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Uncemented Total Knee Replacement - Rediscovering the Past

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Abstract

Total knee replacements (TKR) both cemented and uncemented were developed almost simultaneously in the 1980's. Cemented TKR found favor among the surgeons due to its technical ease and early failure of uncemented TKR due to poor design. In the past two decades; however, interest has been generated in uncemented TKR both because of design improvements which, in turn, has led to better results, especially in young active, obese, and active geriatric patients but active patients where cemented TKR's have been found to have increased failure rates. Active research is ongoing to refine the designs of uncemented TKR and future holds promise for this re-emerging technique and implant. This review helps to summarize the reasons for increasing interest in uncemented TKR, the newer designs and their results and the future developments expected.

Keywords: Uncemented total knee replacement, cementless total knee replacement

Introduction

Total knee replacement (TKR) historically has been done as treatment for sedentary elderly patients with end stage knee arthritis to offer painless mobility. While uncemented and cemented TKR were developed almost at the same time cemented TKR has found favor among surgeons. Early failures of uncemented TKR and better results with cemented TKR meant that cemented TKR were widely adopted. A study of various registries including NJR-England, New Zealand, and Swedish ones show that 85–95% of the surgeons preferred cemented TKR [1].

History of Cementless TKR

Uncemented TKR was first reported in late 1980's where interest was generated for its comparable mid-term results in young patients as compared to cemented TKR [2, 3]. The potential advantages considered were the osteointegration of the prosthesis with native bone providing better long-term survival of the prosthesis in younger patients. The implant bone interface was thought to be dynamic in that it would adapt to changing stress patterns in active patients. A shorter surgical time (save cementing), potential for bone preservation, easier revision due to absence of cement, potentially less damage to bone (caused by the exothermic process may damage bone), and lesser osteolysis due to lesser wear particles (cement bone junction) were the other potential advantages thought to be associated with cementless implants.

While early research showed promising results, increasing number of research papers demonstrated osteolysis, loosening, and failure of the tibial component [3,4].

Early failures of uncemented TKR were attributed to metal backed patellae [4], smooth finish on the under surface of the implants [5], porous coating that debonds from the prosthesis [6], and the use of titanium alloy for the femoral component [7].

Why Cemented TKR Gained Prominence

In the early 21st century a randomized control study showed a survival rate of 91.7% and 93.3% for cemented and cementless PCL sparing press fit condylar TKR at 10 years. The same authors reported a 15-year survival of 80.7% and 75.3% for cemented and uncemented TKR. The authors inferred that the cost of uncemented TKR could not be justified by the lower revision rates or improved survival rates at 10 years [8, 9].

Uncemented TKR implants are costlier than cemented implants due to the high costs of manufacturing bioactive surfaces. Uncemented TKR was technically challenging as the bone cuts had to be accurate with very little margin

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Table 1: Lists some of the salient meta-analyses published in last the decade

