bone quality. Few data exist on the amount of bone ingrowth needed to achieve adequate long-term fixation in cementless TKA. Turner et al\textsuperscript{53} found 40% to 90% ingrowth needed to be adequate in canine models, but they found that in retrieval settings, < 30% ingrowth was noted in clinically well-functioning knees. Most studies do not control for bone quality in their reporting,\textsuperscript{50,51} and more data are needed to clarify this issue.

There are concerns regarding the ability of osteoporotic bone to provide adequate ingrowth and resist implant migration. Petersen et al\textsuperscript{54} reported 25 patients treated with cementless TKA with pre- and post-operative measurements of BMD and RSA of tibial baseplate migration. They found that the migration of the tibial component was the highest in the first year, with a mean migration of 1 mm. They also found a positive relationship between BMD and migration and concluded that tibial components in patients with higher BMD showed less migration.

Multiple RSA studies have shown similar findings of small, early migration, mostly occurring during the first three months and then stabilising at one year.\textsuperscript{55-57} Gao, Henricson and Nilsson\textsuperscript{58} used RSA to evaluate migration of 41 patients treated with a cementless device and 41 patients treated with an identical cemented device, and found no difference. Cemented implants also show migration when evaluated using RSA, and some authors have reported similar migration between cemented and cementless versions of the same device.\textsuperscript{32,50,59}

There is a lack of scientific data regarding the outcomes of cementless TKA. Most studies do not stratify outcomes or revisions based on component failure, patient gender, and patient comorbidities. These deficiencies contribute to the limited endorsement of cementless TKAs by orthopaedic surgeons.

In 2014, Pulido et al\textsuperscript{33} reported one of the few level-one studies on cementless TKA. They performed a clinical trial of 397 patients who were randomised into three well-matched groups: traditional modular cemented tibial component; cemented highly porous tibial component; and uncemented highly porous tibial component. An identical cemented posterior stabilised femoral component and tibial component were used in all groups. At five-year follow-up, the authors found no significant difference in the three groups in outcome, based on Knee Society Scores,\textsuperscript{60} range of motion, and complications. More randomised controlled trials are needed.

Questions about the bone-implant interface have led authors to study the indications for cementless TKA in elderly patients as well as younger, more active patients. Whiteside and Viganò\textsuperscript{47} studied a large, consecutive group of patients < 55 years old and weighing > 90 kg (167 knees), treated with the same cementless device. This group was compared with 167 knees in patients > 65 years old and < 80 kg. Minimum follow-up was five years, with a mean of 7.3 years. They found similar Knee Society Scores in both groups at all intervals with similar survivorship with only one polyethylene liner change in the younger group. They concluded that cementless TKA is safe and effective, regardless of age or weight. Dixon et al\textsuperscript{10} prospectively studied 559 patients (of whom 135 were > 75 years old) undergoing TKA with an HA-coated implant and found no functional differences between the >75-year age group and any other of the age groups.

Many early reports on cementless devices have raised questions concerning their durability,\textsuperscript{61-63} but more recent publications show better results. There is a lack of consensus on the ideal design of cementless tibial trays, as well as the ideal surface ‘roughness’. Early designs were compromised by problems such as poor design and fixation to bone. Multiple reports have examined devices that have stems, keels, pegs, or combinations of these.\textsuperscript{33,38,47} However, there is a general agreement that correct sizing and capping of the tibial cortex is associated with more predictable fixation and less baseplate migration.\textsuperscript{51,58,64}

The current literature does not provide sufficient information to compare design concepts such as rotating platforms, fixed bearings and cruciate-retention or substitution. Further study is needed to evaluate these comparisons.

Cementless patellar component failures account for most early reported failures after cementless TKA.\textsuperscript{6,63,65} Whereas many early designs provided ingrowth into the patellar component, other design features of cementless patellar components proved problematic. Improved patellofemoral designs and the elimination of thin polyethylene and sharp metal borders have led to improved results in the use of cementless patellar components.\textsuperscript{66}

In some previous cementless TKA designs, tibial baseplate loosening was shown to be the weak link.\textsuperscript{58} Carlsson et al\textsuperscript{67} and Sadoghi et al\textsuperscript{68} found higher rates of cementless tibial loosening using RSA analysis when compared with cemented baseplates at five years.

