Cementless Total Knee Arthroplasty 61

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Introduction

Cementless total knee arthroplasty (TKA) currently demonstrates a success rate equivalent to cemented TKA. Like early cemented TKA systems, cementless total knee replacements had both development and design difficulties [1–4]. Several early implant designs, especially metal-backed patellas, revealed poor results [5–7]. However, clinical outcomes in cemented TKA have improved compared to early cemented total knee replacement as surgical techniques and implants were further developed [8, 9]. Similarly, advancements in cementless TKA have also improved clinical results. While both fixation techniques are alike in their requirements for precise bone cuts, ligament balancing, and overall limb alignment, cementless TKA likely requires greater surgical precision and optimal implant design to achieve durable fixation.

As rates of TKA continue to increase and the patient population is becoming younger with a projection that patients younger than 65 years old will account for 50 % of all primary TKAs by the year 2016 [10], cementless fixation in TKA may offer several advantages for these younger and more active patients. Mainly, a more durable biologic interface is advantageous to handle the increased life expectancy in this younger patient population.

When optimal design is matched with proper surgical technique, multiple recent reports show that excellent results can be attained with cementless fixation in TKA [11–13]. In the authors' experience, primary cementless TKA in the properly selected patient population can offer similar outcomes seen in cemented TKA with the advantage of removing the potential problems seen with methylmethacrylate fixation [14, 15].

Cementless Implant Considerations

Several key design and surgical considerations exist for the cementless TKA components. Important biologic factors to promote bone ingrowth into the component are the coating utilized on the implant, the use of morselized autogenous bone chips, and careful patient selection. In addition, geometry of the components and their alignment and kinematics after implantation is also important.

Biologic Considerations

Patient Selection

The senior author treats a relatively young (average age of TKA: 64 years) and active patient population with osteoarthritis or well-controlled rheumatoid arthritis. In this patient population, roughly 50 % of his patients can receive TKA with cementless fixation. Cemented fixation is selected for older, sedentary patients with poor bone quality and/or major comorbidities.

Porous Coating

Porous coating of an implant provides an interface for bone ingrowth into the implant; therefore, optimal pore size and porosity should be implemented to optimize bone ingrowth. Optimal pore size has been reported to be 50–400 μm to maximize bony ingrowth and interface strength [16]. Likewise, implants with higher porosity have been shown to allow greater bone ingrowth which increases interface strength [17]. The senior author's choice for porous coating of the femur consists of commercially pure titanium or asymmetric cobalt chrome particles sintered to a cobalt chrome alloy substrate which has an average pore size of 400 μm and 55 % porosity. Since this porous coating provides an optimal pore size and good porosity, it has been shown to deliver excellent bone ingrowth (Fig. 1) [18]. The ideal tibial component is titanium with commercially pure titanium particles sintered onto the substrate [19].

It is important to note that porous coated pegs with bone ingrowth may cause stress shielding of the remaining interface and significant bone loss if revision arthroplasty is required. Therefore, to minimize stress shielding and preserve bone during revision, coated pegs and stems should be avoided.

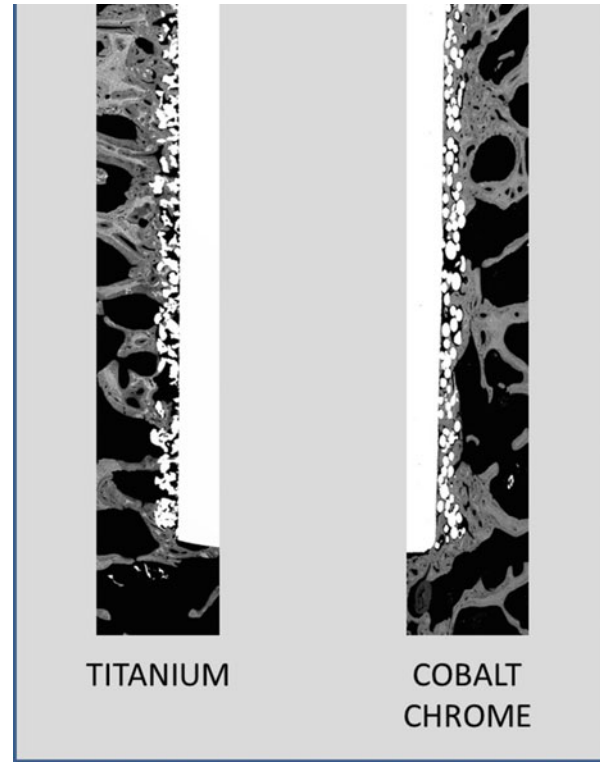

Fig. 1 Histologic images of porous coated implants after being implanted in the distal femur of sheep for 12 weeks. Both porous coatings provide optimal pore size and good porosity which is evidenced by bony ingrowth on the histologic specimens

