MENTORS IN ORTHOPEDICS

NEW PERSPECTIVE IN CEMENTLESS TOTAL KNEE ARTHROPLASTY

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SUMMARY

Background: Total knee arthroplasty (TKA) remains a high-volume procedure with an increasing demand projected through 2030. While cemented fixation is the established gold standard, concerns regarding the polymethylmethacrylate interface and aseptic loosening of the tibial component have led to a resurgence of interest in cementless designs.

Objective: This review evaluates contemporary cementless TKA systems, focusing on advancements in biomaterials, tibial fixation strategies, and specific surgical techniques required to optimize biological osseointegration.

Key Points: Modern cementless implants utilize osteoconductive materials such as hydroxyapatite, porous tantalum, and 3D-printed titanium to facilitate bone ingrowth. Tibial component designs have evolved from simple pegs to complex configurations involving central keels and peripheral spikes to enhance primary stability and minimize micromotion. Clinical success depends on precise surgical execution, including the mitigation of thermal necrosis through cryocompression and cooled irrigation during osteotomy. Achieving a perfectly flat, symmetrical tibial resection and ensuring cortical contact for the baseplate are critical for long-term fixation. Furthermore, femoral components now incorporate specialized coatings, such as oxidized zirconium or titanium niobium nitride, to reduce ion release and polyethylene wear.

Conclusion: Innovations in porous surfaces and implant geometry have improved the primary stability and mid-term survivorship of cementless TKA. When combined with meticulous bone preparation and temperature control during surgery, these designs offer a viable alternative to cemented fixation, particularly for younger, active, or obese patient populations.

KEYWORDS

Arthroplasty, Replacement, Knee; Bone Cements; Osseointegration; Porous Materials; Tibia

INTRODUCTION

Total knee replacement is one of the most frequently performed procedures in orthopedic surgery. Arthritis is a common disease that is estimated to affect approximately 78.4 million adults until 2040. It is expected an increasing demand for total knee arthroplasty (TKA) due to the high number of arthritis patients among baby boomers by 2030 [1]. TKA has been implanted with cemented and cementless fixation for many years. Cemented fixation has been considered the gold standard with high survival rate at long follow-up [2]. Nevertheless, cemented fixation has still some bias considering the presence of a “weak” link represented by the polymethylmethacrylate interface. Uncemented knee replacements have been developed with the rational of offering a more durable biologic fixation without the potential of third-body wear from cement particles. Initially this was enthusiastically received but through the various decades cemented TKA remained the gold standard [3].

Although several studies report similar outcomes between cementless and cemented TKA, a major concern remains aseptic loosening of the cementless tibial component [4], which is particularly relevant in certain cohorts, especially women over 75 years of age with poor bone quality [5].

Another debated point was the pure implant cost which is generally higher for cementless TKA and has limited its use [6]. Recently, it has been observed that the reduction of the overall procedural cost of implanting a cementless TKA has made net costs even more favourable than a cemented one [7].

Cementless TKA procedure is associated with a surgical time reduction [8], avoid cement-related thermal complications [9], and allows greater bone preservation with potentially more bone stock available at revision if well-ingrowth implant extraction is not detrimental [10].

Over the last few years, there has been a renowned interest in cementless TKA [11]. Advantages at long-term for younger, more active and overweight patients has been demonstrated in the meanwhile [12],[13]. Excellent implant survival of cementless TKAs has been observed with the recent designs and materials, although still with short follow-ups [14],[15].

The development of new materials and different designs, especially for the tibial component, opens new perspectives for the use of cementless TKA as the potential new gold standard in a specific population [16].

DESIGN OF PROSTHESES AND COATING MATERIALS

First generations of cementless TKAs showed several issues, mainly in the tibial side (Table 1 and 2). Common problems included short or inadequate primary fixation, patchy fixation surfaces with limited secondary fixation, disassembling of sintered coatings [4]. Implant manufacturers have improved materials and designs of their cementless TKA portfolio through the years. It is the purpose of this paper to review the most modern and most representative cementless TKA options of the various companies in the market.