S. No.	Authors	Year of publication	Type of study	Inference	Drawbacks and comments
1	Gandhi*et al*. [13]	2009	Meta-analysis	Overall cemented prosthesis better than uncemented in terms of survival Subgroup analysis of only RCT's show that both are equal in terms of survival	Meta-analysis of 5 RCT's and 10 observational studies
2	Voigt *et al*. [14]	2011	Meta-Analysis	Using Radio-stereometric analysis – HA coated tibial components are less likely to be unstable at 2 years than porous uncemented and cemented prosthesis The addition of screws in the tibial base plate increases instability of the base plate No difference in clinical outcomes and adverse events including loosening and infection at 2 and 5 years	Meta-analysis of 14 RCT's. Cost effectiveness of HA coated implants could not be proven
3	Wang *et al*. [15]	2013	Meta-analysis	Excluding design related failures uncemented TKR's have similar survival as cemented over 5 years The incidence of infection in two groups was same	Meta- analysis of 3 RCT's and 6 retrospective case series. Many known and unknown confounding variables
4	Zhou*et al.* [16]	2018	Meta-Analysis	No difference in the implant survivorship, MPTM, radiolucent line and clinical outcomes at mean 7.1 years (Range 2–16.6 years) among cemented and uncemented TKR	Meta-analysis of 7 RCT's. All RCT's used a PCL retaining fixed bearing prosthesis None of the studies used screws to assist in tibial fixation
5	Wang *et al.* [17]	2019	Meta-analysis	Cementless TKA was associated with higher KSS-function ($P <$ 0.0001), higher KSS-pain ($P = 0.005$), better ROM recovery ($P = 0.01$), and fewer radiolucent lines (<1 mm) ($P = 0.04$) compared with cemented TKA. No difference in total complications, aseptic loosening, or reoperation rate	Meta-analysis of 6 RCT's of patients under 65 years of age (mean age between 54 and 58.4 years). All the TKR's were fixed bearing PCL retaining prosthesis with no screws used in tibial prosthesis
6	Horváth*et al*. [18]	2020	Meta-analysis	MPTM of the HA uncemented tibial stems had no difference as compared to cemented ones and was lower than that of uncoated uncemented tibial stems The knee society scores and knee function scores of both HA coated TKR and cemented TKR was similar	Meta-analysis of 11 RCT's. MPTM at 2 years of more than 0.2 mm considered a sign of instability
8	Prasad *et al*. [19]	2020	Meta-Analysis	No difference in revision rate and post-operative knee function scores and outcomes at a mean of 8.4 years (range 2–16.6 years)	Meta-analysis of 6 RCT's. In 2 studies HA coated, 2 studies press fit and one trabecular metal and one study low contact stress implants were used.
5	Liu*et al*. [20]	2021	Meta-analysis	Uncemented TKR did not decrease the rate of revision as compared to cemented TKR Uncemented TKR patients had better functional score and lower rate of manipulation. Other complications such as infection were similar. Aseptic loosening was significantly lesser in uncemented TKR	Meta-analysis of 11 RCT's and 15 non-RCT's Included studies were mostly with follow up less than 10 years
6	Chen *et al*. [21]	2021	Meta-Analysis	At a mean 8.8 years follow-up (8.8–16.6 years) uncemented TKR had Knee society score, function and pain scores, WOMAC score, HSS score and range of movements equivalent to cemented TKR Radiolucent lines >2 mm was more common in cemented TKR MPTM on RSA <1 mm was more common in uncemented TKR	Meta-analysis of 8 RCT's. All RCT's used a PCL retaining fixed bearing prosthesis. None of the studies used screws to assist in tibial fixation

of error. Cemented TKR was a more surgeon friendly procedure as minor errors in bone cuts could be filled with cement mantle. All these factors made cemented TKR the gold standard treatment and surgeon's choice.

Re-emergence of Cementless TKR

The indications for TKR expanded after the initial success in geriatric patients. TKRs were increasingly being done in younger patients, obese patients and in active geriatric patients with a longer life expectancy. Over a period of two decades, it was realized that cemented TKR had a higher failure rate in patients younger than 55 years and in obese patients [10], due to the higher stress over the implant bone junction as compared to sedentary geriatric patients. The rate of obesity in Indian and American population is projected to increase alarmingly in the immediate future. In India, the prevalence of obesity is stated to be between 11.8% and 31.3% and projected to increase with time [11]. Similarly, the proportion of males more

than 65 years of age has been estimated to increase from 32.37% to 42.84% and females more than 65 years of age from 33.82% to 44.68% over the past decade in India. The Life expectancy at birth has improved from 64.9 years to 69.4 years in males and from 68.2 to 72.8 years in females over the past decade [12]. With an increasing geriatric population and a higher life expectancy along with younger and obese population needing knee replacements; there is a need for biological fixation which would improve longevity of the index TKR and decrease the need for revision.

A significant number of randomized trials and retrospective studies have been published in the past decade comparing cementless and cemented TKR. Last few years have seen some meta-analysis and systematic reviews of the previously published studies. Table 1 lists some of the salient meta-analyses published in last the decade.