The use of adjunctive fixation is controversial. Bone ingrowth can occur to a maximum distance of 0.3 mm to 0.5 mm between the bone and implant.\textsuperscript{69} The concept of using screws to provide more predictable initial stability led to many early designs incorporating screws into tibial baseplates.\textsuperscript{61,70} However, reports\textsuperscript{3,71} show osteolysis associated with the use of screws and discuss the theoretical risks of debris formation, channels for osteolysis, and neurovascular damage. Many surgeons now recognise that stems, keels and pegs provide sufficient initial fixation, and the use of baseplates with screws is less popular. Ferguson, Friederichs and Hofmann\textsuperscript{72} compared groups of patients treated with an identical baseplate with and without screws with a maximum follow-up of seven years, with the results
showing no difference between groups. Likewise, Schepers, Cullinghamworth and van der Jagt\textsuperscript{23} and Ferguson et al\textsuperscript{66} showed no advantage in the use of screws.

There are questions regarding patient selection. Few studies have evaluated the safety and efficacy of cementless TKA in patients with rheumatoid arthritis. Eskola et al\textsuperscript{74} studied 42 patients with rheumatoid arthritis, and although there was one revision due to ligamentous laxity and two patients had radiolucencies of more than 2 mm, the authors found no clinically-evident loosening in cementless knees in this group of patients. Woo et al\textsuperscript{75} reported 179 rheumatoid arthritic knees with a mean follow-up of 10.1 years and estimated the 15.5 year survivorship of this fully cementless TKA group to be 96.8%.

Concerns about peri-operative complications in cementless TKA centre on potential blood loss. Several authors\textsuperscript{76-78} have reported greater blood loss during cementless TKA as, when used, cement can act to tamponade the bleeding. However, a more recent publication by Demey et al\textsuperscript{79} in 2010 showed no difference in blood loss in cemented versus cementless femoral components.

Cementless TKAs are more expensive than uncemented devices, and this cost differential has hampered its use. However, in part, the additional expenditure can be offset by savings from the absence of cement, as well as shorter operative times. Kamath et al\textsuperscript{80} showed that, as in the hip, after removing the costs associated with longer surgical time, irrigation, cement and cement-mixing devices, the cost difference between cemented and cementless devices is small.

**Alternative methods of fixation**

**Cemented/cementless.** The use of cement has the advantages of immediate fixation, may compensate for slightly inaccurate bone cuts, provides local delivery of antibiotics and the possible tamponade effect to decrease bone loss during surgery. Conversely, concerns regarding late loosening caused by tension and shear, third-body wear from cement debris and possible increased bone loss during revision, are reasons for interest in cementless fixation.

Unfortunately, there are few randomised controlled trials comparing the performance of cemented versus cementless TKA.\textsuperscript{63,80-82} Level-I data are rare. Gao et al\textsuperscript{83} reported a small series of 41 patients randomised to receive identical devices with cementless or cemented femoral components with cemented tibial components. They found no difference in terms of RSA analysis or clinical outcomes in the hybrid or the cemented knee. Choy et al\textsuperscript{49} compared two groups of 86 cemented and 82 cementless identical knee prostheses with a follow-up of eight to 11 years. They found no difference in clinical outcomes and 100% survivorship of implants in both groups. Baker et al\textsuperscript{80} reviewed a group of patients randomised to either a cemented or cementless prosthesis with a follow-up of 15 years and found no difference in survivorship between the two groups. Revision rates were reported to be 8.7% in the cemented and 8.9% in the cementless cohort. Park and Kim\textsuperscript{83} performed a prospective study of 100 patients randomised to receive either a cemented or cementless version of the same device, with a mean follow-up of almost 14 years. They showed no significant difference in outcomes or survivorship between the two groups.

Authors have addressed concerns regarding stress shielding in cementless TKAs. Bone loss can be caused by stress transfer from the proximal to distal tibia, and this occurs in cemented, as well as cementless implants. Chong et al\textsuperscript{84} showed that the proximal stress shielding seen in TKA ranged from 11% to 29% at five years. Their study showed that the amount of shielding was actually greater in fully cemented tibial baseplates. Small et al\textsuperscript{85} studied 67 cemented and 67 cementless knees for 15 years and found that age, length of follow-up, gender, and body mass index all influenced BMD, with no differences between the cemented and cementless groups.

Two meta-analyses\textsuperscript{85,65} have compared cemented versus cementless fixation in TKA. In 2009, Gandhi et al\textsuperscript{86} used aseptic loosening as the end-point for their analysis, with the Knee Society Score as their secondary end-point. Their analysis showed a statistically significant improvement in survivorship of the cemented TKA, but they were unable to show any differences in clinical outcomes between the two groups. In a 2014 meta-analysis, Wang et al\textsuperscript{85} found that cemented TKA offered better survivorship than cementless TKA. However, when design-related TKA failures were excluded, there was no difference in the survivorship between cemented and cementless TKA.