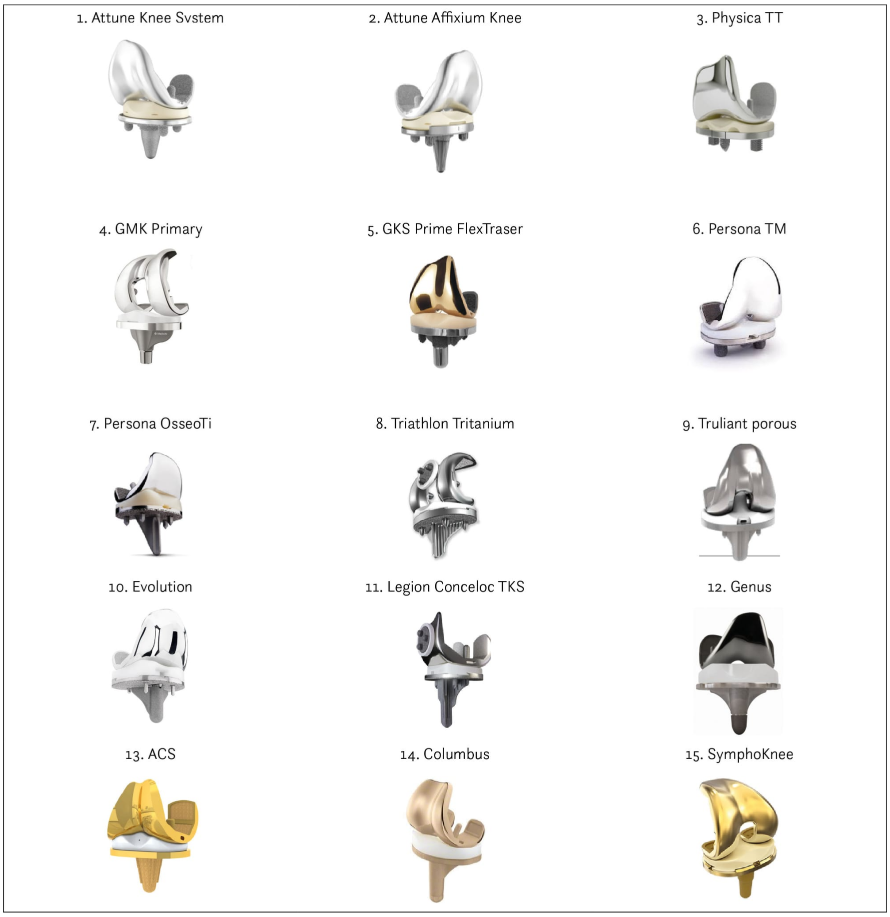

Table 1: 1. ATTUNE Cementless Knee System (DePuy Synthes); 2. ATTUNE AFFIXIUM Knee (DePuy Synthes); 3. Physica TT Tibial Plate (Lima Corporate); 4. GMK Primary (Medacta Corporate); 5. GKS Prime Flex Traser (Permedica Orthopaedics); 6. Persona Trabecular Metal (Zimmer Biomet); 7. Persona OsseoTi (Zimmer Biomet); 8. Triathlon Tritanium (Stryker); 9. Truliant Porous Knee (Exactech); 10. Evolution (Microport); 11. Legion Conceloc TKS (Smith & Nephew); 12. Genus (Adler Ortho); 13. ACS (Implant cast); 14. Columbus (Aesculap B Braun). 15. SymphoKnee (Link)

	DePuy Synthes		Lima Corporate	Medacta International	permedica ORTHOPAEDICS	ZIMMER BIOMET	
	1. Attune Knee System	**2.Attune Affixium Knee**	**3. Physica TT**	**4. GMK Primary**	**5. GKS Traser**	**6. Persona TM**	**7. Persona OsseoTi**
FEMORAL COMPONENT MATERIAL	Cobalt Chromium Molybdenum alloy	Cobalt Chromium Molybdenum alloy	Cobalt Chromium Molybdenum alloy + Titanium nitride and niobium coating	Cobalt Chromium Molybdenum alloy	Titanium Aluminium Vanadium alloy + titanium nitride and niobium coating	Cobalt Chromium Molybdenum alloy	Cobalt Chromium Molybdenum alloy
TIBIAL COMPONENT MATERIAL		Titanium alloy	Titanium Aluminium Vanadium alloy		Titanium Aluminum Vanadium alloy	Titanium Aluminum Vanadium alloy	Titanium alloy
TIBIAL COMPONENT FIXATION TYPE	Spiked keel + 4 radial cylindrical pegs	Extended central cruciform keel + 4 peripheral octagonal porous pegs	2 posterior hexahedral pegs + 1 anterior tetrahedral spike	Winged keel	Antirotational flange + 4 square anchoring pegs	2 hexagonal pegs	Spiked keel + 4 eccentric quadrilateral pegs
OSTEOINTAGRATING STRUCTURE	Porocoat Sintered Titanium metal beads	Porocoat (femur) / 3D printed titanium (tibia)	Plasma Spray (femur) / 3D printed trabecular titanum (Tibia)	MectaGrip CoCr beads / Titanium plasma spray Hydroxyapatite double coating	Traser Trabecular laser melted Titanium	Porous plasma spray (femur) / Trabecular metal Tantalum	Porous plasma spray (femur) / OsseoTi porous metal 3D printed Titanium Aluminum Vanadium alloy

