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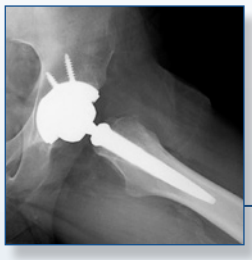

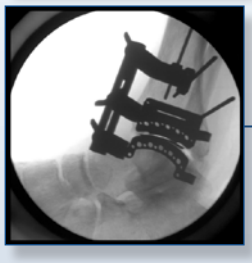

Arthroplasty of the Lower Extremities:

A Special Monograph Volume of the *Rhode Island Medical Journal*

LEE E. RUBIN, MD
GUEST EDITOR

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As our population ages and continues to live longer than ever before, there will be a dramatic increase in the burden of musculoskeletal diseases within our society. It is currently estimated that 10,000 Americans will turn 65 every day for the next 20 years, and between 2011 and 2030, the percentage of the American population over 65 years old will shift from 13% to 18%. These "Baby Boomers" will challenge the capabilities of our healthcare system, and place unprecedented demand on our healthcare system to restore joint junction and eliminate pain from arthritis to help maintain active, functional, and productive lifestyles.

Over the past 50 years, total joint arthroplasty has become one of the most common and successful types of orthopaedic surgeries, and total hip arthroplasty (THA) is perhaps the most successful surgery that has ever been developed. The high success rates enjoyed by both patients and surgeons following THA have helped to establish the procedure as the "gold standard" against which all other surgical procedures are compared regarding quality of life improvement. Accordingly, the British *Lancet* celebrated THA as the "Operation of the Century" in 2007.[1]

Currently, over 750,000 THA and TKA are performed yearly in the United States, and the numbers are expected to increase exponentially in the coming years.

A recent study of Medicare data presented at the 2012 Annual Meeting of the American Academy of Orthopaedic Surgeons[2] showed for the first time that if patients in matched groups with severe knee osteoarthritis undergo total knee arthroplasty (TKA), patients with TKA actually have a 7-year mortality rate that is half of those who don't undergo the procedure. Similar findings for THA have also been discussed at recent arthroplasty meetings in advance of publication, suggesting the notion that THA and TKA procedures not only relieve pain from arthritis, but may be viewed in the future as "public health interventions" that may predictably help people lead longer, more comfortable, and more productive lives.

Utilization trends verify the growing importance of total joint replacement within our national healthcare system. A recent *JAMA* article[3] analyzing Medicare data in the United States reported that primary TKA volume increased 161.5% and revision TKA volume increased 105.9% between 1991 and 2010. These increases were felt to be driven both by increases in the number of Medicare enrollees and by per capita utilization rates.

Although THA and TKA are the most common types of joint replacement surgery, orthopaedic surgeons now have the capability to perform joint replacements in nearly every region of the human body. Total disc arthroplasty for the spine, total shoulder and elbow arthroplasty, and total ankle arthroplasty have also emerged as viable treatments for patients afflicted with degenerative diseases of these joints.

VIDEO Lee E. Rubin,MD

Currently, over 750,000 THA and TKA are performed yearly in the United States, and the numbers are expected to increase exponentially in the coming years. By 2030, it is anticipated that there will be a 274% and a 673% increase in the respective number of THA and TKA procedures performed annually.[4]

Unfortunately, the burden of revision arthroplasty surgeries is also expected to climb at a similar rate as an increasing number of primary joint arthroplasty surgeries are performed annually. Most TKA and THA revisions are currently related to "osteolysis" from plastic wear. Thankfully, in the past decade, improvements in plastics bioengineering have reduced plastic wear rates in artificial joints by up to 1,000 fold. The effect on revision rates remains unclear, but is expected to significantly reduce the need for repeat surgery as longer-term data becomes available.

'Supply Side Crisis'

At the same time, there is a looming public health crisis in hip and knee replacement surgery that has been labeled by experts as a "Supply Side Crisis."[5] The number of young surgeons specializing in total joint replacement is declining, thought to be related both to declining reimbursement rates from cuts to the Medicare system, as well as the demanding nature of providing inpatient care for these patients. Since many senior arthroplasty surgeons are within 10 years of retirement, there is going to be a manpower crisis in arthroplasty surgery for the American public unless more orthopaedic residents and fellows can be skillfully trained to meet demands of an aging population.

LIFESPAN

Dr. Gary Ferguson, center, in the operating room at The Total Joint Center at The Miriam Hospital, a program of Rhode Island and The Miriam hospitals. It celebrated its one-year anniversary several months ago. The Center performs more than 100 cases a month.

With the recent development of Rhode Island's only academic Total Joint Center at the Miriam Hospital in 2011, we now have the capability to engage and develop the skills of talented young orthopaedic surgeons to help meet this important public health need. As we continually improve the quality and capability of joint replacement surgery in the state, our ability to care for local patients undergoing arthroplasty will be on par with the finest institutions in the country.

In this special volume of the *Rhode Island Medical Journal* (RIMJ), I have assembled a series of outstanding articles written by expert local authors about aspects of medical and surgical care related to lower-extremity joint arthroplasty. We will develop an improved understanding of the biology of osteoarthritis, explore novel ways surgeons and hospitals are working together to improve arthroplasty care delivery, and review current strategies to manage blood utilization surrounding arthroplasty surgery. We will gain insight into the diagnosis and management of ankle arthritis, and review cutting edge techniques relevant to THA and TKA that include both unique concepts and futuristic treatment options.

I wish to thank the leadership of the Rhode Island Medical Society and the editors of the *RIMJ* for granting the opportunity to present this unique monograph. I am also deeply grateful for the efforts of each author who contributed their insight and expertise towards making this a valuable collection of articles.

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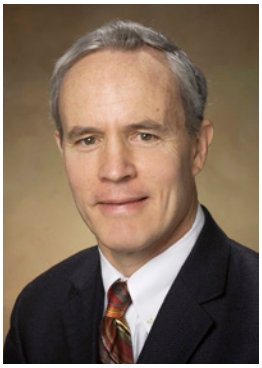
Establishing a Center of Excellence: The Total Joint Center at The Miriam Hospital

GARY M. FERGUSON, MD, CLINICAL DIRECTOR
JOHN A. FROEHLICH, MD, PROGRAM DIRECTOR

BACKGROUND

Challenges to the delivery of state-of-the-art healthcare to our patients continue to increase in recent years for nations, states, hospitals, physicians, nurses, and support staff. Administrative requirements, documentation demands, and remaining up to date with current principles of care challenge all of us. In the midst of this challenge, The Miriam Hospital has successfully launched a specialized program in orthopedic total joint replacement. In this article, we will describe the development of that program, its guiding principles, challenges, and early results. As a model for the delivery of care, it may also be useful and practical in its application to other specialties.



LIFESPAN

Gary M. Ferguson, MD

LIFESPAN

John A. Froehlich, MD

Stimulated by a journal publication in July, 2008[1] which described the projected increased demand for joint replacement surgery for the next 20 years, the surgical and administrative staffs at The Miriam Hospital launched an overhaul of the total joint replacement program. We were motivated by existing waste in resource integration, sparse shared governance between the administration and surgeons, inadequate alignment of surgical care protocols, and inadequate data-driven outcomes management. We embraced Lean Six Sigma methodology[2] to insure administration/surgeon shared governance, service integration, and the need to establish program champions in our 247-bed teaching hospital.

ESTABLISHING THE PROGRAM

We began by establishing monthly meetings including surgeons, nurses, recovery personnel, physical therapists, case managers, occupational therapists, the hospital's chief operating officer, admission personnel, administrative staff, and anesthesiologists. This spanned the course of one year. We went to great lengths to ask each service sector to describe its expertise in detail, written on a storyboard, outlining all features of care delivery relative to that sector. Over time, it became clear how expert, but separate, each service sector was in relation to the whole program. Biases and inherent resistance to change created by years of clinical experience had to be overcome. This process caused all participants to begin to propose specific changes that would help integrate their service expertise to the rest of the hospital-wide total joint replacement program. In some cases, it was necessary to alter protocols to maximize integration. The obvious commitment of surgeon champions to this process was essential.