Autogenous Bone Chips as Biologic Cement

Examination of the resected proximal tibia shows that total surface area consists on average of 6 % cortical bone, 18 % cancellous bone, and 76 % bone marrow [20]. This finding is problematic as the lack of bone is not favorable in providing a stable attachment between the tibial component and proximal tibia without the use of "cement." The senior author advocates for the routine use of biologic "cement" in the form of autograft cancellous bone chips [21, 22]. This biologic "cement" is used to enhance ingrowth by creating a dense neocortex at the implant interface which increases the surface attachment at the bone-implant interface. The autologous bone chips are obtained from the cut surface of the resected portion of the tibia using a patellar reaming instrument. Multiple studies demonstrate improved fixation of cementless components with the use of morselized autogenous bone chips [18, 21, 22].

Cementless Implant Design

Anatomic design of the implants with near-normal restoration of the native knee kinematics is desired for successful cementless TKA. The pegs on the femoral, tibial, or patellar component should be smooth rather than porous coated to minimize stress shielding and preserve bone during revision.

Femoral Component Design

A femoral component with a deep trochlear groove is recommended as this will improve range of motion, prevent excess wear of the patella component, and decrease patellar subluxation or dislocation [2]. Moreover, the groove should be angled at 7–8° as in the normal distal femur for optimal patellar tracking; and a deep groove avoids functional shortening of the

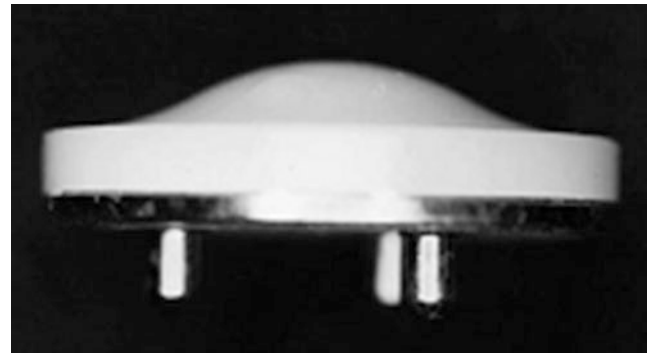

Fig. 2 Photograph of Natural-Knee patellar component demonstrating metal-backed component with a minimum of 3 mm peripheral polyethylene thickness

extensor mechanism as seen in femoral components with a shallow groove [2].

Tibial Component Design

Anatomic studies of the proximal tibia demonstrate that the lateral tibial plateau is 5–6 mm smaller than the medial side [23]. Therefore, an asymmetric replacement or a kidney bean shape will provide good coverage of the proximal tibia and avoid impinging nearby soft tissues [24]. In addition, tibial base plates with four pegs and central keel have been shown to be biomechanically superior in regards to liftoff and micromotion than tibial base plates with two hexagonal pegs [25]. The greater length, perpendicular orientation, and large surface area of the central keel is likely responsible for the decreased liftoff and micromotion. Furthermore, a keel that allows stem extensions for softer bone or in heavier patients would be ideal. Although initial stability of the tibial base plate is enhanced with two 6.5 mm titanium alloy cancellous screws, clinical outcomes and implant survival are equivalent between implants with additional screw fixation compared to implants without additional screw fixation [26].

Patellar Component Design

Early metal-backed patellar components were fraught with complications [27] which led to some surgeons using cemented patellar components in cementless TKA. However, these early failures have been linked to inadequate polyethylene thickness around the periphery of the metal backing and the absence of an anatomic trochlea design in the femoral component. The senior author prefers a patellar component with a modified dome-shaped sombrero polyethylene button with a minimum of 3 mm thickness at the periphery and no overhang of the polyethylene (Fig. 2). To accommodate the metal-backed component, the implant is countersunk 2–3 mm so that over-thickening of the patella-implant complex is avoided. This improved design and surgical technique of the patella component has demonstrated improved survivorship [28, 29].