Table 2: Prosthesis Characteristics

stryker	Exactech	MicroPort Orthopedics	smith&nephew	ADLER ORTHO	implantcast	AESCULAP B BRAUN	LINK
8. Triathlon Tritanium	**9. Truliant porous**	**10. Evolution**	**11. Legion Conceloc TKS**	**12. Genus**	**13. ACS**	**14. Columbus**	**15. SynphoKnee**
Cobalt Chromium alloy + Periapatite coating	Cobalt Chromium alloy	Cobalt Chromium Molybdenum alloy + Titanium nitride and niobium coating	Titanium Aluminum Vanadium alloy + Oxided Zirconium coating	Cobalt Chromium Molybdenum alloy + Titanium nitride and niobium coating Anallergic choice	Cobalt Chromium Molybdenum alloy Titanium nitride coating	5 Transition Layers (CrN-CrCN-CrN-CrCN-CrN) + ceramic sufrace (Zirconium Nitrid Layer)	Cobalt Chromium Molybdenum alloy /Titanium Niobium Nitride (anallergic choice)
Titanium alloy	Titanium alloy	Titanium alloy	Titanium Aluminum Vanadium alloy	Cobalt Chromium Molybdenum alloy			
Spiked keel + 4 cruciform pegs	Dual V-channeled winged keel + 4 peripheral pegs	Winged keel + 4 peripheral pins	2 press-fit pegs and self preping ribs	Winged keel	Winged keel	Winged keel No pegs	spiked keel + 2 cylindrical pegs
Tritanium- 3D printed titanium laser beam to sinter numerous layers of porous titanium powder	Truliant Porous (Femur) Asymmetric Cobalt Chromium beads Truliant Porous (Tibia) 3D Printed Titanium Alloy	BioFoam® Cancellous 3D printed Titanium	Conceloc Advanced porous Titanium - 3D printed Titanium Aluminum Vanadium alloy	Ti-Por® 3D printed Titanium alloy Co-Por® 3D printed Cobalt Chromium + Molybdenum alloy + Hydroxyapatite	Implafix® Plasma spray cpTi commercialy pure titanium	Titanium microporous plasmapore surface	TiCap Double Titanium Calcium Phosphate

Table 2: Prosthesis Characteristics

1. Materials

Hydroxyapatite (HA), a biocompatible osteoconductive ceramic composed of calcium phosphate ($CaPO_4$), promotes de novo bone formation through its surface chemistry and topography. This property is advantageous in cementless TKAs, where HA coating applied to the metallic implant substrate enhances osseointegration by facilitating early bone apposition and subsequent conversion of the initial periprosthetic fibrous tissue into bone [17]. This type of solution, also in combination with other materials, has been adopted by numerous companies, including ©Medacta International, ©Stryker (for femur only) and Adler Ortho®.

Trabecular Metal™ (Zimmer Inc., Warsaw, IN, USA), is a biomaterial made from tantalum with excellent mechanical and biological properties. This type of porous material was introduced in orthopedic surgery in 1997. It has several advantages: it's flexible, strong enough for implants without needing a metal base and it has high coefficient of friction against bone (m ¼ 0.88), high volume (average 80%) and better-connected pores (550 µm) and low stiffness. Previous cell studies confirmed that osteoblast cells respond well to tantalum, supporting its long history as a safe biocompatible material [18],[19],[20].

Among materials with characteristics suitable for the development of cementless prostheses, titanium is one of the most widely used and popular. Titanium is a very porous material and different studies show it promotes bone growth, proving osteoinduction and osteoconduction properties, and blood vessel formation [21],[22]. One of the features to consider is the pore size, which must be approximately in the range between 100 and 600 microns. In fact, smaller pores lead to fibrous tissue growth instead of bone, while larger pores lead to slower and incomplete bone filling [18],[23]. Porosity should also be between 50-70%, to achieve a good balance between maximizing bone ingrowth and maintaining adequate mechanical strength of the implant. Several companies have developed proprietary materials with varying characteristics, starting from titanium. Products made from titanium have already been on the market for several years, such as Porocoat™ (DePuy Synthes). More recently, several companies are marketing products developed with different technique to give specific geometries and properties: 3D printing technology, such as Trabecular Titanium™ (LimaCorporate), Affixium™ 3DP Technology (DePuy Synthes), OsseoTi® Porous Metal (Zimmer Inc.), TiPor® and CoPor® (3D-Por® surface manufactured also in CoCrMo alloy) (Adler Ortho®), Tritanium® (©Stryker), Conceloc◊ (Smith&Nephew, Inc.), Truliant® Porous (Exactech, Inc.) ; Selective Laser Melting (SLM) technique, as Traser® (Permedica); titanium foam, as BioFoam (Microport Orthopedics, Inc), or spray, as Plasmapore® (Aesculap® B. Braun) and Mectagrip (©Medacta International).

2. Tibial component fixation type

As with the materials, different options have been developed for tibial component design, to obtain initial implant stability necessary to achieve adequate biological fixation in cementless TKA [24].

In the past, early tibial designs only had relatively small pegs, which did not guarantee adequate initial fixation. Screws and a central stem were added to try to improve stability and reduce micro-movement [25].

At the beginning of the 21st century, one of the most widely used prostheses was NexGen Trabecular Metal™ Monoblock Tibial Component (Zimmer), characterized by monoblock baseplate made of porous tantalum featuring two 16-mm-long hexagonal pegs. Several options have developed from this type of tibial component, such as Persona® TM, from the same company, which also features a tibial component with two hexagonal pins, but without being a monoblock component [26]. LimaCorporate decided to start from this kind of design without a keel, unlike other tibial component choices on the market, to allow for bone preservation and easy removal procedure, if necessary. Physica TT Tibial Plate was developed with two central hexagonal pegs and an anterior spike with the aim of reducing micromotions [27].