VIDEO Total Joint Center at The Miriam

Revamped patient education process

A good example is the preoperative patient education process. This evolved from an unstructured attempt by preoperative testing personnel to answer patient questions, to a formal patient education session now mandatory and offered by a combined surgeon, therapist, case management, and nursing team. Lean Six Sigma methodology was employed.[2] This process, popularized by Motorola after the 1970s, seeks to eliminate errors and minimize variability in a business process or in manufacturing. Creating the education session meant integrating the nursing and physical therapy care over several cooperative sessions. Pain management, wound care, timing and location of therapy services, and diet and bowel function management were all integrated to coordinate delivery and minimize potential delays. Special protocols were developed for the planned day of discharge, compared to other days. Surgeon-to-surgeon variability in therapy management, wound care, bowel management, thrombosis prophylaxis, and pain management was addressed through a surgeon committee that meets monthly. This allows us to address all concerns of participating surgeons and reach consensus for a common order set. Once all of these efforts were complete, a combined patient education session for all patients could be delivered. Since its inception, it now consumes 90 minutes during a visit for routine preoperative testing. Our outcomes data shows that

over 80% of patients regard the session as essential or helpful. An institution-wide commitment to co-governance has been the common thread.

Genesis of Joint Center

The monthly institutional meetings mentioned earlier created opportunities for integrating care and led to results like the patient education session. In 2010 Lifespan made a formal financial commitment to fully develop a joint replacement center located at The Miriam Hospital. With this support, an outside consultant was hired to refine our efforts into a fully functioning Joint Replacement Center. This phase began in October 2010, allowing a full Joint Center launch in November 2011. We also visited another regional joint center to glean insight from that program's development and experience. From the outset, each stakeholder at our institution put his or her signature to a framed Pledge, an eight-point document. This is displayed at several sites in the hospital and describes the program's commitment to shared governance and data-driven outcomes management.

Shared governance

A governance committee was developed to oversee the entire effort, chaired by the director of Surgical Services and two surgeons. It continues to meet monthly, and members from all service sectors are represented, including purchasing, marketing, and information technology. Co-governance and transparency in management across service sectors is stressed. Our data (referred to as the "dashboard") is reviewed each month, providing current information on features such as cost consumption, length of stay, transfusion rates, discharge destination, patient satisfaction, etc. (*See Table.)* It is also tracked on a surgeon-specific basis. This outcome data is then used to pose specific projects to address and facilitate improvement, with a team leader for each project, and a clear deadline for completion. The Committee then reviews the results, and protocol changes implemented as needed. This structure and process has lead to a large number of successful outcomes data-driven program changes.

Patient navigators

Our management now includes the work of a full-time registered nurse/manager to serve as a patient navigator. This individual follows the patient closely throughout the entire hospital experience, providing extra advice, reassurance, and serves as a liaison with case management to facilitate discharge planning and expectations. She also sits on the governance committee to help facilitate continuity of care. Patient-care problems can be brought directly to her attention, and direct surgeon feedback offered. This individual also gives the primary care physician a summary of the hospital experience after each patient discharge. In August 2012, a second full-time nurse practitioner also began assisting the surgeons and nursing staff with direct postoperative medical care for all of our patients.

Multi-disciplinary approach

The basis of the total joint center's early success is the use of a multi-disciplinary approach with collaboration between various care and service providers. To achieve this we had to learn or re-learn what others do and make a concerted effort to meld these services. Obviously, this requires working not as individuals but rather as a team. The ultimate focus is on the patient and his/her needs. To achieve the goals we set, we used the governance model to reach consensus and achieve well-defined outcomes.

PROGRAM GOVERNANCE

A key organizational component of the Total Joint Center is the governance committee. As mentioned, this is comprised of key service providers to our patients before, during and after discharge. To maintain a focused and direct approach, a dashboard was created with components that were felt to be key to the success of the program and the needs of our patients. The dashboard is a monthly "snapshot" of our trends and associated success as intervention is pursued. The dashboard is divided into four sectors: 1. Financial, 2. Operational, 3. Patient experience and 4. Quality. (*See Table.*) This design allows us to provide direction to the entire Total Joint Center team and promotes a process of continual inspection/re-evaluation. Using this approach, we have been able to achieve impressive results in our first year of formal operation. Specific components within the dashboard

Table: Total Joint Center of Excellence Management Data Dashboard

FINANCIAL
- Combined Hip/Knee/Shoulder Caseload
- Total Supply Cost per Case
- Total Labor Cost per Case

OPERATIONAL
- Average Length of Stay
- OR Room Turnover Time
- OR First Case On-Time Starts
- Discharges to Rehabilitation

PATIENT EXPERIENCE *(From Press-Ganey Survey Scores)*
- How Well Was Your Pain Controlled?
- Likelihood of Recommending Hospital?
- Did the Staff Include You in Decisions Regarding Treatment?
- Discharge Composite Score
- Patients Attending Preoperative Education Class

QUALITY
- SCIP Criteria: Patients on Recommended VTE Prophylaxis
- SCIP Criteria: % Of Patients Who Received Timely VTE Prophylaxis
- Surgical Site Infections
- Patient Falls While in Hospital
- Readmissions Within 31 Days
- Transfused Cases for Total Hip and Total Knee Replacement
- Transfused Cases with Hemoglobin >/= To 8g/Dl
- Urinary Catheters Removed by Post-Op Day 1

may be modified (for example, changed to a higher goal), eliminated (no longer appropriate) or a new parameter added.

Specific Trends

Several specific trends are worthy of mention. Prior to the onset of this program, the average length of stay for the total joint patient was 3.7 days. This has continued to trend down and currently is 3.2 days. This alone represents a significant savings to the institution, especially since the number of patients who underwent replacement was 1,208 in calendar year 2012. Greater efficiencies in the operating room have resulted in an average decrease in room turnover time from 41 minutes to 21 minutes in 2012. Prior to this program, the typical patient went to a skilled nursing facility on average 75% of the time. With patient/family education, more comprehensive and consistent pain management, and accelerated inpatient rehabilitation during the hospital admission, this number has decreased to 29%.

We have seen truth to the adage: "If you build it they will come." The number of participating surgeons has increased from an initial core of 5 to 9 currently, with interest among others in the community to participate. Patient volume has also increased substantially from roughly 750 procedures in 2010 to 1,208 in 2012. Now over 80% of cases start on time in the morning, whereas fewer than 1 in 4 achieved this prior to the program. This feature alone illustrates the effectiveness of establishing a team-oriented multidisciplinary approach. Many perceived this as an "anesthesia issue." Further analysis showed this to be multi-factorial. Adjustments were made in patient arrival, staffing, a call-in system to assure surgeon availability and adjustment in anesthesia availability. The results are impressive. Rooms are better utilized, work is completed sooner, patients arrive sooner on the nursing floor facilitating care, and patients are available sooner for the initiation of same-day physical therapy.

Achieving these and other goals is important. Equally as important, the program has created a cooperative and cohesive environment, which is appreciated not only by the institution and staff, but also the patients themselves. It is an incredibly positive attribute that promotes further improvements in the program. We have also found that this team cohesion promotes a collegial "buy-in."

Additional features

Several additional features of the program warrant mention. We were fortunate to have at our disposal the hospital's data system and an individual very facile in data analysis. This allowed us to rapidly evaluate data and/or issues and create action items that were used to rectify problems or facilitate improvement. Another key to the entire program is its patient-centric approach. As such, the dedicated nurse navigator and nurse practitioner contribute to patient care in the pre-operative, post-operative and post-discharge phases of patient care. They also contribute greatly to building the relationship between the institution, the surgeons and the primary care physicians. Having all stakeholders involved and informed is imperative for optimal patient care. Finally, the surgeon committee, which meets monthly, has provided an important forum for surgeons from different groups to interact, discuss, and share ideas so as to reach consensus on common issues, which leads to streamlining of care and greater efficiencies.