Cementless Implant Alignment and Kinematics

Restoration of Normal Alignment

The normal joint line is oriented horizontally in anatomic and radiographic studies. The average 4° of overall tibiofemoral valgus is created by an average 5–6° of distal femoral valgus and an average 2–3° of proximal tibial varus [30]. This orientation should be followed during TKA to restore an anatomical alignment of the lower limb. The mechanical axis passes slightly into the medial compartment which provides an even distribution of forces. Importantly, no external rotation of the femoral component is required if the anatomic alignment is recreated.

However, most TKA systems produce a nonanatomic joint line that is oriented perpendicular to the mechanical axis of the lower limb because the tibial resection is made perpendicular

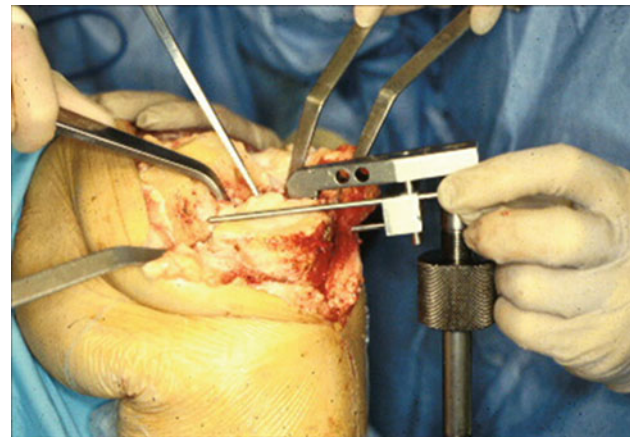

Fig. 3 A pin through the tibial cutting guide is used to ensure the tibial slope is matched

to the long axis of the tibia. This method creates a joint line that is generally 2° from parallel to the floor, thereby necessitating 3° of external rotation of the femoral component to compensate for iatrogenic soft tissue imbalance.

The senior author recommends recreating the normal kinematic anatomy as closely as possible so that the goal of normal knee kinematics can be obtained. Proper positioning of the implants is typically acquired by cutting the tibia perpendicular for the valgus knee, the tibia in slight varus in the coronal plan for the varus knee, and the distal femur in 5° of valgus from the anatomic axis. This creates an overall alignment of 3–4° of varus which is near-normal anatomic alignment.

The tibial cut should be made parallel to the joint line in the sagittal plane so that the posterior tilt of the tibia is maintained. The normal posterior tilt is not a fixed angle as it varies from individual to individual with a range of 4–12°; therefore, the angle of the cut must be adjusted so that the individual's normal posterior slope is recreated (Fig. 3). If the posterior slope is not maintained when cut, the normal kinematics of the knee will be disrupted as the posterior cruciate ligament (PCL) will be either too tight or too loose. Moreover, a tibial cut parallel to the patient's natural posterior slope was found to greatly improve the load-carrying capacity of the supporting bone [32] and avoid subsidence of the tibial implant [33].

Restoration of Anatomy

Measured resection technique [31] references the least involved portion of the tibial plateau, the least-disease portion of the femoral condyle, and thickest area of the medial facet of the patella when cutting the distal femur, proximal tibia, and patella, respectively. The implant then replaces the resected bone millimeter for millimeter thereby restoring bony anatomy and an anatomic joint line. In addition, the replacement of resected bone with an equal amount of implant provides a knee with near-normal varus, valgus, and rotational stability throughout a full range of motion.

PCL Retention or Substitution

The authors argue that PCL retention better maintains normal knee kinematics; however, balancing of the flexion and extension gap is critical and usually dependent on the state of the PCL. Therefore, if the flexion-extension balancing is difficult due to a contracted PCL typically seen in valgus knees or knees with flexion contractures, the PCL should be sacrificed to obtain balanced flexion and extension gaps. Traditionally, the PCL is substituted with a central polyethylene post in the posterior middle portion of the tibial insert that articulates with a transverse cam on the femoral component. Thus, as the knee flexes to 75°,