An hystorical common option is the use of a single central keel, with different shapes depending on the company: GMK Primary (©Medacta International), ACS (Implantcast®), Genus (Adler Ortho®) and Columbus (Aesculap®BBraun). The most common design option employed by several companies is characterized by a central keel with four pegs or spikes. Several studies[24],[28],[29] have shown better initial and long-term stability with this solution. Numerous companies have introduced this type of design, with different component shapes: Persona® OsseoTi® (Zimmer), GKS PRIME Flex TRASER (Permedica), Attune cementless knee system (DePuy Synthes) and its evolution Attune cementless Affixium™ 3DP Technology, Triathlon® Tritanium® (Stryker), Legion Conceloc◊ (Smith&Nephew, Inc.), Evolution® (Microport Orthopedics Inc.), Truliant® Porous Knee (Exactech, Inc.).

3. Femural coating

Metallic materials, inside the body, can be subject to corrosion and thus to the release of ions, which, in some cases may lead to hypersensitisation reactions. Various types of implant coatings are employed by manufacturers both to reduce sensitization issues and to smoothen rough surfaces such as titanium on the femoral component of cementless TKAs. Coatings are mave through various techniques, being physical vapor deposition (PVD) the most common one. One of the most effective surface treatments with excellent long-term survival results is OXINIUM® Oxidized Zirconium (Smith&Nephew). Titanium Nitride or Titanium Niobium Nitride has demonstrated excellent results as well to minimise ions release and reduce wear [30],[31]: Bioloy® (Permedica), TiN (Implantcast®), SensiTiN (©Medacta International), TiNbN (Adler Ortho®), NitrX™ (Microport Orthopedics Inc). Another solution was developed by Aesculap® B. Braun with Advanced Surface (AS), a multilayer coating consisting of seven layers of which the most external includes a ceramization process.

Bone manipulation with motorized instruments may raise temperatures (45°C, 47°C and the most severe at 60°C) to a level which induces bone necrosis and cellular depletion. Reducing the heating to a minimum promotes a greater osteointegrative capacity of uncemented components. Furthermore, it has been shown that a mild heat shock (below 47°C) for the duration that occurs during surgical cutting can even promote the proliferation of osteoprogenitor cells [32]. There are several strategies to reduce the risk of thermal necrosis:

1. With preoperative cryocompression (1 hour at 5 degrees Celsius) it is possible to reduce the bone temperature at 20-23° on average (WAC 2024, Baldini et al) (Figure 1).
2. Using a 1.27 mm saw-blade, and irrigating with 0.9% NaCl physiological solution (Figure 2) cooled
3. Reduction of cutting time to a minimum and using thinner blade may further reduce the risk of heating [33].

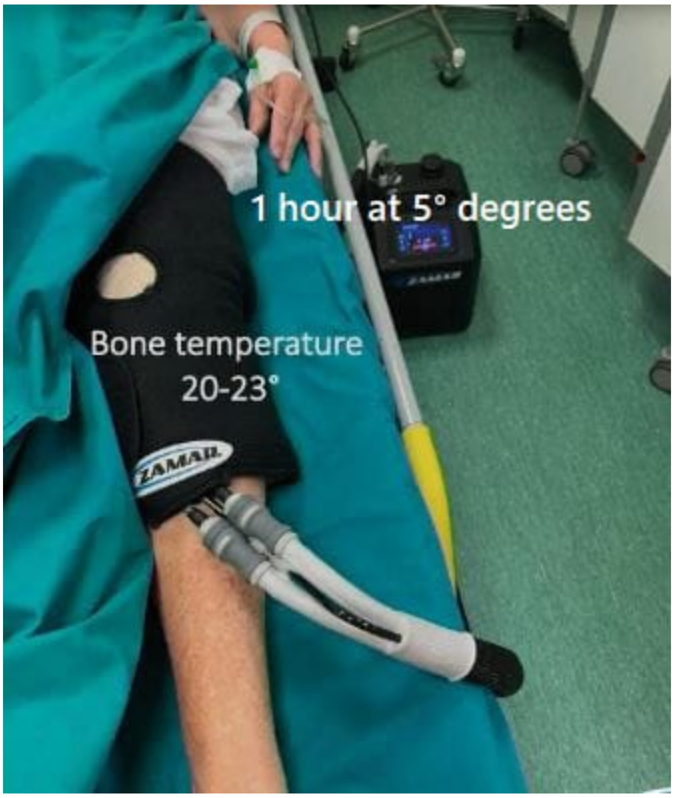

Figure 1: Preoperative cryocompression.