SUMMARY

The Total Joint Center at The Miriam Hospital has been very successful and now serves as a model for other specialties. Key to this program's success is the cooperative relationship between various stakeholders. Leadership is required yet the input and participation of all is necessary to achieve the desired outcome. To achieve efficiencies, there must be a willingness to deeply integrate clinical services. Again, this requires input from sectors that in the past typically did not communicate with each other. Finally, surgeons and staff need to "pledge" and show their willingness to practice based on sound patient data and modify treatment based on this same data.

We are extremely proud of the results achieved. Also impressive is how, in a very short period of time, we have been able to bring together an extremely dedicated team of professionals who work cooperatively in a seamless fashion. With this approach we are able to meet our strategic goal of providing state-of-the-art, high quality, patient-centric, efficient healthcare.

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Disclosures

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Pathogenesis and Epidemiology of Osteoarthritis

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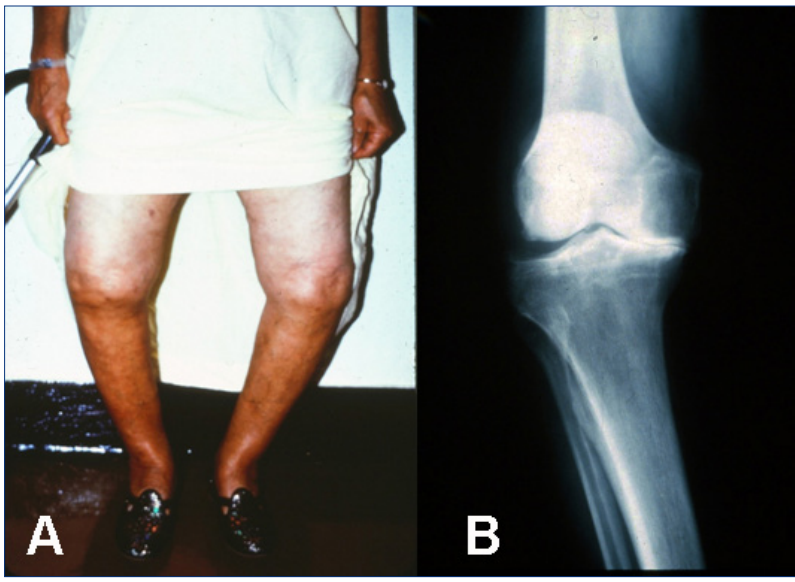
ABSTRACT

Osteoarthritis (OA) is a disease of high prevalence that produces substantial morbidity and is a leading cause of physical and psychological disability and expense, including time lost from work, medical care, and disability support. Until recently, the focus of research into the pathophysiology of OA has been on articular cartilage and has not resulted in either biomarkers of OA activity or effective targets for disease-modifying therapy. The contemporary paradigm of OA considers involvement of all joint tissues. It has been shown that, in later-stage OA, bone blood flow and oxygen content are markedly reduced and have a deleterious effect on bone cells, inducing them to release proteins (cytokines) that contribute to the bone remodeling and cartilage breakdown seen in OA.

KEYWORDS: Osteoarthritis, pathophysiology, articular cartilage



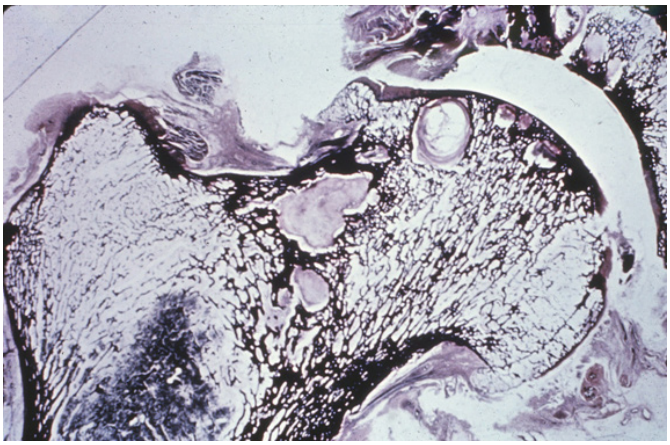
OA of the knee. Typical varus deformity is observed in the patient (A) with corresponding angular deformity in the joint due to asymmetric loss of cartilage (B).

Pathogenesis

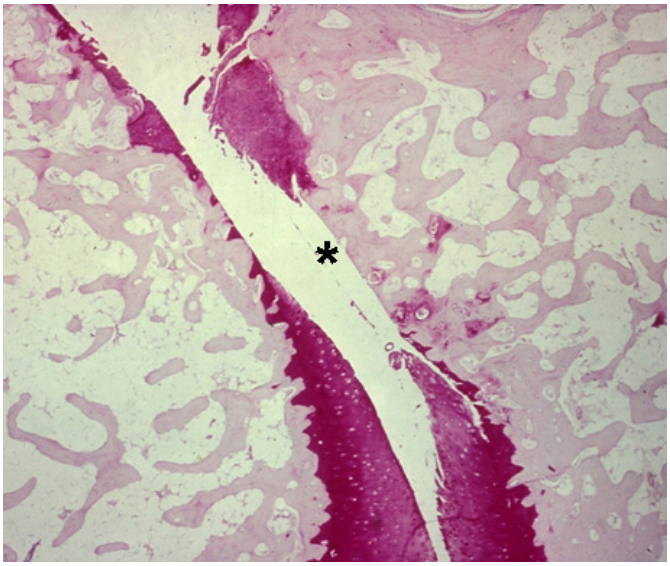
The contemporary paradigm of osteoarthritis (OA) is that its pathogenesis involves all joint tissues including cartilage, bone, synovium, ligamentous capsular structures, and surrounding muscle. It is characterized structurally by active bone remodeling, degradation of articular cartilage, and synovial inflammation resulting in loss of joint function and angular deformity or malalignment. A focus on the articular cartilage pathology has not led to novel biomarkers or therapeutic targets and many pharmaceutical manufacturers; notably, AstraZeneca, Pfizer, and Stryker Biotech have discontinued their OA research programs because disease modifying drugs were thought unlikely to be developed soon. Although a variety of synovial fluid markers provide insight into the biological response of joints to injury, no chemical or anatomic (imaging) biomarkers have been identified that monitor the development and progression of OA or the response to therapy. Certain factors increase the risk of developing OA, such as repetitive trauma/loading, joint injury, age, obesity, physical activity, bone mineral density (BMD), and in some subgroups, congenital anomalies. OA is thought to be highly cytokine-driven, and is associated with mechanical stress resulting from overloading of subchondral bone from dysplasias, malalignment, and trauma. Interest has been focused recently on small protein mediators (cytokines) that provide chemical signaling or "cross-talk" among involved tissues. These signaling molecules incite inflammation in the synovium, remodeling subchondral bone, and enzyme activation and extracellular matrix degradation in articular cartilage.

Subchondral Bone

Interest in structural remodeling, vascular biology, and osteoblast cytokine expression of subchondral bone in OA has been stimulated by a large number of studies suggestively associating a role for subchondral bone changes in the pathogenesis of OA. Active bone remodeling is associated with the initiation and progression of OA including sclerosis of the subchondral bone plate, alterations in trabecular structure, osteophytes and bone marrow lesions.[2-5] Some studies with a guinea pig OA model suggest that subchondral bone changes precede degradation of articular cartilage.[6, 7] Additionally, several cytokines have been found in subchondral bone that play major signaling roles associated with cartilage degradation including IL-1, TNF-α and those of the fibrinolytic system including plasminogen, tissue and urokinase plasminogen activators (tPA, uPA), and plasmin.[8]



OA of the hip. Coronal, histological section of an osteoarthritic hip showing the hallmarks of OA including loss of articular cartilage, osteophytes, subchondral cysts, osteoporosis, and osteosclerosis.