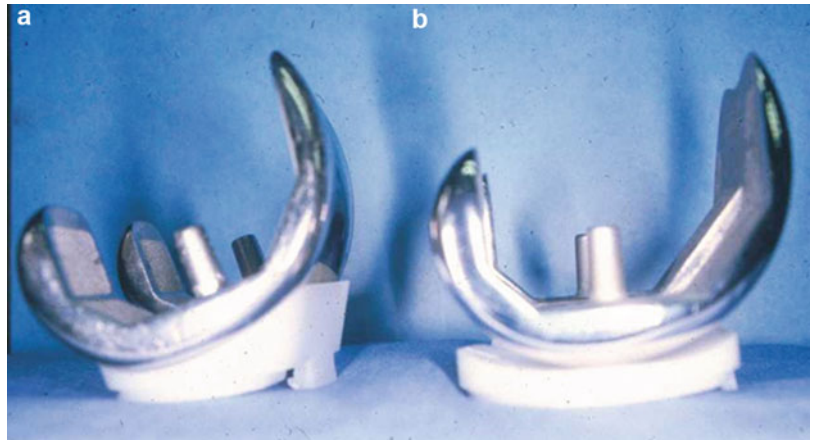

Fig. 4 Photograph of an (**a**) ultracongruent polyethylene insert with a standard femoral implant compared to a (**b**) standard polyethylene insert with a standard femoral implant. Notice the 12.5 mm anterior buildup which is used to stabilize the femur in the anteroposterior plane without the risk of cam failure

the post contacts the cam preventing the tibia from subluxating posteriorly and restoring femoral rollback. However, this design can result in post failure or dislocation. Alternatively, a more congruent (ultracongruent) tibial polyethylene insert with 12.5 mm anterior buildup can be used to stabilize the femur in the anteroposterior plane without the risk of cam failure (Fig. 4). This implant has proven clinically successful [34].

Surgical Techniques

Surgical Approach

The subvastus approach [35] is desirable for many total knee arthroplasties. This approach is amenable to minimally invasive technique which has been shown in cadavers to cause less muscle damage [36]. In this approach, the deep fascia of the thigh covering the vastus medialis is incised in line with the skin incision. This fascia is then bluntly elevated off the vastus medialis obliquus (VMO). After identifying the inferior edge of the vastus, the VMO is lifted off the intermuscular septum with blunt dissection. The VMO is then retracted anteriorly and the transverse tendonious insertion to the medial knee capsule is incised at the level of the mid patella.

The arthrotomy is then performed vertically along the medial patella and patellar tendon. To minimize bleeding, the fat pad is incised at the medial edge. The patella is then everted or subluxated as the knee is maximally flexed to provide full exposure of the distal femur. If the patella is difficult to evert, a partial lateral release is performed. This is often needed in obese patients or a valgus knee with a subluxating patella. The patella component insertion device can be used to aid in patellar eversion.

Next, the initial proximal release of the tibial soft tissue is completed and should extend to the posteromedial corner of the tibia. Osteophytes are then removed to aid in identifying true bony landmarks and component sizing. In the case of severe deformity, further soft tissue release may be necessary prior to making bone cuts.

Bone Cuts

Thermal necrosis of the bone facilitates bone resorption and fibrous tissue formation which may negatively impact future cementless implant fixation. Thermal necrosis occurs when the bone is heated to above 47°C for longer than 1 min. During joint replacement surgery, saw blades have been shown to reach 200°C [37]. Therefore, it is extremely important that all bone cuts be made with new sharp saw blades and with extensive irrigation so that thermal necrosis is avoided.

Cementless implants also require precise surgical technique since there is no cement to fill gaps in imperfect bone cuts. To confirm that the cuts are near perfectly flat, all bone cuts are viewed in two planes against the cutting block. The flatness can

also be examined using an auxiliary cutting block. Typically, an off central high spot near the intercondylar notch of the femur persists and requires additional planing. This is important as the high spot can cause the implant to become "high centered" when it is implanted. The high spot is removed by performing extra passes with the sawblade by adding a slight upward spring of the blade against the bone.

PCL Preservation

During bone cuts, the PCL should be protected by placing a small one-fourth-inch osteotome anterior and deep to the ligament. This prevents the sawblade from going to posterior.

PCL Resection

The PCL should be resected, if preoperatively the patient has a more than 10–15° flexion contracture or more than 10° varus or valgus deformity, to aid in obtaining balanced flexion and extension gaps. A slightly flatter tibial cut will tighten the relaxed flexion gap and requires a slightly thicker (2 mm) tibial insert.

