A Review Paper

The Design Principles of the Natural-Knee System

Aaron A. Hofmann, MD

Abstract

The clinically successful Natural-Knee system was introduced 25 years ago. More than 1 million patients have been treated with this design since the first implantation in October 1985. This article reviews the design principles and evolution, over 25 years of clinical performance, of this cementless and cemented system, in which measured resection techniques are used to anatomically resurface the knee joint.

The Natural-Knee (NK) knee replacement system (Figure 1) was conceived by Dr. Aaron A. Hofmann in 1985 working with the talented engineers Joe Skraba and Jim Dales. The design principles of this system were based on restoration of anatomy and alignment of the knee joint. Bone resection, followed by an equal amount of prosthetic replacement, provides the knee with near normal varus-valgus and rotational stability throughout full range of motion. Cementless replacement required an understanding of cancellous bone structure, the nature of human cancellous bone healing and biology, and incorporation of host autograft bone for improving skeletal attachment. In addition to incorporating these important design parameters into the system, we instituted, at the time of the design program, a commitment to careful patient follow-up studies[1,2] and institutional review board (IRB)–approved implant retrieval investigations[3,4] to validate the clinical performance and design principles of the NK system.

Careful observations of the anatomy of the human knee joint helps the orthopedic surgeon to realize that there are variations (0°-10°) in the posterior slope[5] of the tibial plateaus. There is also an asymmetric natural bone adaptation of the proximal tibia to accommodate the larger surface area on the medial compartment of the knee compared with the lateral aspect of the articulating tibial surface. Bloebaum and colleagues[6] found that, when the tibia was resected with the patient's own anatomical slope, the bone was stronger, and anterior medial tibial component subsidence was avoided. In addition, when the asymmetric geometry of the resected tibia was matched by the tibial component, the surface area of the component fit the patient's anatomy better—affording excellent implant stability and preventing the clinical complication of pes bursitis, which is caused by medial tibial component overhang. Symmetric tibial component designs may leave the medial compartment compromised as well, because of limited implant coverage from accommodating the smaller surface area on the lateral compartment of the tibia.[6] Symmetric tibial components are also more difficult to place in the appropriate rotation. Anatomical studies have demonstrated that the lateral side is 4 to 5 mm smaller than the medial side in the anteroposterior plane.[7,8] Fixation of the tibial component is augmented by 4 peripheral pegs and a central keel with the option of cancellous screw fixation. A well-fixed, stable implant contributes significantly to the long-term success of the arthroplasty.

The femoral component of the NK system was the first to have a stepped anterior chamfer cut to allow bone resection and replacement with a deeply grooved trochlea, anatomically restoring the patellofemoral joint.[8] As a result, patellofemoral stability is achieved with few lateral releases and avoids abnormal patellofemoral compressive forces.

Initial component stability and coverage of the bone with cementless implants also require a knowledge of the structure and healing principles of the predominant cancellous bone type (94%) in the knee joint.[6] To examine the biological principles of tissue healing, we conducted an IRB-approved bilateral human knee study to confirm that the autograft bone slurry made at the time of surgery from the underside of the resected tibia, and then placed between the knee components and host bone, was effective in optimizing the skeletal attachment of femoral, tibial, and patellar components clinically and was confirmed in implant retrievals.[4,9-11]

Figure 1. Natural-Knee system.

Dr. Hofmann is Professor, University of Utah Orthopaedic Center, Salt Lake City, Utah.

Address correspondence to: Aaron A. Hofmann, MD, University of Utah Orthopaedic Center, 590 Wakara Way, 3rd Floor, Salt Lake City, UT 84108 (tel, 801-213-3783; fax, 801-587-5411; e-mail, aaron.hofmann@hsc.utah.edu).

Am J Orthop. 2010;39(6 suppl):2-4.

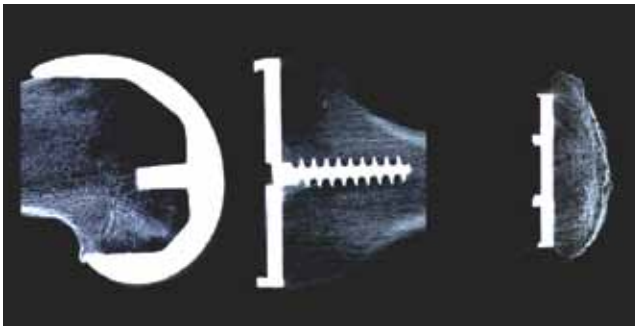

Figure 2. High-resolution contact radiographs of 3-mm-thick sections of all femoral, tibial, and patellar components from 24-year retrieval.