OA joint surfaces. Histochemical section of opposing osteoarthritic joint surfaces showing focal cartilage loss, subchondral sclerosis and eburnation (asterisk).

Distal femur at knee replacement. Focal nature of OA is evident with loss of articular cartilage (eburnation) on one femoral condyle (asterisk).

Vascular Biology of Subchondral Bone in OA

Intraosseous hypertension, venous stasis, and outflow obstruction are associated with bone pain and produce physiologically relevant reductions in perfusion and pO_2. These relationships are of extreme importance in understanding the physicochemical environment of OA and its pathologic significance. Collective observations suggest that the physicochemical environment consisting of pressure, blood flow, and oxygen, among others, may constitute signaling mechanisms to osteoblasts resulting in alterations in cytokine expression. Changes in perfusion, then, bear a functional relationship to bone remodeling and cartilage degeneration.

Osteoblasts (bone-forming cells) alter their cytokine expression profile in response to their physicochemical environment, and changes in the physical environment in subchondral bone in OA are well within the range to which osteoblasts are sensitive. Several studies have demonstrated a 2- to 3-fold increase in venous outflow obstruction in late stage OA of the hip.[9] One study, using intraosseous phlebography, also demonstrated markedly delayed venous drainage and occlusion of retinacular veins, with drainage of the proximal femur through diaphyseal intramedullary vein.[10] Several observations have suggested that intraosseous hypertension is caused by increased venous resistance resulting in outflow obstruction and venous stasis.

Intraosseous hypertension produced experimentally by venous ligation results in the histopathological hallmarks of OA – focal avascular necrosis (AVN), trabecular remodeling, thickening of the subchondral bone plate, endosteal and periosteal new bone formation and sclerosis.[10-12] The pathophysiological consequences of intraosseous hypertension may lie in its association with diminished perfusion and hypoxia, which could serve as parts of a signaling complex to osteoblasts. Several studies describe linear relationships between perfusion and intraosseous pressure.[13] An elevation in intraosseous pressure from 26 to 45mm Hg results in a reduction of intraosseous blood flow by 60%. A decrease in perfusion of 60% has been shown to reduce the pO_2 from 75 to 50mm Hg, within the range of hypoxia measured in OA bone. Measurement of intraosseous pO_2 shows significant hypoxia in OA.[14-16]

Osteoblasts Recognize and Respond to Altered Perfusion and Hypoxia

Osteoblasts derived from OA bone express increased amounts and types of cytokines that are related to bone remodeling and cartilage breakdown. The cytokine expression profile of osteoblasts is altered in response to changes in pressure, perfusion, and oxygen concentration of the type and magnitude seen in OA, raising the hypothesis that physicochemical changes observed in OA subchondral bone may serve as disordered signaling pathways to osteoblasts which, in response, alter their cytokine expression profile in ways relevant to bone remodeling and cartilage breakdown.

The relationship between increased bone remodeling and

cartilage degradation in OA has been recognized for many years but understanding the role of subchondral bone in the pathophysiology of OA remains elusive. In particular, the role of the osteoblasts in subchondral bone remodeling and cartilage breakdown remains unclear, as does the significance of recent descriptions of bone marrow edema and altered perfusion. Osteoblasts are also responsive to hypoxia. Osteoblasts subjected to hypoxic conditions with pO_2 of 35-40 mmHg, markedly alter the expression profile of growth factors associated with the pathologic findings of OA, increased bone remodeling and cartilage degradation.

Epidemiology and Economic Impact

The prevalence of OA is difficult to determine because symptomatic OA (joint pain, swelling, and stiffness) does not always correlate with the pathology of OA.[17] Prevalence of pain associated with joint degeneration varies among joints and among individuals.[18] Individuals with advanced degeneration of the joints may have minimal pain and disability, and for this reason, investigations of the prevalence of OA based on evidence of joint degeneration by itself, such as imaging studies or direct inspection of joints, yield larger numbers of affected individuals than do studies that require evidence of joint degeneration and joint pain together for the diagnosis of OA.[19, 20]

Recent information on the epidemiology of OA originates from population-based radiographic surveys.[21] Population-based studies in the United States suggest prevalence rates comparable to those in Europe, increasing from 1% for severe radiographic disease among people aged 25-34 to 30% in those aged 75 and above.[21] In 1997, a study in the Netherlands demonstrated that of the 1040 participants (aged 55-65), only 13% (135) were free from radiographic evidence of OA studied in the knees, hips, hands, wrists, and thoracolumbar spine.[22] According to some population surveys, evidence of radiographic OA of the knee increases up to 80% for adults over the age of 65.[23]

While most studies have focused on information from radiographic OA, there is increasing interest in the prevalence of symptomatic conditions of OA. This is important in order to determine the healthcare needs and options for patients. Symptomatic OA affects nearly 27 million Americans and is the most common form of arthritis. It is the leading cause of disability in the US.[24, 25] OA has a higher incidence in the hips and knees resulting in pain and stiffness and because these are large weight-bearing joints, it often leads to significant problems with mobility and disability requiring expensive surgical treatments.[26] In the United States alone, more than 350,000 knee and hip replacements are performed each year.[21]

Radiographic and symptomatic OA have been compared with age and gender. Using the Kellgren/Lawrence scale, they found that among different populations (NHANES study, Boston, MA, and Johnston County, NC) the prevalence of symptomatic OA was higher in women (62.9%) than men (46.5%).[27] Nearly half of the participants from the Johnston County, NC, study are expected to develop symptomatic OA by age 85.[28] Another study used age and sex prevalence in persons ≥26 years old and, using 2005 Census Bureau data, estimated that 9,267,000 adults have symptomatic knee OA.[27] As the population over 40 increases, the number of people experiencing symptomatic OA will rise as well.[29]

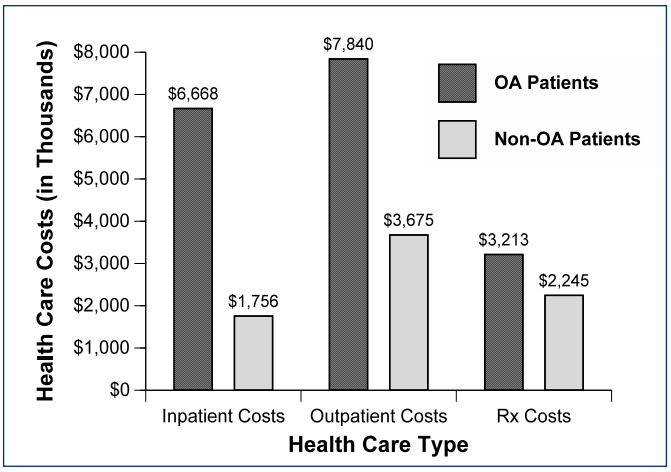


Figure 1: Regression-adjusted healthcare costs over one year. Non-OA patients had comorbidities shown to be prevalent among OA patients (eg, hypertension, diabetes, obesity, injuries, peptic ulcers, etc).[1] (*Source:* Graphic data from T.K. Le, *Journal of Pain and Research*, 31 January 2012.)

OA contributes to a decrease in activities of daily living, and quality of life, and an increase in loss of work days, all of which result in out-of-pocket costs to the patient. The World Health Organization (WHO) has estimated that 10% of the world's population over 60 years old suffers from OA; 80% of people with OA experience limitation of movement; and 25% cannot perform major daily activities.[30] One observation reported that of 9,933 participants from the Medical Expenditures Panel Survey (MEPS) who have OA, 92% see physicians during the year, 34% visit at least one OA specialist, 25% see an orthopedist, 11% a physical therapist, and 6% a rheumatologist.[31] Another study found that OA accounted for 7.1 million (19.5%) of all arthritis-related ambulatory medical care visits, of which 4.9 million were female patients, while 2.2 million were male.[25] OA is a major contributor to the total economic burden (1 to 25% of the gross national product of Western nations).[32] In addition, another study reported that OA costs more than $60 billion per year in the US.[29, 31] In 1997 alone, $7.9 billion estimated costs were attributed to knee and hip replacements.[33] In 2000 it was estimated that the total costs in the United States were calculated at $254 billion.[30] Le et al. recently reported that OA patients incur annual total direct costs that were $10,941 higher, on average, than patients without OA.[1] In their article, the total average healthcare costs (outpatient, inpatient, and Rx) for OA patients is $18,435 compared to $7,494 for non-OA patients (Figure 1). Direct costs included hospitalizations, emergency department visits, office visits

(primary and specialist), physical/occupational therapy, and medications. This figure does not include the costs due to decreases in productivity, such as time out of work for both patient and non-patient (i.e. care taker).