A cursory look at the above table shows how the narrative has changed over the past decade. Results of design improvements of uncemented implants are reflected in these studies. Randomized control trials and their meta-analysis have demonstrated better results especially in the past 5 years. Interestingly, a study published after a 10 year gap by hospital for special surgery, signals a change in trend to uncemented TKR from cemented TKR which it had endorsed earlier [1, 22].

Other Positive Developments

Infection rate

A lower rate of infection (1.2%) and increased probability of retaining the prosthesis in cases of post-operative infection with <1/4th the cases needing a revision of the prosthesis have been reported with uncemented TKR [23]. The rest needed only an arthroscopic or open debridement. This has been attributed to the absence of an avascular bone cement interface [24].

Age

Uncemented TKR has been shown to produce equally good results in elderly above 75 years of age [24]. The presence of rheumatoid arthritis and osteonecrosis is also not a contraindication in these geriatric groups of patients as implant survival as high as 98.6% have been reported at mid-term follow-up of 4 years [25].

Tourniquet time

Uncemented TKR requires on an average a significantly less tourniquet time (45.7 vs. 54.8 min) and a lower rate of manipulation as compared to cemented TKR. The blood loss has also been reported to be lower, although not of statistical significance [26].

Rheumatoid arthritis

Rheumatoid arthritis is associated with osteopenic bone and has been viewed as a relative contraindication for uncemented TKR in the past. With recent advances, the implant survivorship at 5 years was 99.2% with only one aseptic failure in 126 TKRs done [27].

Osteonecrosis of knee

Osteonecrosis of knee has also been seen as a relative contraindication for uncemented knee as any remnant or newly developed dead bone under an uncemented prosthesis would lead to loosening and aseptic failure. A prospective study of 49 TKR's at a mean follow-up of 3 years had a survival of 97.9% with one aseptic and septic failure each. The functional outcome in the patients was considered excellent with KSS pain score of 93 and KSS function score of 84 [28].

Cost effectiveness

The overall increased survival and better results of uncemented TKR has allowed for relook into the cost dynamics of this procedure using modern methods and recent change in costs. Uncemented TKR is on an average is $ 366 costlier than cemented implants. Cost of cementing, including cement, could increase the price from $170 for normal cementing to $ 1043 for vacuum cementing along with all its consumables. Cemented TKR took an average 11.6 min more which translated to an additional cost of $ 418. Other factors like a lower infection rate, lower blood loss, lower cement related systemic complications, and opportunity cost of saved time if also taken into consideration would make uncemented TKR more cost effective [29]. Another retrospective study also seconded this finding asserting that the increased cost of uncemented TKR implant was recouped through savings in the lower cement costs and shorter operative times [30].

Not all agree though and a study of the National Inpatient Sample database has shown higher inpatient costs for uncemented TKR while also stating that these patients had a lesser inpatient stay and higher odds of being discharged home. A long-term study is required to ascertain the cost benefits of uncemented TKR [31].

Uncemented TKR in Young Patients

Cemented tibial components have a cement bone interface which is exposed to shear forces which, in turn, makes it prone to loosening in the long-term. Cemented TKR's in patients less than 55 years have been reported to have revision rates of 4.7–5 times as compared to those above 70 years [32].

In young patients, uncemented TKR's appear to be better as reported in some recent meta-analysis. Uncemented TKR's have been found to have better pain scores and radiological outcomes at 2–13.6 years follow-up. Clinical outcomes and rate of complications such as aseptic loosening were similar [33]. A meta-analysis of randomized and non-randomized control trials in 2021 with a follow up of 2–5 years found a significantly lower aseptic loosening,

revision rate, and better functional recovery with uncemented as compared to cemented TKR [20].

Even in vivo during revision of knee replacements, there was no difference seen in the fixation strength of uncemented versus cemented stems [34].

Not all studies though support uncemented TKR for young patients. A registry data of 778 patients younger than 55 years reported better survival for cemented implants at 14 years follow-up. The fact that 738 cemented implants were compared with 40 uncemented implants in a retrospective fashion makes the reliability of this data questionable [35].

Further long-term studies are needed to conclusively prove that uncemented TKR is the way forward in younger population.

