Session 21: Technologic Developments in TKA

Learning Objectives
Upon completion of this activity, participants should be able to:

1. Understand how the mechanical properties of bearing surfaces affect the performance and outcome of TKA.

2. Understand the implications of gender differences in knee morphology and kinematics, as it relates to knee arthroplasty.

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Crosslinked Polyethylene Has Its Benefits

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Over the past decade, investigators in orthopaedic biomechanics at the Massachusetts General Hospital have contributed extensively to the development of the highly crosslinked ultra-high molecular weight polyethylenes (UHMWPEs). These highly crosslinked polyethylenes exhibit significant improvement in wear performance when compared with the conventional polyethylenes when studied in vitro in hip simulators. These efforts have led to several new forms of highly crosslinked polyethylenes, which are currently in clinical use.

A key wear mechanism related to polyethylene implant wear is the surface reorientation and crossing patterns that occurs in vivo. Crosslinking of the polyethylene chains was identified as a candidate solution to reduce the surface orientation and reduce wear. In order to evaluate and determine the optimum conditions of crosslinking, several new methods were developed: accurate quantification of crosslinking, a bidirectional pin-on-disk wear screening device, a knee pin-on-disk wear tester, and a multistation hip and knee simulator. These investigators developed the now-widely used irradiated and melted polyethylene. This first-generation highly crosslinked polyethylene is used in both hip and knee applications. The investigators also discovered that irradiated polyethylene can be stabilized against oxidation by diffusing vitamin E; the resulting polymer is not only
resistant against wear and oxidation, but also exhibits higher mechanical properties and fatigue strength than the first-generation highly crosslinked polyethylenes.

The simulated gait studies of the hip and knee joints have demonstrated markedly improved wear resistance with the highly crosslinked polyethylenes. These findings are now being corroborated by our analysis of surgical explants with short-term in vivo duration. Recent retrieval analyses have revealed that this unique multidisciplinary research and development effort from concept to clinical use resulted in new materials that could substantially improve the outcomes of total joint arthroplasty. In addition, we will present the surgical implications of this new material in primary and revision arthroplasty, such as diminished periprosthetic osteolysis with larger head sizes, increased implant stability, and decreased dislocation rates.

References:

Alternate Bearing Surfaces May Further Reduce Wear

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*Background:* Polyethylene provides a low friction bearing against highly polished metallic surfaces, but both surfaces can wear, limiting the implant’s longevity. The wear problem has led to introduction of alternative bearing combinations.

*Materials:* One alternative has emerged by removing the chance that polyethylene can oxidize during sterilization, thus reducing the chance for subsequent oxidation. Another
alternative is the use of elevated radiation to induce high levels of crosslinking between the polymer chains.

Ceramics provide hard, wear-resistant surfaces, but have few other advantages; their most significant disadvantage is their brittle nature. Knee replacements require non-conforming articulations to provide adequate function, making the advantages of ceramics unclear. Recently, a zirconium alloy with a zirconia surface has been introduced to provide wear resistance without brittleness.

Results: Highly cross-linked polyethylenes have been used clinically in hip arthroplasty for > 8 years with dramatic decreases in wear over that with conventional polyethylene. Changes in mechanical properties with cross linking pose the biggest threat. Reduced fracture properties have been equated with reports of broken components, leading to the introduction of newer forms of cross-linked polyethylenes intended to impart increased toughness. Clinical use is currently too limited to draw conclusions about efficacy.

Knee simulator data show substantial decreases in wear with crosslinking, though the clinical benefit remains uncertain without long-term data. The main problem in knee replacements has been fatigue-related wear dominated by large cyclic stresses at and near the bearing surface. Ceramics provide little advantage; thus, while clinical results with ceramics in knee arthroplasty have been adequate, no data exist to prove superiority over metal-on-polyethylene articulations.

Conclusions: Changes in bearing surface materials can improve wear resistance, though improvements depend on the manner in which material properties affect the wear modes that afflict knee replacements. Laboratory data suggest advantages for highly cross-linked polyethylenes, though reduced fracture properties may yet prove problematic for locking mechanisms and constraint posts subject to high loads.

Clinical Relevance: Properties of bearing materials affect wear, which in turn affects osteolysis and implant failure. Understanding the link between properties and performance allows the surgeon to make choices among available bearing combinations for TKA.

References:

Session 21
Cementless Fixation Is More Biologic

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Cement fixation is currently the gold standard in cementless total knee replacement, with greater than 95% success rates at more than 15 years.\textsuperscript{1-4} In addition, cementless fixation in total knee arthroplasty has enjoyed limited use in recent decades due to past failures in the early generation of cementless designs. Screw track osteolysis, poor polyethylene, and metal-backed patellar component failures have contributed to a controversial track record and created a reluctance to embrace cementless fixation in total knee arthroplasty.