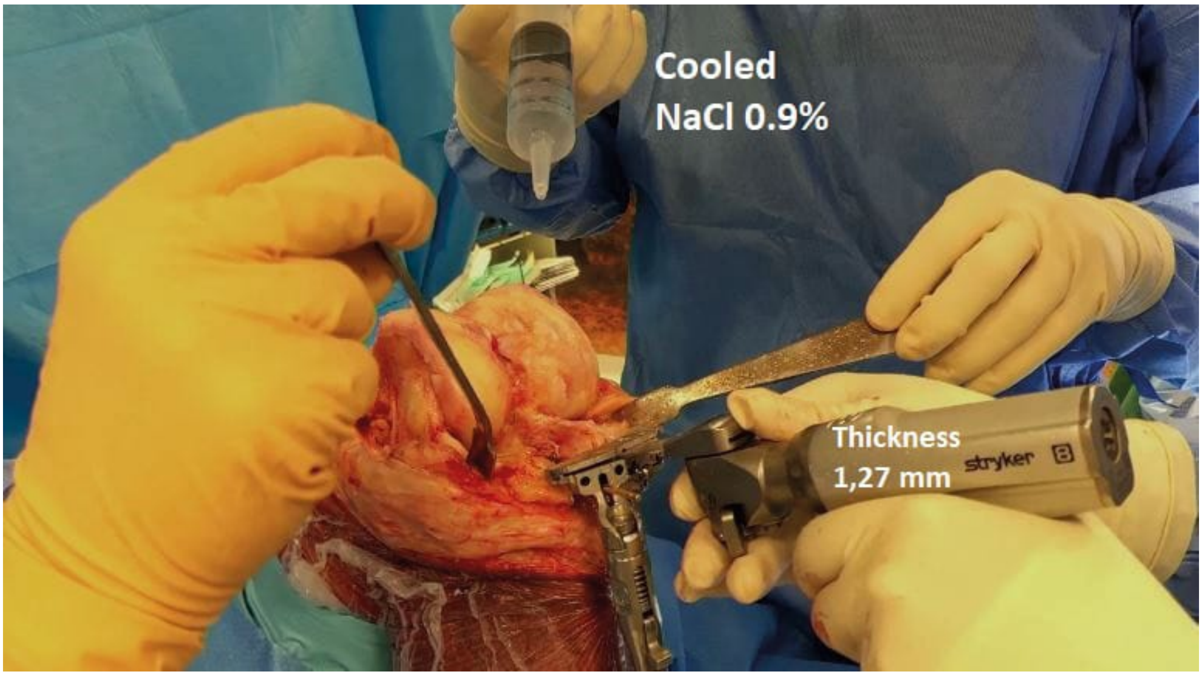

Figure 2: Tibial cut with a 1.27 mm saw-blade and cooled irrigation.

After resection, the plane of the tibia should be symmetrical and flat. Any recutting may introduce additional imperfections. Any asymmetry can reduce the support of the component and some areas will not be able to osteointegration [34]. Generally, the greatest difficulty encountered is ensuring the flatness of the resection of the posterolateral portion of the tibia.

During the preparation of the femur, the “chamfer first” technique (Figure 3) reduces the possibility of imperfections on the surface of the cuts, in fact the anterior and posterior cuts being parallel are less at risk of deviating the resection plane.