Cementless TKR in Obese Patients

According to American Association of hip and knee surgeons a BMI >40 is the threshold from where the complications in TKR become significant [36]. Most of the studies and meta-analysis consider a BMI >30 as the threshold where complications and poor results become significant [37]. These initial studies did not distinguish between cemented and uncemented implants.

Later studies, comparing uncemented versus cemented TKRs in morbidly obese patients (BMI >40) reported that cemented TKR had higher rates of aseptic loosening and other complications as compared to uncemented TKR. Failure rate of 5.4% for uncemented TKR's as compared to 25.9% for cemented TKR's at 8 years was observed. The survivorship at 8 years was 88.2% for the cemented TKR's and 95.4% for the uncemented group [38]. A more prolonged follow-up yielded a 79.6% survival at 15 years for cemented TKR [39].

The probable mechanism postulated being the cement bone interface fails due to increased stress and shear forces. The relatively increased quantum of wear particles generated due to the increased weight per surface area also may contribute to aseptic loosening of cemented prosthesis [40].

While some studies have published contradictory results, doubts were raised if these studies were adequately powered and the fact that they contained a mixed population of cemented and uncemented TKR's [41,42].

To summarize it may seem prudent to advise uncemented TKR in obese patients with BMI >30.

Implant Designs and Their Results

Over the years uncemented implants have undergone a lot of change in terms of design with resultant improvement in results. The traditional points of discussion of PCL sparing versus posterior stabilized, fixed versus mobile bearing, and various types of implant bone interface make this a rather difficult exercise. Some of the most commonly used implant types and their results have been discussed in the section below.

PCL sparing versus posterior stabilized uncemented TKR

Very few studies have addressed the comparison of PCL sparing versus posterior stabilized TKR.

At an average 8 year follow-up of HA coated posterior stabilized knee the all cause survivorship has been 98% with a knee society pain score of 93 points and function score of 78 points [43].

A 13-year survival rate in a small cohort of 54 patients has also been reported to be 96.7% with PCL retaining Co-Cr prosthesis with Co-Cr beads at the implant bone surface [44].

Similarly, a PCL sparing total condylar prosthesis has also shown a 10-year survival of 97% in one study [45] and 75.3% at 15 years in another; although in the later instance the survival was at par with its cemented counterpart [9].

The results in both PCL sparing and posterior stabilized uncemented TKR seem to be comparable.

Rotating platform versus fixed bearing uncemented TKR

Rotating platform designs have been postulated to decouple femoral liner and tibial liner articulations, thereby reducing poly wear and improving knee dynamics. At a mean follow-up of 18 years in 141 knees with a mean age of 71 years; the implant survivorship for all causes of revision was 97.4% with acceptable patient satisfaction and function scores. Out of the 141 knees, there was one case of aseptic loosening and three cases of insert spin off were observed. The authors asserted that on review of the literature the incidence of instability and dislocation was much higher in fixed bearing prosthesis [46]. A 10-year survival of 98.9% has also been reported with only one aseptic loosening in 140 knees for a rotating platform design [47].

On the other side a meta-analysis of seven randomized control trials of PCL sparing fixed bearing prosthesis found survival and clinical results were no different from cemented prosthesis. The longest follow-up of a PCL sparing fixed bearing prosthesis at 17 years reported a survival rate of 98.7% in patients younger than 55 years [48].

Although there are no studies at present comparing PCL sparing and posterior stabilized uncemented TKR, both options have given equally good results. The choice would rest on surgeon preference and training. Future long-term level 1, comparison studies are warranted in this field.

Monoblock versus modular tibial polyethylene insert

Scant data exist on this topic in uncemented TKR. Backside wear due micro-movement between polyethylene insert and metal baseplate and the resultant aseptic loosening of modular tibial prosthesis have been postulated. A

2 year follow-up on radio-stereometric analysis (RSA) of uncemented implants has shown that both modular and monoblock tibial designs show increased Maximum total point motion (MPTM) till 3 months after surgery after which it stabilizes. At end of 12 and 24 months, the MPTM of modular design was more than monoblock design. The clinical outcomes, were similar and longer follow-up would be necessary to assert the difference in implant survival [49].