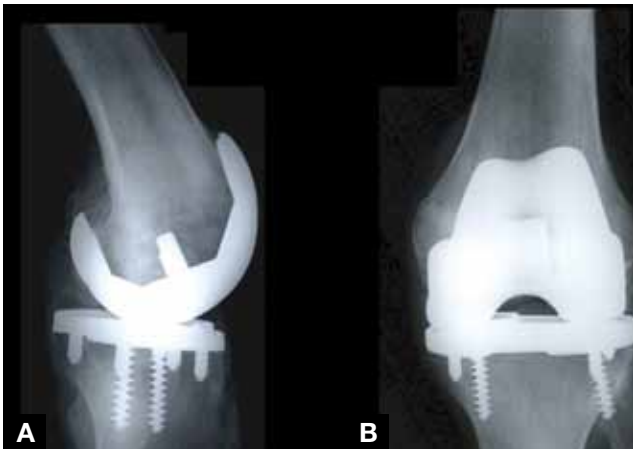

Figure 3. (A, B) Postmortem contact radiographs from 85-year-old female donor at 25-year follow-up.

Cancellous-structured commercially pure titanium (CSTi) coating was chosen as the porous coating to ensure optimal material porosity for bone ingrowth and to provide a high-contact roughened surface area for osseointegration of bone (Figure 2). Another design feature unique to the CSTi coating is its ability to be bone-sparing when revision is required for infection or osteolysis. When revisions were clinically indicated, the operative results clearly demonstrated that the host bone tissue would be spared by separating off at the CSTi coating–bone interface, preserving bone stock. This important design feature helps reduce the need for extensive allograft bone use during revision procedures.

Results were supported in IRB-approved postmortem donor implant retrieval studies showing excellent bone attachment.[3,4] These investigations demonstrated consistent attachment of cancellous bone to CSTi coating in patients with the NK system at follow-up of up to 25 years (Figures 3, 4). This attachment is considered an important advantage in supporting the excellent 98% survival rate of the NK system at 10- to 14-year follow-up.[2,12]

The issue of patient knee instability secondary to compromised or resected posterior cruciate ligament (PCL) was addressed by introducing the ultracongruent polyethylene insert design with the NK system (Figure

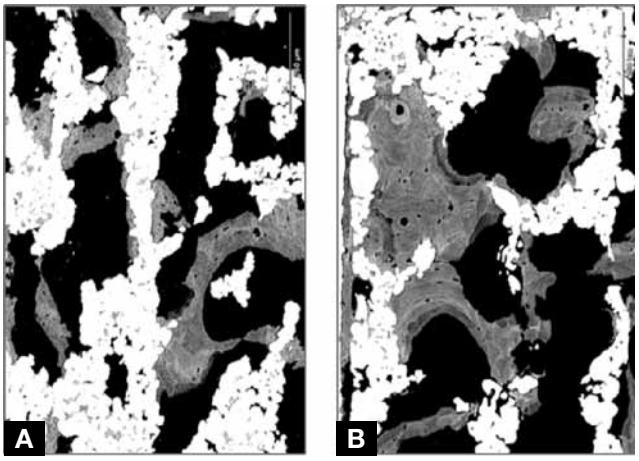

Figure 4. (A, B) Bone ingrowth into Cancellous-Structured Titanium (CSTi) coating of donor's postmortem femur and tibia at 25-year follow-up.

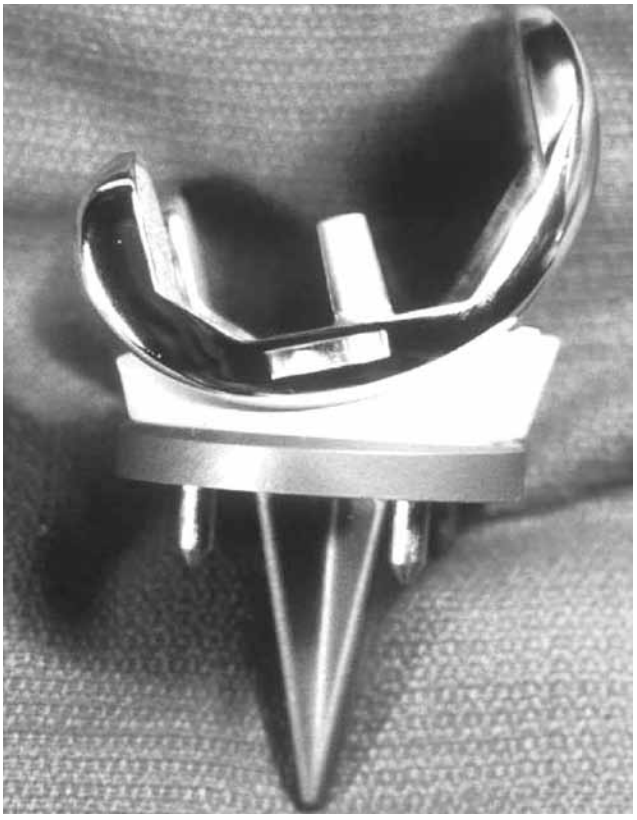

Figure 5. Profile of ultracongruent tibia on Natural-Knee system.

5). The geometry of the polyethylene insert—raised anterior flange (up to 12 mm) and increased radius—prevented excess anterior-posterior femoral translation during flexion in a PCL-deficient knee. An additional advantage is the decrease in femoral inventory requirement, as cruciate-retaining and -sacrificing primary knees share the same femoral component. This design concept avoids the clinical compromises that existed in the post and cam knee design types.[13] The literature demonstrates that post breakage and cam articulation wear were major clinical concerns. There were also

complications when the cam portion dislocated over the post during deep knee flexion and required intervention. Patellar clunk was also a concern, with soft tissue proximal to the patella becoming entrapped within the intercondylar cutout for the cam and requiring additional surgery. These issues were avoided with the ultracongruent design.