However, these failures mechanisms are correctable and long-term reports exist of successful designs of cementless knee arthroplasty that are nearly equal to results of cemented designs.\textsuperscript{5-9} There is renewed interest in cementless fixation due to recent development of improved biomaterials. Highly porous metals composed of tantalum and titanium\textsuperscript{10-13} may provide greater osseointegration and a more iso-elastic behavior with adjacent bone that may minimize stress-shielding and facilitate long-term bone preservation. Early clinical results of porous tantalum tibial component fixation demonstrates reliable osseointegration at minimum of 3 years.\textsuperscript{14} In addition, newly developed highly cross-linked polyethylene is likely to reduce wear-associated osteolysis.\textsuperscript{15}

As has been established with hip replacement, improved long-term survivorship with cementless fixation in total knee replacement should be anticipated. Highly porous metals, biomaterials with elastic properties more similar to bone and highly crosslinked polyethylene are anticipated to provide optimal biologic fixation, bone preservation and improved long-term outcomes.
References:
Does Gender Matter?

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For 3 decades, joint arthroplasty has been performed in a very androgenous fashion. Total knees, in particular, have been implanted in a manner irrespective of sex. Little accommodation has been made for known and observable differences in anatomy, physiology, and psychology in joint replacement.

“Women’s diseases” for centuries have largely been gynecologic problems. The “sexual dimorphism” revealed by the uncoding of human genome has given scientific credence to the already well-known female predilections for certain orthopaedic conditions. One could argue, for example, that an anterior cruciate ligament (ACL) rupture is currently on a percentage basis, and soon on a volume basis, legitimately described as a “women’s disease.”

Many factors are currently promoting our differentiation of male and female pathologies. Women are living longer, are more athletic, are more empowered in the decision-making for themselves and their families, and are clearly the target population for future arthroplasties. Indeed, the postmenopausal, obese, osteoporotic female is the most likely recipient of a total knee arthroplasty in the first half of the 21st century.

These issues are pushing us to increase levels of surgical sophistication. It is no longer acceptable to perform an “average total knee.” Mass customization is the mantra of the future, and navigation and computerized instrumentation systems are the empowering technologies.

Most orthopaedic surgeons are subliminally aware, if not consciously inarticulate, of the gender differences with which they deal every day. Skin turgor, fat distribution, limb alignment, ligamentous laxity, and metabolic issues are all well known, if not consciously verbalized. Twenty-five years ago, John Insall created a subset of femoral components to accommodate the variational anatomy of the female femur. We know full well that the anteroposterior/mediolateral (AP/ML) diameter of female femora is quite different from that in males. The 0.8 aspect ratio to which most implant designers subscribe is indeed only an average which actually favors the male population. Female knees are quite different, as are knees from inflammatory arthropathies, epiphyseal dysplasias, and autoimmune diseases. Interestingly, the AP/ML ratio in Asian populations is actually the reverse of that in the occidental world.

The kinematics of a “natural knee” are still imperfectly understood even after all these years. Most surgeons still make subconscious accommodations for female knees in the face of patellofemoral arthritis, obesity, and medial fat pad adiposity, and lateral femoral condylar hypoplasia. Problems such as recurvatum remain unresolved, as none of us
knows whether to accommodate or anticipate that phenomenon when performing a total knee.

From an instrumentation standpoint, there are clear decision points that need to be evaluated. The conventional wisdom that posterior-stabilized (PS) knees, when “in between sizes,” should be upsized and that cruciate-retaining (CR) knees in similar circumstances should be downsized tends to aggravate the overhang problem for women and accentuate the sizing problem for men. On the other hand, those who favor the AP diameter play into the concept of kinematics, while those who prioritize the ML diameter enhance the contact area and force distribution issues germane to male needs.

Further sophistication is clearly needed, and this is probably the most favorable outcome of the computerized navigation systems extant today. Our ability to define the differences in gender-specific knees and to accommodate them from both an implant and an instrumentation viewpoint will define the next generation of knee arthroplasty.

What Is the Evidence-Based Data for Gender Arthroplasty?

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Differences in knee dimensions between women and men have been documented in several studies, and there is concern about the effects of this on the outcomes of total knee arthroplasty. Specifically, women typically have smaller mean medial-lateral dimensions relative to the anterior-posterior axis than men in both the femur and the tibia. As a result, knee arthroplasty prosthetic designs may be too wide for women, which might lead to medial-lateral overhang of the prosthesis, which might affect ligament balancing and patellofemoral forces. If the component is downsized, then the prosthesis may be too small in the anterior-posterior axis, which may be associated with poorer flexion, increased wear, and notching of the anterior cortex. Women also may have significantly shorter femoral condyle heights than men, and most prosthetic designs do not account for this. This may affect flexion and patellofemoral tracking, although the clinical importance of this is unknown.

Multiple studies have compared the long-term results of total knee arthroplasties in men and women, and have found similar ranges of motion, knee and pain scores, as well as survival rates at 10- to 15-year follow-ups, although some studies found higher revision rates in men compared with women.

Some total knee replacement systems have been developed that incorporate gender-specific sizing. Studies of these systems have reported excellent short-term clinical outcomes, but no differences between men and women were noted.
In summary, the dimensions of previous gender-neutral systems have been based upon a mean of all knee sizes and may not have been ideal for either men or women. Multiple studies have compared men to women with various implants, and have often found no clinical differences between the genders. To assess whether gender-specific implants have a clinically meaningful difference, future studies could compare these specialized prostheses with gender-neutral implants.

References:

**Case Presentation & Discussion Panel**
Harry E. Rubash, MD; Timohty Wright, PhD; R. Michael Meneghini, MD; Robert E. Booth, Jr, MD; Michael Mont, MD