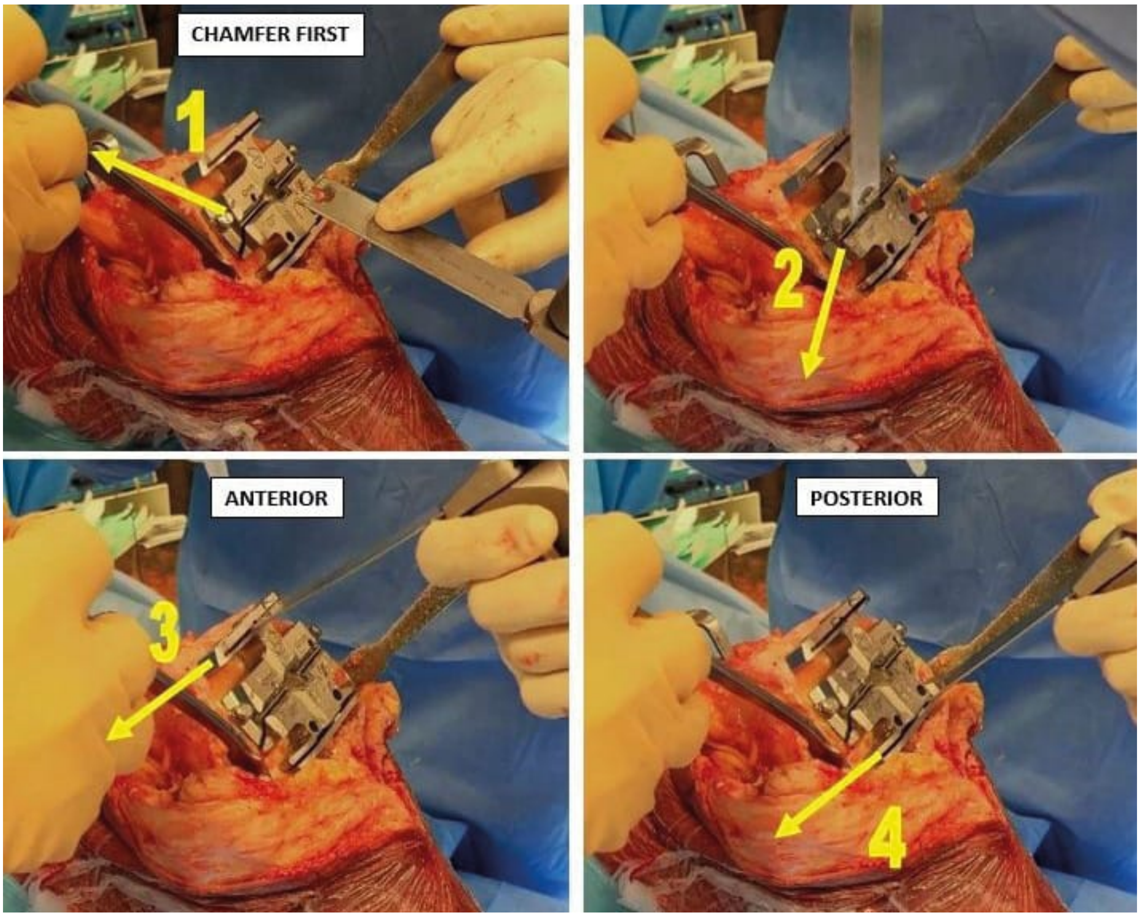

Figure 3: Suggested sequence for femoral resection in cementless TKA.

The posterolateral portion of the tibial plateau may be difficult to be exposed for vertical insertion on the tibial component. This space should always be cleared in order to avoid asymmetric engagement of the tibial pegs in the prepared holes (Figure 4).

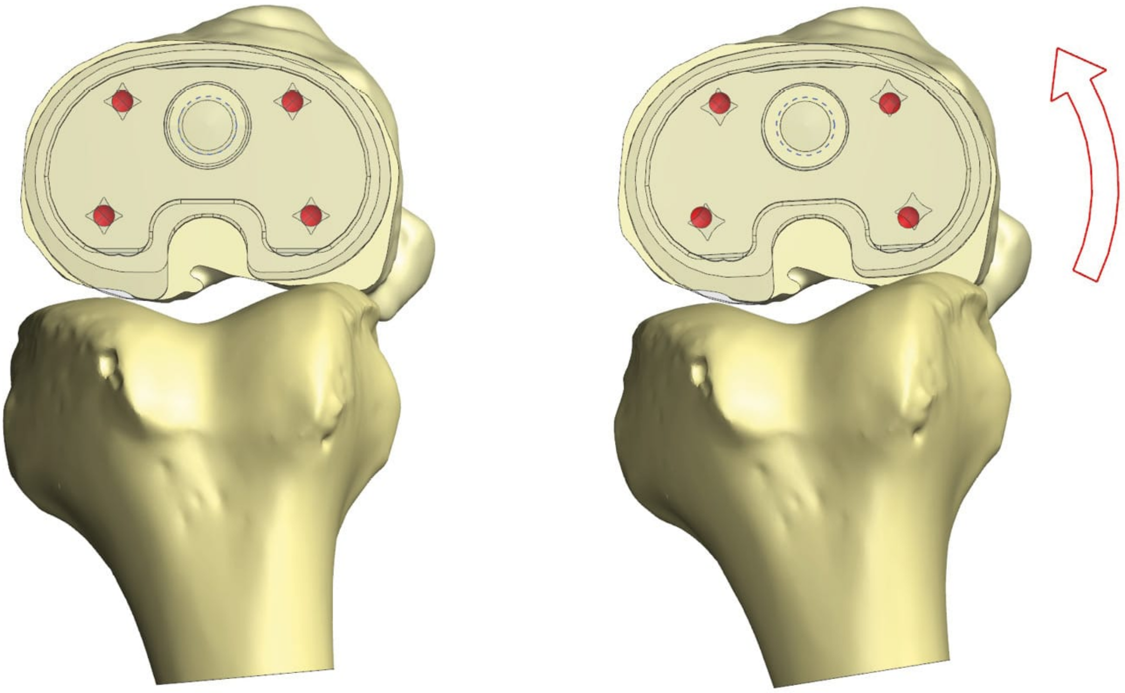

Figure 4: How lateral femoral condyle impingement with tibial component during insertion can compromise the correct entry point of cementless pegs.

Optimal adaptation of the base plate in the tibial sizing, close to the cortical layer provides additional useful surface for primary fixation (Figure 5).

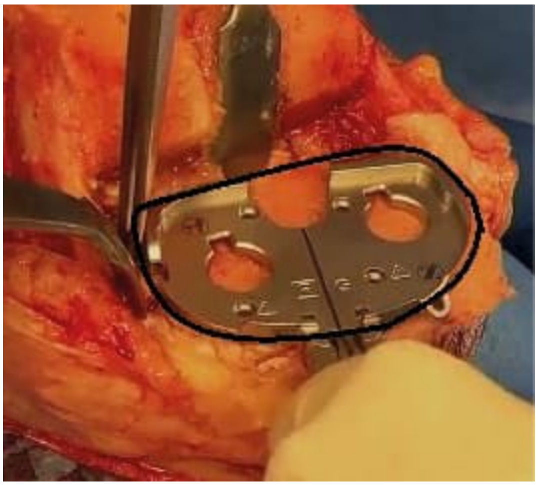

Figure 5: Full coverage of tibial plateau with asymmetric baseplate enhances primary fixation.