CONCLUSION

There is currently no biological cure for OA. The number of U.S. adults with OA is expected to increase, affecting the healthcare system and society as a whole. Because of these reasons, it will be necessary to find ways of preventing and reducing the progression of OA. Translational research should be directed toward understand how aging and mechanical loading may lead to joint degeneration, how some joints are resistant to primary OA, and how joints can partially reverse the degenerative process.[18]

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Advanced Blood Management Strategies for Elective Joint Arthroplasty

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(*NOTE: ALL AUTHORS ARE MEMBERS OF THE MIRIAM HOSPITAL'S TRANSFUSION COMMITTEE.*)

ABSTRACT

There is a high prevalence of anemia detected in the preoperative work-up of elective surgical patients preparing for total joint replacement. The impact of anemia in this population has significant implications due to elevations in postoperative morbidity and mortality. By using current clinical guidelines and medical evidence, clinicians can improve outcomes for these patients by employing a three-phase approach, focused on preoperative assessment, intraoperative hemostasis, and postoperative blood product management. Strategies to optimize preoperative hemoglobin levels, reduce intraoperative blood losses, and decrease postoperative transfusion rates can independently and collectively improve overall patient care and surgical outcomes following lower extremity total joint arthroplasty.

KEYWORDS: anemia, total joint arthroplasty (TJA), tranexamic acid (TEA)

INTRODUCTION

Anemia becomes more prevalent as our population ages. Based on World Health Organization (WHO) definitions, the prevalence of anemia will reach approximately 11% in the elderly (age >65 years old). The presence and degree of anemia is affected by comorbidities such as diabetes, cardiovascular disease, renal disease, and other inflammatory conditions. Patients often present to orthopedic surgeries for elective joint arthroplasty at older ages and thus, anemia is a common finding among this population.

Prevalence of Anemia in Elective Orthopedic Surgeries

It is recognized that approximately 40% of patients evaluated prior to elective orthopedic surgeries are found to be anemic by WHO definition (women Hb <12 g/dL, men Hb < 13 g/dL) (WHO, Shander, Saleh).[11,14,16] Preoperative anemia has been shown to be an independent prognostic factor for increased morbidity and mortality following orthopedic surgery. It is well known that preoperative Hb level is a major predictor of perioperative transfusion rates (Salido).[15] Allogeneic transfusions have been shown to increase hospital length of stay, rate of infections and perioperative mortality (Salido, Wu, Beattie).[15,18,1] Some orthopedic surgeries are associated with an anticipated high level of blood loss, thus increasing the possible need for perioperative transfusion. Given the independent risks for morbidity and mortality associated with previously unrecognized preoperative anemia and transfusion rates, guidelines have been developed to address the following areas of need: the preoperative, perioperative, and postoperative periods of patient care.

A standard approach to the detection, evaluation and treatment of anemia in the preoperative period has been identified as an area of unmet need. The Network for the Advancement of Transfusion Alternatives (NATA) developed practice guidelines from a systematic review of the literature. Goodnough, et al. reviewed published literature on the impact of preoperative anemia on clinical outcomes and recommended a standardized approach to detect preoperative anemia. Patients undergoing elective orthopedic surgery should be screened for anemia in order that the underlying cause can be indentified and corrected whenever possible.

Preoperative Detection and Management of Anemia

Preadmission testing can occur anytime before a scheduled elective surgery. However, to allow adequate time to detect and correct for anemia, testing should occur as close as possible to 28 days prior to the surgery. For those patients already known to have preexisting anemia, evaluation and treatment should begin as soon as possible.

The most common causes of anemia detected in preoperative testing include iron deficiency anemia, vitamin B12 deficiency, chronic kidney (and associated decreased erythropoietin production), chronic inflammatory diseases, and folate deficiency. As part of the preadmission testing, a complete blood count (CBC) should be drawn and anemic patients identified. Subsequent laboratory tests should screen for the most common etiologies including iron studies, ferritin, vitamin B12, creatinine, and in appropriate patients, folate, thyroid stimulating hormone (TSH), and CRP levels. Algorithms depicting initial and reflexive testing during the work-up of preoperative anemia are available and published (NATA guidelines, Munoz).[6,10] Treatment of the underlying cause of anemia should then commence to reach to target Hb levels within the normal range (female ≥12 g/dL, male ≥13 g/dL) within 4-6 weeks by the anticipated time of surgery.

For iron-deficient patients, replacing iron stores with oral versus intravenous iron is somewhat controversial. Overall,

both have been proven to correct iron deficiencies prior to orthopedic surgeries (Beris, Munoz).[2,10] Oral iron is least costly and easy to administer, however patients often experience gastrointestinal side effects and replenishing iron stores within the limited time frame can be difficult to achieve. Intravenous iron is now available in much safer forms; however, allergic reactions and anaphylaxis are still reported with all formulations. The ease of administration and ability to replenish iron stores during the time frame allotted preoperatively must be balanced with relatively higher costs compared to oral iron.

In the absence of preoperative iron supplementation, postoperative iron repletion has not been shown effective (Munoz, Beris).[10,2] This is likely due to postoperative healing and inflammatory cytokines altering hepcidin levels thus impairing iron absorption and mobilization in the postoperative period. Postoperative iron supplementation, oral or intravenous, is not recommended.

For patients in whom nutritional deficiencies have been corrected or ruled out, the use of erythropoietin stimulating agents (ESAs) has been shown to decrease perioperative transfusion requirements (Goodnough).[6] Patients with ferritin values <100 ng/mL or transferrin saturations <20 percent should have iron repletion prior to initiation of ESAs to increase their efficacy. Concurrent iron supplementation with ESAs has also been shown to decrease the dosage of ESAs necessary to correct preoperative anemia.

Anemia should be considered as a treatable symptom of an underlying disease. Preoperative evaluations will sometimes identify more significant comorbidities. If preoperative screening detects evidence of gastrointestinal bleeding, bone marrow disorders or significant renal disease, referrals to specialists such as gastroenterologists, hematologists, or nephrologists may be indicated. A delay in elective surgery may be necessary to insure patient safety and care.

Intraoperative Methods for Reducing Acute Blood Loss Anemia

Attention to meticulous hemostasis has always been paramount during total joint replacement surgery, and remains a crucial element in reducing postoperative anemia. Even when surgeons make a consistent effort to prevent ongoing blood loss via cauterization of peri-articular vessels, there can still be ongoing postoperative bleeding from cut bony surfaces or from bone canals that have been instrumented in the surgery. Efforts to mitigate these "ongoing" blood losses have resulted in improvements in the global understanding and the management of blood loss following arthroplasty surgery.

Two separate meta-analyses, published in 2004 and 2007, both looked at the use of closed suction drainage following orthopaedic surgery in a total of 8959 patients and 9386 surgical wounds. (Parker, Parker)[12,13] Both reports came to virtually identical conclusions, namely that the use of surgical drains following orthopaedic surgery showed no difference in the rates of wound infection, wound hematoma, or reoperation rates, but did show significantly increased risk for postoperative blood transfusion. Thus, the routine use of closed suction drains within the intra-articular space following hip and knee arthroplasty has no established clinical benefit for the patient, and now has a strong association with increasing the requirement for postoperative blood transfusion.