Measured Resection Technique

In a patient with normal proximal tibial varus, it is preferable to make a 2° varus cut. This allows a more symmetric wedge of proximal tibia to be resected, improved soft tissue balancing, and proper orientation of the joint line. A caliper is used to measure the tibia in areas of normal cartilage. By adding 1 mm to account for the kerf of the saw, the thickness of the tibial implant can be predicted.

Before making any bone cuts, the maximum thickness of the patella is measured with the caliper. Except for cases of severe patella wear, the total patellar resection should equal the thickness of the patella implant. Increasing the overall thickness of the patella-implant construct should be avoided as this will increase the patellofemoral joint forces which may cause tracking problems and excessive wear. For improved fixation of the cementless patella component, the senior author advocates for countersinking the 10 mm component 2–3 mm.

Tibial Sizing

The tibia should be sized with the largest tibial baseplate that does not overhang as medial overhang has been recognized as a source of pes bursitis. An asymmetric or kidney bean shaped tibial tray provides maximum coverage of the resected bone surface. Slight lateralization of the tibial tray decreases the Q-angle and provides better patellar tracking. Tibial rotation should be based on the middle of the tibial tubercle. Internal rotation of the tibia is avoided by having circumferential exposure.

Patella Medialization

The middle of the highest portion of the sagittal ridge patella is drilled perpendicular to the articular surface with a one-eighth-inch drill roughly 12 mm deep. The saw is then used to make an osteotomy across the patella at the osteochondral junction, removing 7 mm of bone. The aforementioned drill hole is then identified and acts as a landmark for centering the patellar component (Fig. 5). The patella sizer is then positioned centered over the drill hole. This technique allows for proper medialization of the component by reproducing the position of the patient's native patellar high point while also creating a rim of bone around the implant (Fig. 6).

Removal of Posterior Femoral Osteophytes

Prior to trial reduction, the posterior femoral osteophytes are removed with a three-fourth-inch osteotomy while lifting the femur with a bone hook. This step is essential to provide maximal knee flexion.

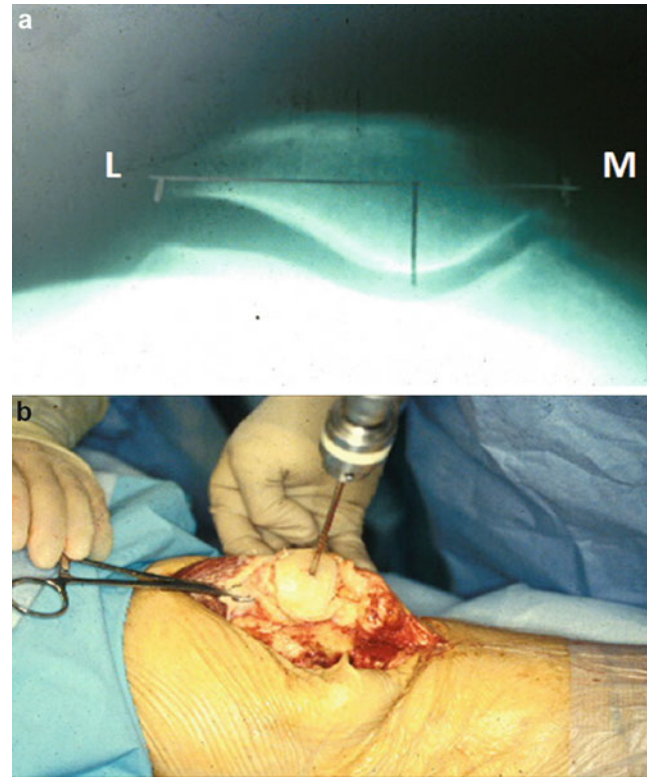

Fig. 5 (**a**) Preoperative radiograph demonstrating medial position of the sagittal ridge of the patella. (**b**) Drilling the midpoint of the sagittal ridge to mark the medialization of the patellar component