The RSA pattern does sustain even with excellent clinical results at 9 years, even in patients younger than 60 years with excellent outcomes and average knee flexion of 130° [50].

The discussion thus remains open to further investigation.

Type of Implant Surfaces

Various implant surfaces have been designed and tested by different manufacturers. These can be beaded, irregularly roughened, plasma sprayed, meshed or made to mimic bone like porous structure as in tantalum. These can be coated or left alone. A brief update of the results of the surfaces and the various coatings of those surfaces is given below.

Surfaces

Trabecular metal

Trabecular metal or porous tantalum is a highly porous 3D structure which may or may not be coated with titanium. This surface offers a high coefficient of friction (u = 0.88) for high initial fixation strength, high porosity with interconnected pores for bone ingrowth and a modulus of elasticity equal to bone which allows for bone ingrowth and diminished stress shielding. No aseptic loosening has been reported after 10–13 years with a 10-year survival rate of 96.9% using a monoblock tibial prosthesis and cemented femoral component [51]. The 5 year survival of metal backed fixed bearing TKR has been shown to be 99.5% with functional outcome similar to cemented TKR [52]. Even in younger patients <60 years at average 10 years loosening were reported in only 1% cases with a survival of 94% [53].

Uncemented monoblock cruciate retaining trabecular metal TKR has been shown to have the same migration patterns as a posterior stabilized knees with equal clinical scores at 9 years.

To substantiate further a meta-analysis of six randomized and non-randomized studies reported a slightly better functional outcome, lesser radiolucent lines and shorter surgical time of the trabecular metal uncemented prosthesis (both cruciate retaining and posterior stabilized) as compared to cemented TKR at average 5 years follow-up. Other outcomes such as reoperation, loosening, complications, infection, and range of movement were not significantly different from its cemented counterparts. Overall trabecular metal uncemented prosthesis was not found to be greatly superior to cemented prosthesis and further studies are needed to substantiate its superiority [54].

A study of radiolucent lines on X-rays of trabecular metal backed prosthesis found these lines were found most frequently at 2–6 months, mostly around the medial peg and may increase in size up to 1 year and there after decrease in size till 3 years. Any progressive radiolucent lines beyond 1 year associated with clinical findings should be taken seriously [54].

Titanium mesh

Ten year follow-up studies of other types of uncemented surface like titanium mesh have also shown equivalent migration to cemented counterparts and equally good clinical results even in patients <60 years. A variation of that where randomly arranged titanium beads either coated with HA or uncoated are available [55].

Surface Coatings

Hydroxyapatite (HA) coated implants

HA coating of the implant at the bone interface promotes early fixation and stability as compared to cemented and porous coated implants [14]. Similarly, it may shield the joint from debris at implant bone junction by forming a biological seal [56].

The longevity of HA coated cementless prosthesis and loosening rates have been studied on radiographs and radiostereometric analysis.

With respect to radiolucent lines, fully HA coated implants are better than partial coated ones. Radiolucent lines at the bone implant junction were observed around the uncoated portions of 31–42% of femoral and 33% of tibial portion of partially HA coated prosthesis as compared to <3% of knees with fully HA coated prosthesis. Earlier thought to be precursor of aseptic loosening these lines were found to be not of any clinical significance [57].

Radiostereometric analysis: Radiostereometric analysis has been used to study micromotion and instability at the bone implant interface and hence the probability of implant loosening. A meta-analysis of 11 RCT's inferred that although HA coated uncemented tibial prosthesis have more MPTM as compared to cemented counterparts it does not affect the loosening, longevity, or clinical results in patients. HA coating significantly decreases micro motion as compared to non-coated uncemented implants [18]. RSA at 10 years have shown that HA coating reduces migration of cementless tibial components even as cemented ones fared better. This increased migration was not clinically significant [58]. A Cochrane database review also found the displacement of HA coated tibial prosthesis to be more than that of cemented ones at 2 years. However, the risk of further subsidence and instability was more with cemented ones as compared to the uncemented ones. Meta-analysis of the clinical outcomes could not be done but all the RCT's in the study reported equivalent outcomes

[59].