More recently, mounting clinical evidence has emerged on the role of using tranexamic acid (TEA) at the time of total joint arthroplasty to reduce the rate of postoperative anemia and transfusion. The pooled risk ratio for needing a transfusion after orthopedic surgery was 0.55 in one review of TEA in 10,488 surgical patients. (Ker)[8] A second meta-analysis looked more specifically at the use of TEA in total knee arthroplasty, and found that both the amount of blood lost per patient and the number of blood transfusions needed after surgery were significantly less with the use of TEA. (Yang)[19] Importantly, the risks for myocardial infarction, deep vein thrombosis, and pulmonary embolism was not increased in these large series of cases when administering TEA. The ideal TEA dose and route of administration is still under investigation, since it can be given either by injection to the joint immediately following capsular closure in the OR, or via single- or multiple- intravenous injections given in the peri-operative window. (Maniar)[9]

Other methods for intra-operative reductions of blood losses may also prove to be effective, and will be reassessed in the future based on the availability of high-level clinical evidence. For example, the use of neuraxial anesthesia, saline coupled bipolar tissue sealer devices, and the application of topical hemostatic material within the joint are currently under investigation in a number of studies.

Postoperative Tolerance of Normovolemic Anemia and Transfusion Thresholds

The hemoglobin threshold for perioperative transfusion is controversial. Carson et al suggested that symptom-driven transfusion triggers might be an effective blood conserving approach. (Carson 1998)[4] The Transfusion Requirements in Critical Care (TRICC) trial evaluating clinical outcomes in patients in the critical care setting found that a restrictive transfusion strategy had a non-significant decrease in 30-day mortality; this study did not endorse a restrictive strategy in patients with active cardiac disease. (Hebert)[7] Given the degree of blood loss expected during elective hip and knee arthroplasty, postoperative transfusion has been commonplace for many decades. Multiple strategies in the preoperative and intra-operative periods aim to reduce postoperative allogeneic transfusion rates. Concern for increased cardiovascular events and impaired quality of life postoperatively has led some to adopt relatively high hemoglobin trigger thresholds for transfusions in "at-risk" patients.

To address these issues, the FOCUS trial (Transfusion Trigger Trial for Functional Outcomes in Cardiovascular Patients Undergoing Surgical Hip Repair) evaluated higher blood transfusion thresholds (hemoglobin <10 g/dL)

compared with a more restrictive transfusion strategy (hemoglobin < 8 g/dL) on functional recovery, morbidity and mortality in the immediate postoperative period. Carson et al[3] concluded that a liberal transfusion strategy did not reduce either the rates of death or inability to walk independently on 60-day follow-up. In this study, there was no appreciable reduction of in-hospital morbidity in elderly patients at high cardiovascular risk following hip fracture surgery using the "restrictive" hemoglobin trigger of 8 g/dL. An additional study focused on quality-of-life measures in the immediate postoperative period after hip or knee arthroplasty, concluding that moderate anemia (across all hemoglobin levels between 8 g/dL to >10 g/dL) was not associated with an impaired functional recovery or a decreased quality of life. (Vuille-Lessard)[17] These more recent studies have led some clinicians and institutions to establish more restrictive transfusion thresholds of asymptomatic anemia to 8 g/dL, even for the elderly or in those patients with underlying cardiovascular risks.

CONCLUSIONS

Preexisting anemia detected prior to surgery, intraoperative blood loss, and postoperative allogeneic transfusion rates have been proven as independent prognostic factors for morbidity and mortality associated with elective orthopedic joint arthroplasty. Blood management strategies to optimize preoperative hemoglobin levels, reduce intraoperative blood losses, and decrease postoperative transfusion rates can independently and collectively improve overall patient care and surgical outcomes following lower extremity total joint arthroplasty.

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Management of the 'Young' Patient with Hip Disease

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ABSTRACT

Although hip arthritis typically affects older patients, there is a rapidly growing population of "young" patients experiencing debilitating symptoms from hip disease. Most commonly, osteoarthritis and avascular necrosis affect this population, but a variety of other primary structural and metabolic causes can also occur. The expectations of these younger patients are often distinct from geriatric patients, and the challenges in optimizing their care are unique in this demanding population. Selection of the implant, bearing surface, and surgical technique can all impact the success and longevity of total hip replacement. A consideration for respecting the native bone stock is an important consideration that can potentially reduce some of the future challenges of revision arthroplasty in this young population.

KEYWORDS: total hip replacement (THA), neck sparing arthroplasty (NSA)

Diagnosis and Management of Hip Disease in the Young Patient

Advanced arthritis of the hip joint can lead to profound changes in quality of life. Debilitating pain, stiffness, and altered gait biomechanics all affect the ability to stay mobile and maintain gainful employment; these concerns are magnified in the younger patient with hip disease. While hip arthritis typically affects older patients, there is a significant subset of active patients in their 30s, 40s, and 50s who are affected and were previously thought of as, "too young for a hip replacement." Over the last several decades, advances in hip replacement surgery are allowing us to rethink that position. Two major causes of advanced arthritis in young patients are primary (idiopathic) osteoarthritis and avascular necrosis. Most of the remaining cases are caused by inflammatory arthropathies, infections, trauma and congenital or developmental anatomical abnormalities.[1]

Osteoarthritis

Osteoarthritis is a chronic degenerative condition that is associated with, but not caused by, aging. It can be categorized into primary or secondary causes. Primary osteoarthritis remains idiopathic in nature. While its exact pathophysiology is unknown, some believe that minor developmental abnormalities lead to impingement within the joint, altered biomechanics and ultimately cartilage loss.[2] Secondary osteoarthritis can be due to an identifiable cause such as trauma to the femoral head, post-infection arthritis, slipped capital femoral epiphysis, or hip dysplasia.

As we age, the water content of cartilage increases with a concomitant decrease in protein content, both leading to degeneration. The progressive loss of the cartilage matrix leads to recurrent bouts of inflammation as bone contacts bone, and reactive bone called osteophyte forms around the joint. In the subchondral bone, hardening and cyst formation occurs. Repeated bouts of inflammation also extend into the peri-articular soft tissues leading to deformity and contractures of the capsule, supporting ligaments, and tendons. Put together, these changes lead to pain, stiffness, and gait disturbances. Its commonality among close relatives hints at a genetic predisposition, which is not currently understood.[1]

Avascular Necrosis

Avascular necrosis, also known as osteonecrosis, is the most common reason for advanced hip arthritis in the young patient.[3,4] Avascular necrosis occurs when the bone in the femoral head loses its blood supply. The weakened bone leads to cyst formation and collapse of the bony architecture with a resulting deformation in the shape of the femoral head. This painful process results in a rapidly progressing arthritis. Common causes are alcohol abuse, prolonged use of corticosteroids, hypercoagulable states (ie. Sickle cell disease[5] or lupus) and trauma to the hip resulting in altered blood flow to the femoral head. Smoking is also postulated to have a role in the microvascular manifesations of the disease.

Many other cases are idiopathic in nature. Initial treatment begins with medical management and may include anti-inflammatory medication. Some studies have demonstrated bisphosphonate use may delay or prevent femoral head collapse; further studies have not supported it. Though many have been investigated, there is no single pharmacological agent that can prevent the naturally advancing course of osteonecrosis.[4]

If significant pain relief is not achieved with conservative care, most patients turn to surgical management. When diagnosed early before collapse of the femoral head, a core decompression can be performed to preserve the joint. In this procedure, a canal is drilled into the femoral head with the hope of reducing the intraosseous pressure to relieve

pain, and stimulate a healing response in the femoral head by increasing blood flow. Typically these techniques relieve pain, but often only delay eventual femoral head collapse. Unfortunately, many of these patients will still develop femoral head collapse and the associated findings of acute-onset severe arthrosis associated with debilitating pain, and will then need a hip replacement.