Final preparation of tibial pegs may include reverse reaming if there are soft medullary bone parts in the four tibial quadrants (Figure 6). Cleaning every bone particle present on the bone platform and in the holes after preparation ensures a perfect engagement of the tibial plate. During femoral implantation, care must be taken in raising the implanting arm while pushing the femoral component to avoid malseating of the various surfaces. The goal is to achieve no gapping around the femoral component, although a gap of less than 2 mm can be accepted in certain zone (bone bridging during secondary ingrowth is commonly described) (Figure 7). After implantation, stability of the components during the full range of motion should be assessed both with the extensor mechanism dislocated and reduced (Figure 8).

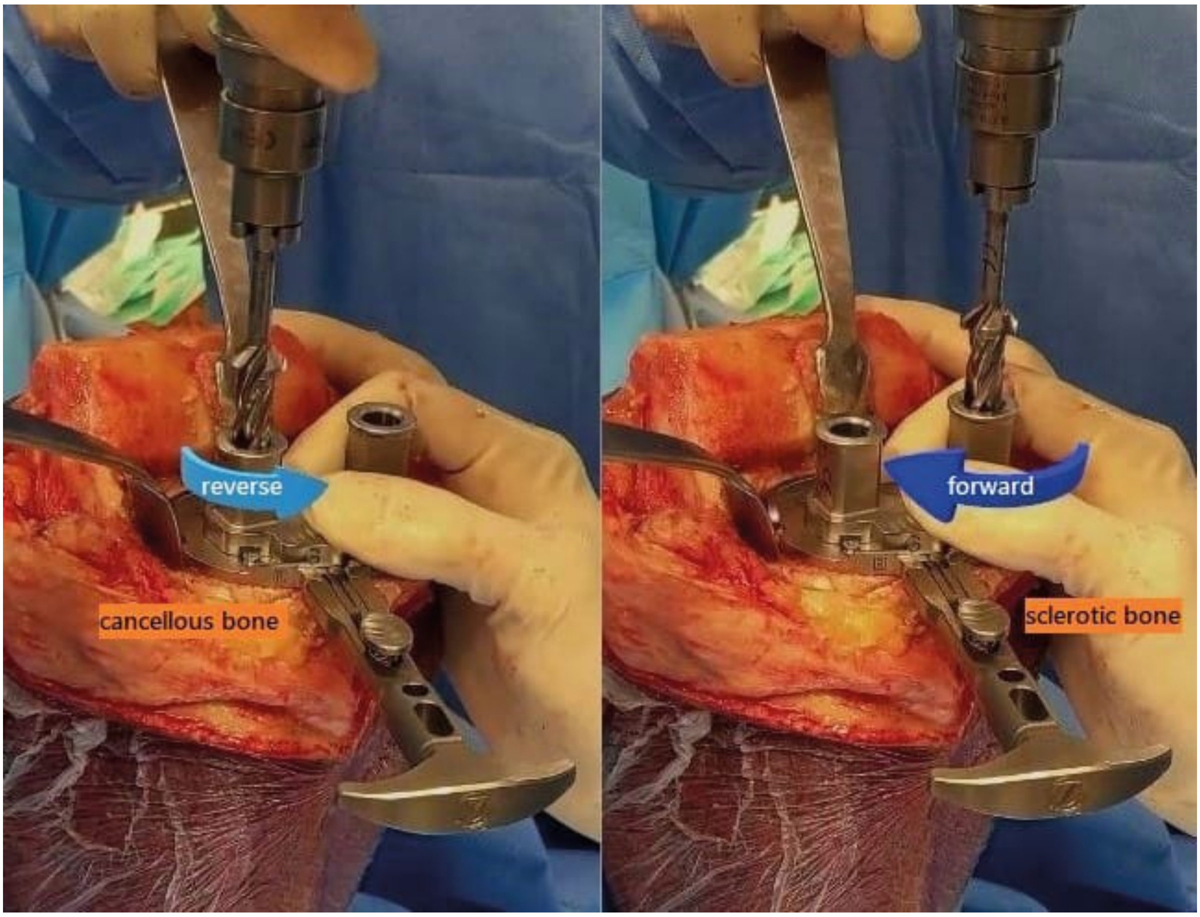

Figure 6: Different preparation of tibial pegs according to the tibial bone quality.