Clinical Outcomes with HA Coated Prosthesis

One of the early designs of uncemented implant had a survival rate of 84.4% at 20 years with failures primarily attributed to early tibial and late patellar component failure [60]. Later implants with better designs with a fixed bearing poly insert and additional titanium screws in the tibial plate had a survival rate of 97.1% at 15–22 years follow-up taking implant failure as an end point and 91.4% considering all causes of failure. The authors emphasized that these results are better than cemented or other designs of cementless TKR [57]. What is interesting to note is addition of titanium screws to tibial base plate has been reported in another study to increase chances of loosening as it acts as a surface for generation of debris [14]. The addition of titanium nitride screws to a HA coated titanium alloy tibial component with CoCrMo femoral stem may have improved the cumulative survival rate at 10 years with revision as end point to 99.14% [23]. Another HA coated fixed bearing prosthesis has also shown 96% survival at 10 years with aseptic loosening as an endpoint and 94.5% survival due to all causes as endpoint [61].

Titanium nitride coating

Cobalt chromium alloy and titanium implants while being ideal bearing surfaces for joint replacement, concerns have been raised regarding the blood levels of these metals and its potential long-term effects. Hence, coating these metal surfaces with inert compounds such as titanium nitride have been studied.

While titanium nitride has been shown to reduce wear in vitro studies, the benefits are not visible in clinical studies where the pain, functional outcomes, loosening, and revision rates were similar at 10 years in a level 1 study [62, 63]. One advantage may be lower blood levels of metal ions such as cobalt, chromium, and nickel in these patients which may have a potential health benefit [64].

Titanium nitride coating and zirconium nitride coating may have a place in patients with hypersensitivity to implants containing nickel (most common), cobalt, or chromium. These coatings allow the implant to retain its advantageous tribological qualities while negating hypersensitivity reactions [65].

Periapatite coating

Periapatite being a highly crystalline liquid allows for better coating demonstrated by decreased migration of tibial components at 10 years as compared to uncoated ones on RSA [66]. Periapatite coating has shown similar clinical results and loosening rates as compared to titanium coating over trabecular metal [67].

The search for an ideal implant bone interface is a continuous process with ongoing research. The longest follow-up available is with HA coated implants while trabecular metal is one of the latest discoveries holding promise.

Future of Cementless TKR

3D printing and robotic assisted TKR

3D printing is finding increasing applications in knee replacement. The longevity of uncemented TKR relies on the early press fit, surface area for bone ingrowth, and optimal alignment of the implant.

3D printing is used presently to manufacture the complex porous structure of the implant bone interface using tantalum or titanium. Similarly, manufacturers are planning patient specific instruments and patient specific implants based on 3D printing using CT scan data done preoperatively. These technologies will help to eliminate to a large extent surgeon error in taking bone cuts and implanting the prosthesis and to achieve optimal alignment implant fit [68, 69].

Long-term results of these 3D printed surfaces are awaited but short-term results appear promising [70].

3D printing has also application in complex TKR with previous implants in situ. It helps in planning selective removal or retaining previous implants while achieving accurate implant position. It also helps in planning the implant size especially on femoral side while achieving an alignment at par with navigation systems. The only disadvantage of this technology is the additional cost and manufacturing time required [69].

Robotic assistance and navigation enabled TKR can also help in reducing bone and soft-tissue trauma while improving accuracy of alignment [70].

Conclusion

In the last decade, due to the technological advancement in the implant designs of uncemented TKR and improved acceptance in the surgeon community, uncemented TKR has shown mid-term results at par and sometimes better than cemented implants. While uncemented implants may not completely replace cemented implants they surely can be useful in young patients <60 years of age, obese patients with BMI >30, geriatric patients with high activity levels and high risk patients where cementing of bone is either undesirable or contraindicated. Relative contraindications may be severe osteoporosis, limited life expectancy and surgeons who are either not trained, or low volume surgeons.

With further advances and more robust clinical data, cementless TKR is likely to find a more deserving place in future.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

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