Presentation and Management

Common symptoms of hip arthritis include pain in the groin, especially while weight bearing and increasing with use. The arthritic hip is typically stiff in the morning and the patient may note difficulty getting up from a chair after a prolonged time seated. There is a noted decreased range of motion and activity tolerance, with particular difficulty in donning socks and tying shoelaces. The resulting disuse of the hip second to pain leads to atrophy of the musculature. Muscle weakness, in addition to avoiding weight bearing on the affected extremity, can lead to the development of an antalgic limp. A cane or crutch may be used to offload body weight, and pain may also be referred to the lower back or ipsilateral knee.

Nonsurgical management of arthritis is typically geared toward the inciting factor whether that is stopping an offending agent (steroids, alcohol), or the use of disease modifying anti-rheumatic drugs (DMARDs) in inflammatory arthropathies. Virtually all patients with arthritis can benefit from other nonsurgical interventions such as weight loss, activity modification and anti-inflammatory medications. Each patient is affected differently and it is difficult to know the expected rate of progression in each.

Patients in significant pain and discomfort will typically seek the help of a hip specialist. For those who quickly progress to debilitating arthritis, a replacement may be the only option regardless of age. In the past, younger patients had limited surgical options. Hip arthrodesis, or fusion, had poor results with limited functionality and frequently lead to atrophy of hip musculature and pericapsular contractures making reversal difficult. Deficient hip abductors predispose to dislocation as well. [3] Healthy, young, active patients with advanced arthritis are ideal candidates for a replacement due to their good muscle tone and ability to remodel bone and enjoy predictable increases in quality of life. Other surgical options not discussed further can include femoral or acetabular osteotomies for deficiencies in the proximal femur or acetabulum respectively. These are reserved for anatomic or congenital abnormalities that lead to altered hip biomechanics and also significant pain.

Surgical Options for Hip Replacement in the Young Patient

A total hip replacement is one of the most reliably successful procedures in orthopaedics. Long-term data has shown that with a well positioned modern prosthesis we can give our patient reliable pain relief that has a very high chance (>80% in most cases) of lasting over twenty years.[6,7] While this may be very comforting to a 75-year-old retired patient with relatively low functional demands, it will not suffice for patient with advanced arthritis in their 30s. For this reason, in the past many surgeons were reluctant to perform joint replacement surgeries in young patients for fear of condemning them to multiple revisions over a lifetime of use. With current technology, we can now provide young and active patients with long lasting pain relief with the confidence that we will be able to revise these prostheses in the future if needed.

The ideal hip replacement prosthesis for a young patient would be easily integrated, forming a long lasting bond with the host bone, yet be easily removed if needed. Most modern hip prostheses are made of titanium and are cementless. They use biological ingrowth for osseous integration of both the femoral and acetabular components. The prosthesis is typically coated with thousands of tiny particles that give the surface a roughened appearance. Between these tiny metallic pores are spaces where the host bone actually grows onto the prosthesis.

Bearing surfaces are the parts of the prostheses that glide across one another to allow motion at the joint. In the past, many different products were used including ivory, glass, plastic and metal. Today popular choices include either a metal (cobalt-chrome) on plastic (called polyethylene), ceramic on plastic, ceramic on ceramic. Metal on metal remains an option, but has fallen out of favor due to poor clinical performance and implant recalls.

As the bearing surfaces rub against each other, the materials begin to wear, shedding tiny micron-sized particles, each at a different rate. Previously, plastic wear particles generated when the head of the prosthesis rubbed on the plastic liner were responsible for a phenomenon termed 'osteolysis.' Osteolysis is an inflammatory condition led by an activated macrophage response to ingested plastic particles which leads to periprosthetic bone loss resulting in implant loosening or fracture.[8] This has largely (but not completely) been solved with the highly engineered "cross-linking" of the polyethylene molecules that makes it almost a thousand times more resistant to wear.

Ceramic bearings are quickly becoming the preferred bearing surface in the young and active patient.[6,9,10] These bearings have lower wear rates than metal on plastic components and have less friction between surfaces leading to smoother motion.[3] Additionally, by eliminating a polyethyelene component, osteolysis is much less a concern.[8-10]

Another aspect of the modern hip prosthesis that has evolved is the actual design of the femoral implant itself. Several implant designs on the market are 'bone sparing,' meaning that less native bone is resected from the femur. Over the past decade, "hip resurfacing" was a popular procedure in this regard. Resurfacing procedures have fallen out of favor recently for several reasons, including the difficulty of placing the prosthesis as well as concerns for metal-on-metal bearing wear and failures.

A "bone-sparing prosthesis" is not a new concept but has been gaining in popularity. This prosthesis is similar in

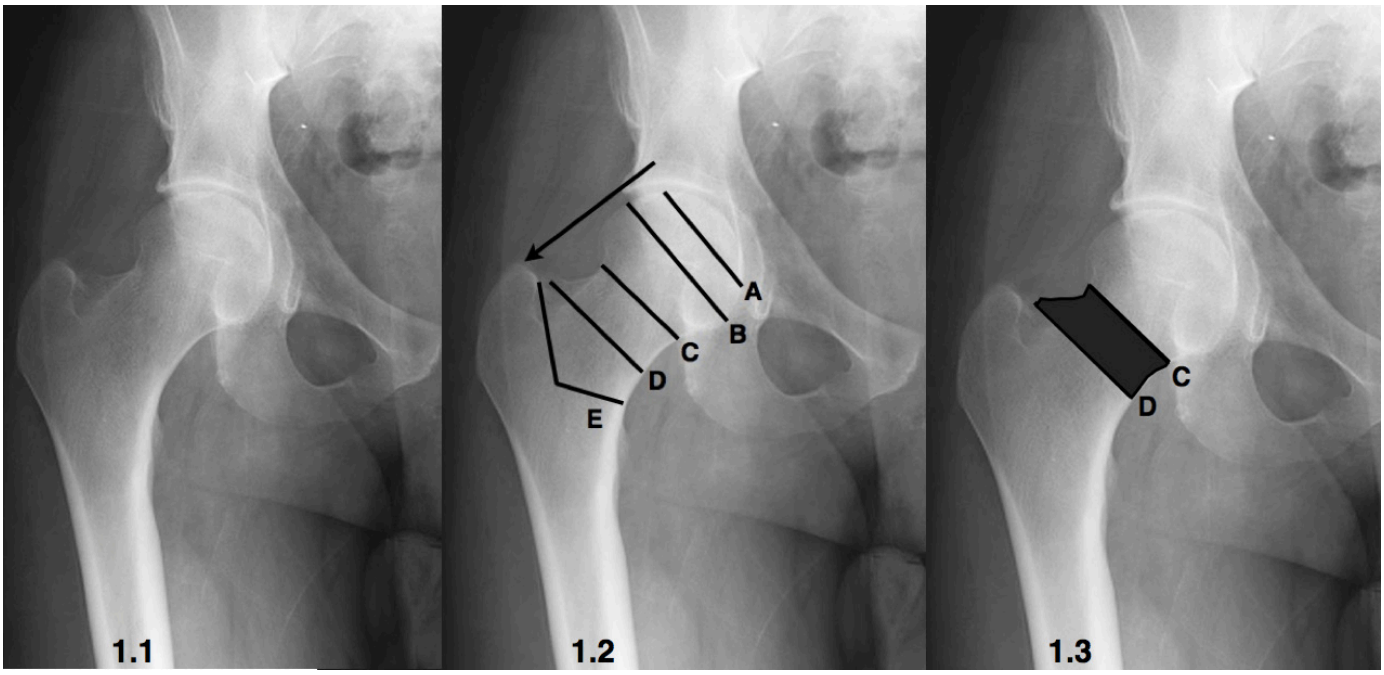

Figure 1.1. AP Radiograph demonstrating a healthy native right hip joint.

Figure 1.2. Various bone resection levels, each taking away more proximal femoral bone from level A (Proximal) through E (Distal). (A: Hip Resurfacing, B: "Mid-Head" Resurfacing, C: "Neck-Sparing Arthroplasty," D: Standard Total Hip Arthroplasty, E: Revision Total Hip Arthroplasty.)