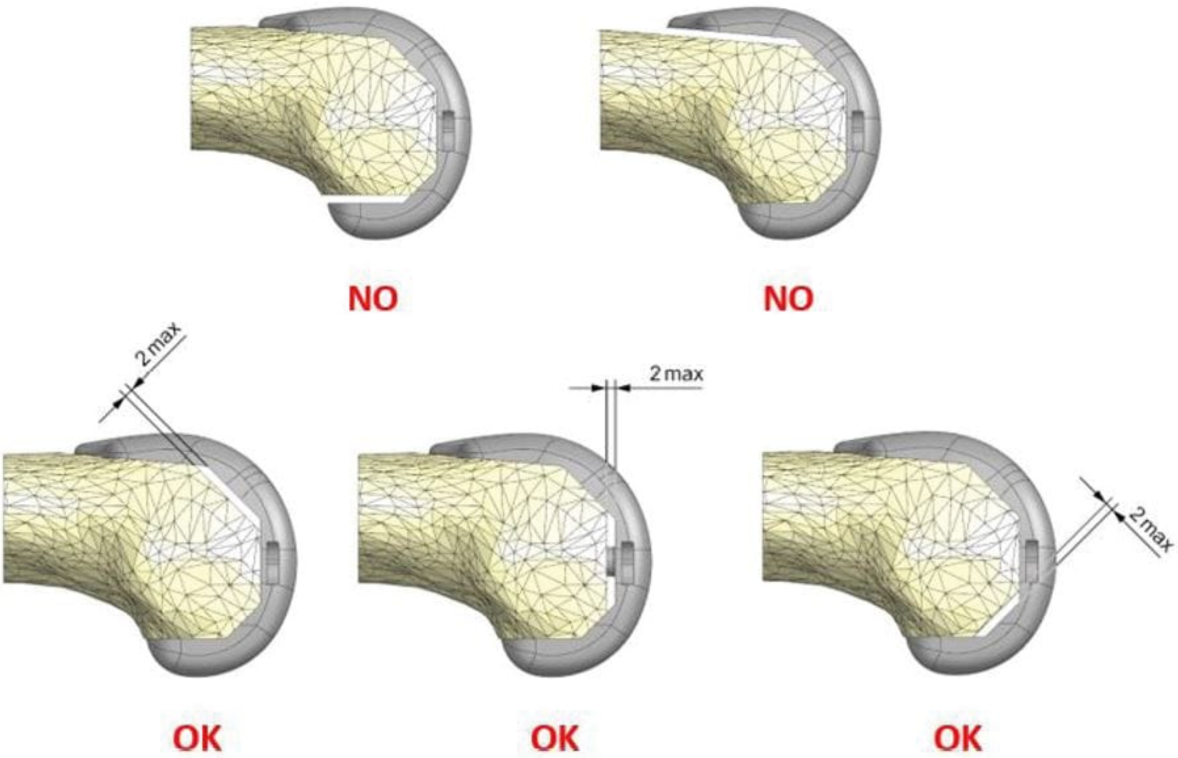

Figure 7: Femoral bone gaps are allowed only on chamfers or distal femoral resections.

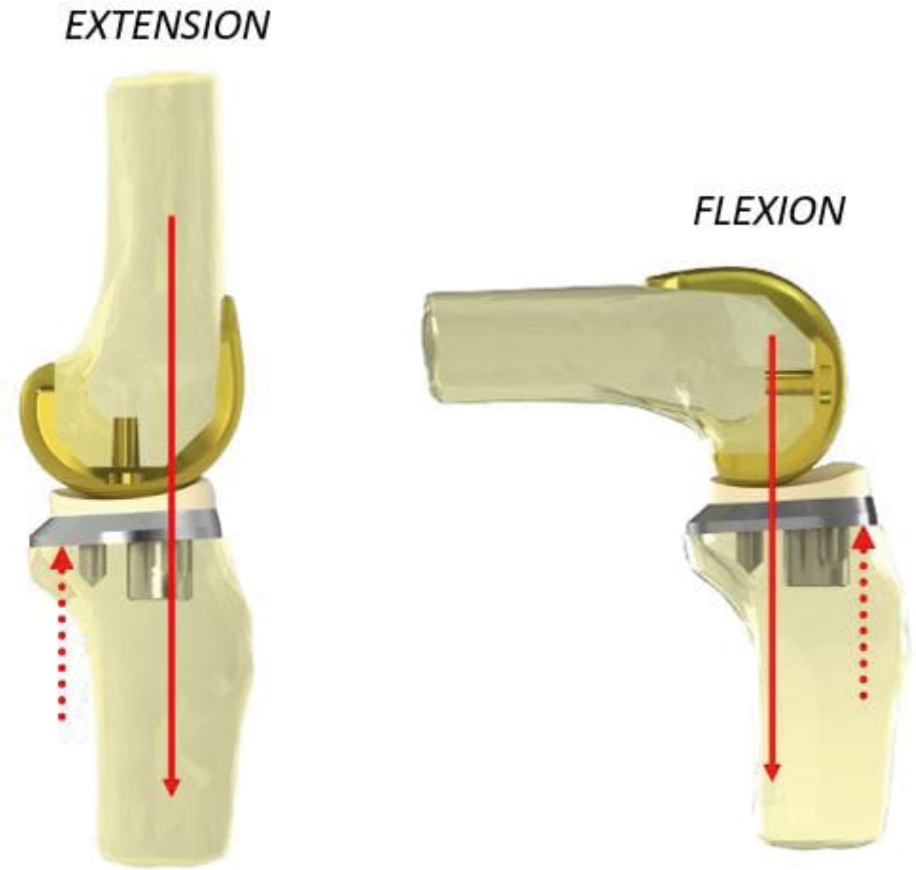

Figure 8: Anterior and posterior pegs showing counter forces against seesaw effect of loading in extension and flexion.

CONCLUSION

Innovations in materials and designs of cementless knee implants have helped to increase their current popularity. Improvement of primary femur and tibia stability, rapid osteointegration, and promising mid-term results, lead to a progressively increased indications in several cohorts of patients.

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