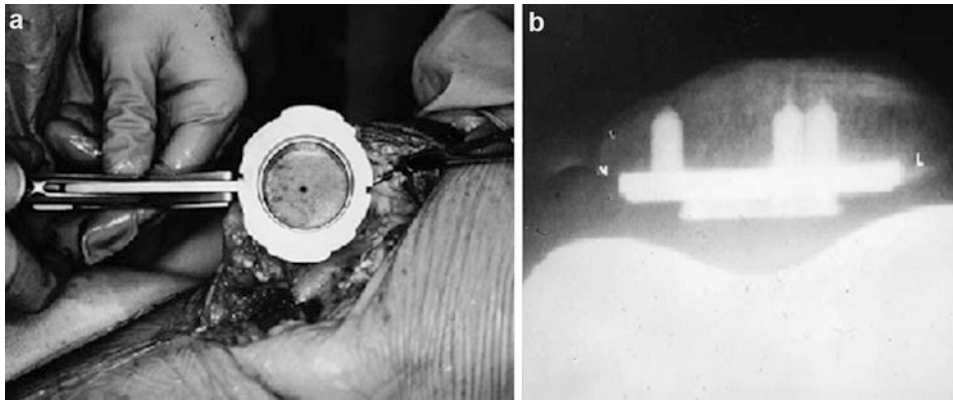

Fig. 6 (**a**) Centering the patellar reamer over the drill hole. (**b**) Postoperative radiograph demonstrating a well-medialized patellar component

Trial Reduction

After trial implants are inserted, stability is checked in full extension, 20° of flexion, and full flexion. Lateralizing the femoral trial prior to drilling the lugholes will aid in better patellar tracking. If the PCL is retained and intact, slight medial and lateral laxity should be allowed. Full extension must be achieved in the operating room. The femur should track in the center of the tibial implant. When using a PCL sacrificing implant, the knee is placed tighter with a spring to the last 10° of extension.

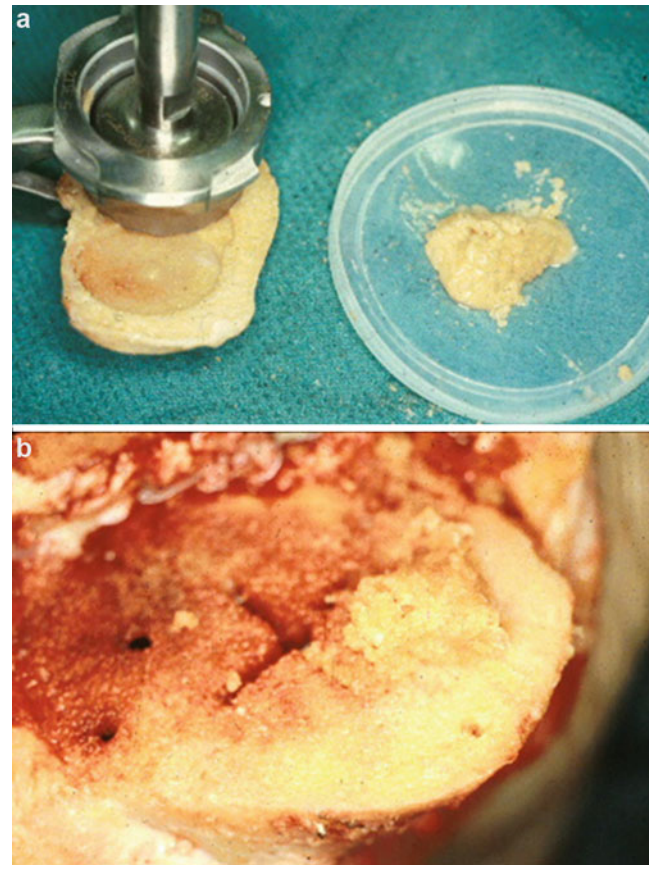

Fig. 7 (**a**) The patellar reamer is used to prepare the "bone paste" from the undersurface of the tibial wafer. The autograft "bone paste" is seen in the plastic tray. (**b**) The "bone paste" is then applied to the cut surface of the tibia

Implantation of Components

Using patellar reamers or a saw, a slurry of cancellous bone is obtained from the cut surface of the resected tibia (Fig. 7). This slurry is used as a biologic bone "cement" and is applied to the cut surfaces of the tibia, femur, and patella to facilitate bony ingrowth rather than fibrous ingrowth. In a varus knee, there is more porotic bone on the lateral tibial cut; therefore, additional biologic bone "cement" is applied to this surface to minimize gaps between the implant's porous coating and bone.

Clinical Results

Early cementless TKA outcomes were inconsistent. Some results demonstrated inferior clinical results when compared to later cemented TKA designs [5, 27]. With development of improved instrumentation, surgical technique and implants, cementless TKA have equivalent results compared to cemented TKA.