Design Changes and Advances

The early NK-I system had a titanium alloy femoral component with CSTi coating. By 1990, the metallurgy was perfected to attach the CSTi coating to the cobalt-chrome alloy substrate; the bimetal femoral component along with the instrument advances were then introduced.

The ultracongruent insert was introduced for PCL-insufficient knees in 1991. In ongoing developments, including introduction of the NK-II system in 1995, the search continued for the ideal polyethylene material to prevent articulating and backside wear. The mechanical capture for the tibial insert was improved to prevent backside wear, and the reversible asymmetric baseplate was replaced with dedicated left and right modular tibia to further improve coverage of the tibia. The rotating mobile bearing version was introduced to the European market in 2000, and it continues to be popular. Low-wear highly cross-linked polyethylene with oxidative resistance for congruent and ultracongruent polyethylene has been available since February 2001.[14] Highly cross-linked polyethylene patellar components were made available for cementing purposes and the patellar and ultracongruent tibial polyethylene was introduced at the same time. A modular cobalt-chrome tibial component was introduced in 2003 to accommodate stem extensions and the varus-valgus constrained insert and is the current mainstay for cemented primary and revision surgery.

As with all knee replacement systems, the limits of polyethylene wear continue to be an issue. Nevertheless, clinical results and implant retrieval data support the design and surgical principles behind the clinical success of the NK system.[2,12]

Author's Disclosure Statement and Acknowledgments

Dr. Hofmann wishes to note that he is Consultant to Zimmer, Inc. The author thanks Roy Bloebaum, PhD, for his scientific encouragement over 22 years and Jeremy McCandless, MD, for his assistance in manuscript preparation.

References

1. Hofmann AA, Tkach TK, Evanich CJ, Camargo MP, Zhang Y. Patellar component medialization in total knee arthroplasty. *J Arthroplasty.* 1997;12(2):155-160.
2. Hofmann AA, Evanich JD, Ferguson RP, Camargo MP. Ten- to 14-year clinical followup of the cementless Natural Knee system. *Clin Orthop.* 2001;(388):85-94.
3. Bloebaum RD, Bachus KN, Jensen JW, Hofmann AA. Postmortem analysis of consecutively retrieved asymmetric porous-coated tibial components. *J Arthroplasty.* 1997;12(8):920-929.
4. Bloebaum RD, Bachus KN, Jensen JW, Scott DF, Hofmann AA. Porous-coated metal-backed patellar components in total knee replacement. A postmortem retrieval analysis *J Bone Joint Surg Am.* 1998;80(4):518-528.
5. Hofmann AA, Bachus KN, Wyatt RW. Effect of the tibial cut on subsidence following total knee arthroplasty. *Clin Orthop.* 1991;(269):63-69.
6. Bloebaum RD, Bachus KN, Mitchell W, Hoffman G, Hofmann AA. Analysis of the bone surface area in resected tibia. Implications in tibial component subsidence and fixation. *Clin Orthop.* 1994;(309):2-10.
7. Krug WH, Johnson JA, Souaid DJ, Miller JE, Ahmed AM. Anthropomorphic studies of the proximal tibia and their relationship to the design of knee implants [abstract]. *Trans Orthop Res Soc.* 1983;8:402.
8. Hofmann AA, Smith JR. Total knee resurfacing with an asymmetric tibial tray and a deep trochlear grooved femoral component. *Techniques Orthop.* 1991.
9. Hofmann AA, Bloebaum RD, Bachus KN. Progression of human bone ingrowth into porous-coated implants. Rate of bone ingrowth in humans. *Acta Orthop Scand.* 1997;68(2):161-166.
10. Hofmann AA, Bloebaum RD, Rubman MH, Bachus KN, Plaster RL. Microscopic analysis of autograft bone applied at the interface of porous-coated devices in human cancellous bone. *Int Orthop.* 1992;16(4):349-358.
11. Bloebaum RD, Rubman MH, Hofmann AA. Bone ingrowth into porous-coated tibial components implanted with autograft bone chips. Analysis of ten consecutively retrieved implants. *J Arthroplasty.* 1992;7(4):483-493.
12. Hofmann AA, Wyatt RW, Beck SW, Alpert J. Cementless total knee arthroplasty in patients over 65 years old. *Clin Orthop.* 1991;(271):28-34.
13. Hofmann AA, Tkach TK, Evanich CJ, Camargo MP. Posterior stabilization in total knee arthroplasty with use of an ultracongruent polyethylene insert. *J Arthroplasty.* 2000;15(5):576-583.
14. Hodrick JT, Severson EP, McAlister DS, Dahl B, Hofmann AA. Highly cross-linked polyethylene is safe for use in total knee arthroplasty. *Clin Orthop*. 2008;466(11):2806-2812.