**Hybrid.** Hybrid TKA, traditionally a cementless femoral component with a cemented tibial baseplate and patella, appeals to some surgeons. Studies have shown equivocal or superior fixation when compared with fully cemented TKA.\textsuperscript{62,86} Chockalingham and Scott\textsuperscript{62} reported a loosening rate of 9.8% with cementless femoral components as opposed to 0.6% with cemented femoral components, and Campbell et al\textsuperscript{86} found a higher revision rate in cementless TKA. Other more recent studies have shown improved results.\textsuperscript{87,88}

In a retrospective study, Illgen et al\textsuperscript{88} showed that in 112 patients who underwent hybrid TKA, there were no failures caused by aseptic loosening at ten years. Demey et al\textsuperscript{87} showed no benefit of cement compared with hybrid fixation in a series of 130 knees randomised into groups with a minimum two-year follow-up. Nilsson et al\textsuperscript{88} and Gao et al\textsuperscript{84} found hybrid femoral fixation to be comparable to cemented fixation in terms of survivorship.

**Comparative studies.** The literature concerning results of TKA with cementless versus cemented versus hybrid fixation is unclear regarding survivorship and outcomes. The cementless literature is less robust, with fewer patients and randomised controlled trials. Most studies do not control for variables such as bone quality, patient selection, patellar resurfacing, and whether the devices preserve or sacrifice the posterior cruciate ligament, are mobile or fixed bearing,
or have bioactive coatings. Studies show that there is no difference in clinical outcomes in cementless, cemented, or hybrid devices.

A review of two joint registries shows mixed results concerning survivorship when comparing the various fixation methods for TKA, with an overall inferior outcome for cementless knees. The 2012 Australian Orthopaedic Association National Joint Replacement Registry annual report shows ten-year failure rates of 6.3% for cementless TKAs, 5.3% for cemented TKAs and 5.0% for hybrid TKAs. The 2013 report of the National Joint Registry for England, Wales, Northern Ireland, and the Isle of Man showed that only 6.1% of TKAs in the registry had been performed in a cementless or hybrid fashion. This number had fallen by approximately one third since 2003. Results showed little overall difference in implant survivorship among the fixation types and no definite advantage of a mobile-versus fixed-bearing design. In 2012, the Canterbury District Health Board reported its 14-year results in terms of revision rate per 100 component-years. The results showed revision rates of 0.90% for cementless TKAs, 0.48% for cemented TKAs and 0.50% for hybrid TKAs, with loosening of the tibial component in cementless designs being the number one cause of failure.

The most recent New Zealand registry revealed that cementless TKA represented only 4% of TKAs and had a significantly higher revision rate. The majority of these cementless knees were of one type (LCS, DePuy Synthes, Warsaw, Indiana). A review of the Swedish registry from 2015 shows a consistent pattern. Despite a slight increase in the use of cementless TKAs, there is low usage along with higher revision rate for cementless devices. The registry reports that when using Cox regression analysis controlling for age, gender, year of surgery and use of a patella, the risk of revision associated with cementless tibial component was 1.6 times higher than that for a cemented tibial component.

A Cochrane review of cementless, cemented, and hybrid TKA fixation was published in 2012. It concluded that cementless tibial components had more displacement than the cemented tibial components in RSA studies, but that cemented tibial components had a greater risk of loosening when evaluated by RSA. They also found no indication that either fixation method resulted in better clinical outcomes.

**Summary**

This review supports the viability of cementless TKA. However, many questions remain to be clarified regarding patient selection, implant design, as well as optimal rehabilitation protocols. However, the quality of publications examining these topics is improving and increasing.

The data in large series of patients with long-term follow-up of cementless TKA are similar to the reported results of cemented TKA with similar follow-up. Registry data are inconclusive in terms of showing an advantage of one type of fixation versus another. The recent publications (Table I) show better results than earlier reports.

Progress has been made in cementless implant design in terms of metallurgy, sizing and surface fixation. Improvements in polyethylene and kinematic topographies have been introduced into cementless and cemented devices. Instrumentation has improved, which should allow for more accurate bone preparation. Lessons have been learnt concerning the importance of initial implant stability.

This knowledge should lead to improved outcomes for cementless TKA, but will require confirmation in future studies. The cemented TKA arguably remains the reference standard and has strong scientific data to support its continued position. As the demographics and expectations of future patients requiring TKA change, the interest in cementless TKA will likely continue to rise. Further study is needed before the correct role of cementless TKA is clarified.

**Take home message:**

We have concluded that although interest in the use of cementless TKA has increased, further study is required to delineate its role.

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