McCaskie [38] compared radiographic and clinical outcomes between 81 cemented knees and 58 cementless knees in a prospective randomized trial, using the press fit condylar knee replacement system. At 5-year follow-up, they found no significant difference between fixation types in regards to pain, mobility, or movement. They did observe a significantly greater number of radiolucent lines the cemented knees group on radiographs; however, this was of unknown clinical relevance.

A more recent study by Park [39] analyzed patients undergoing simultaneous cemented and cementless TKA for bilateral knee osteoarthritis. Importantly, both the cemented and cementless knees received a cemented polyethylene patellar

component. Overall there were 50 cementless knees and 50 cemented knees; and the mean follow-up was 13.6 years. Outcome scores including the Knee Society Score, Western Ontario, and McMaster University osteoarthritis index, knee range of motion, patient satisfaction, and radiographic results were similar in both groups. The femoral component demonstrated 100 % survivorship in both groups. The cemented tibial component had 100 % survival rate while the cementless tibial component had a 98 % survival rate.

Cross [11] reported on 1,000 cementless knees performed in a population with a mean age of 68 years. Seven cases required revision. Infection was the most common reason for revision with four cases due to infection. The other three revision cases include malrotation, aseptic loosening, and supracondylar femur fracture. Overall survivorship of the cementless prosthesis at 10 years was found to be 99.1 %.

Similarly, the senior author [40] reported a comparable survivorship of 95.1 % at 10 years in 300 cementless Natural-Knee prostheses. Notably, this system uses a metal-backed patella. Early metal-backed patellar implants were fraught with complications and revision rates as high as 48 % [27] have been reported. However, with improved component design, proper patellar medialization and countersinking the component, the senior author showed a 95.1 % survivorship of the patella component at 10-years follow-up [40].

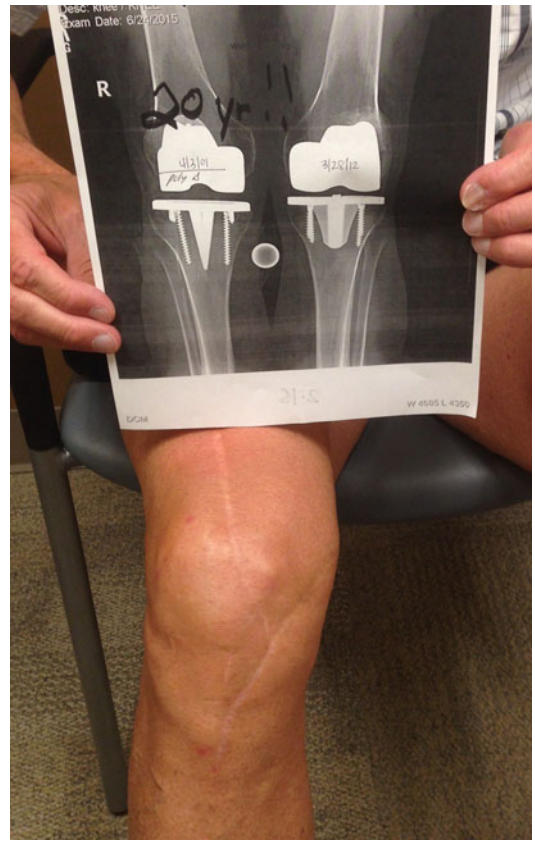

Fig. 8 Clinical and radiographic images of patient at 20-year follow-up from cementless TKA

Conclusion

Despite the long-standing track record of the cemented total knee arthroplasty, the cementless knee implant has shown great promise as a suitable option in certain patient populations. The cementless implant requires greater precision in surgical technique and focus on implant design as there is far less room for error than with cemented bearings. It is best suited for younger, more active patients with adequate bone stock or in those with inflammatory disorders such as rheumatoid arthritis. Cementless implants much allow for adequate bone ingrowth to prevent loosening while avoiding the unwanted consequences of stress shielding or excessive bone loss with revision. Certain porous coatings and the use of bone grafting have helped achieve a fine balance in implant stability and longevity. Early studies have shown great promise for cementless knee arthroplasty with comparable longevity and clinical outcome scores to cemented knee implants. While studies with longer follow-up may help solidify cementless arthroplasty as a suitable option, results thus far have shown cementless total knee arthroplasty to be a safe and suitable alternative to cemented knee arthroplasty when selected for the appropriate patient population (Fig. 8).

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