Figure 1.3. Shaded area demonstrates the retained area of proximal femur preserved with a "Neck-sparing arthroplasty."

design to other modern prosthesis but preserves more bone in the femoral neck of the patient. The hope is to allow implant placement while leaving a viable option for revision at a later date. When the femoral bone cut is made, more femoral neck bone is retained, and the proximally coated implant engages and helps preserve this "extra" bone over time. Plastic, metal or ceramic bearing options can still be used.

The level of the femoral bone resection varies based on the arthroplasty technique. (Figure 1) In hip resurfacing (1.2 A) and "mid-head" resurfacing (1.2 B) (available only in Europe), most of the femoral bone is retained. With neck sparing arthroplasty (1.2 C) and conventional total hip arthroplasty (1.2 D), progressively more bone is resected during the operation. With hip revision surgery, native bone is often eroded, leading to and even lower bony resection level (1.2 E). "Neck-sparing" implants allow the surgeon to retain the native bone between cut levels C and D (Figure 1.3), with the concept of native neck bone stock preservation for future revision surgery in the young patient.

SUMMARY

Over the next several decades we will continue to see improvements in implant fixation, bioengineering of bearing surfaces, and prosthesis design that will allow us to reliably replace hip joints in younger and more active adult patients. In addition to continued improvements, careful outcomes monitoring with joint replacement registries will be needed over the next few decades. Ideally, surgeons would like to provide durable, long lasting pain relief to patients, regardless of their age at presentation, and have the ability to safely revise a prosthesis in the future if needed. The ability to perform hip replacement surgery with a forward thought toward future revision will give hip specialists the confidence to treat patients previously though too young to undergo joint replacement surgery.

Brief Case Example

A 29-year-old man presented with the acute-onset of debilitating pain in his left hip from AVN with collapse secondary to chronic steroid use for immunosuppression of severe lupus. (Figure 2). His symptoms developed over 4 weeks and were incapacitating, requiring the use of two crutches and high doses of long-acting narcotic for comfort. He was treated with total hip arthroplasty using a neck sparing implant and a ceramic on cross-linked polyethylene bearing surface couple. The implants were inserted via the direct anterior approach with a "bone-sparing technique" allowing retention of 1.5 cm of his proximal femoral bone, with anatomic restoration of his hip center of rotation (Figures 3 and 4). His postoperative course showed complete resolution of his pain, dramatic improvement in his hip function, and he was able to begin returning to work as a professional chef after less than 8 weeks of recovery.

Figure 2. Left Hip Joint with AVN and acute collapse of the dome of the femoral head, indicated by arrows.

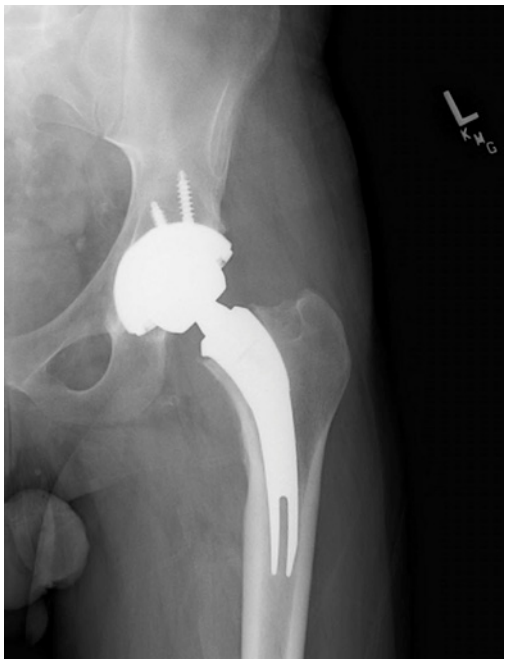

Figure 3. Postoperative AP Left Hip, showing "neck-sparing arthroplasty" in an anatomic position with restoration of hip alignment, offset, and position.

Figure 4. Postoperative Lateral Left Hip demonstrating anatomic prosthesis positioning.

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Current Thoughts on Ankle Arthritis

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ABSTRACT

The ankle is the most commonly injured joint in athletic and work activities. In contrast, osteoarthritis of the ankle joint is relatively rare and is typically post-traumatic or inflammatory in nature. Common symptoms that prompt an orthopaedic consultation include pain, disability and altered gait mechanics. Non-operative management has been the mainstay for previously undiagnosed patients. For those with advanced disease, ankle fusion or total ankle replacement may be the only surgical options. Though some recent studies have shown patients' preference for a well functioning ankle replacement, significant long- term follow-up data is lacking.

KEYWORDS: ankle anatomy, arthritis, arthrodesis, total ankle replacement

INTRODUCTION

The ankle is the most commonly injured joint in the body and is also the most frequently injured area of the musculoskeletal system during athletic activity. In contrast to the hip and knee, primary osteoarthritis of the ankle joint is relatively rare.[1] Cartilage destruction due to trauma to the distal tibia, medial and lateral malleoli, and the talus is the most common etiology of arthritis of the ankle. Similarly, cumulative trauma from chronic ligamentous instability can lead to mechanical derangement resulting in insidiously progressive arthritis. Inflammatory arthropathies account for many of the remaining cases.[1] Ankle arthritis is painful and can seriously alter day-to-day function by causing pronounced deterioration of gait and weight bearing ability. Pain, swelling, stiffness, and deformity due to ankle arthritis are common afflictions evaluated by a foot and ankle specialist.

Ankle Anatomy

The tibia, fibula and talus compromise the ankle joint. While commonly thought of as a simple hinge joint, the ankle joint is better thought of as a rolling cylinder that rotates on an oblique axis between the medial and lateral malleoli.[2] Many ligaments support the bony articulations and hold the talus centered under the tibia and its articulation with the fibula. The tibia and fibula are joined by a complex known as the syndesmosis which is made up of four separate ligaments and is located 2–3 cm above the tibiotalar joint line. These supportive ligaments are very important to the ankle joint stability. Chronic excess movement within the mortise due to ligamentous instability leads to rapidly progressive arthritis. Additionally, the ankle rests directly upon the foot and positional changes or deformities of the foot can have dramatic effects on ankle function, alignments, and symptoms.

Due to the significantly smaller surface area of the ankle, the forces transmitted through the joint are much greater than in the hip or knee. During normal walking, forces up to five times body weight are transferred through the ankle, and this increases with running and other strenuous exercise. The cartilage in the ankle is stiffer and more resistant to deformation than other weight bearing joints, allowing it to support these increased loads. Comparisons of articular cartilage samples harvested from knee and ankle joints have demonstrated a higher composition of glycosaminoglycans and proportionally less water content in the articular surface of the ankle. Simply put, the cartilage in the ankle, despite its relative thinness, is denser and stronger than either the distal femur or proximal tibia, and this difference appears consistent among individuals.[4]

Three views of the ankle joint: AP, Lateral and Mortise; note the well preserved joint space.[3]

TREATMENT

Treatment options for ankle arthritis include non-operative as well as operative management. Traditional non-operative care techniques which should always be considered the mainstay and first-line management for any patient initially presenting with ankle arthritis. These include activity modification, bracing, weight loss, shoe modification and physical therapy. Additionally, intra-articular corticosteroid injection, anti-inflammatory drugs and perhaps even the newer forms of injected hyaluronate viscosupplementation (although supportive scientific data are currently lacking and it remains a controversial therapy) can reduce inflammation and pain. The vast majority of patients presenting with as yet untreated mild or moderate ankle arthropathy can derive great benefit from utilizing varying combinations of these modalities, often for many years. In the face of advanced arthritic disease these combined therapies often have poor outcomes with little positive effect on symptoms. These patients are most frequently the candidates for whom operative management is considered. Open or arthroscopic debridement and decompression can be useful early when the patient's chief complaint is mechanical in nature due to impingement, loose bodies or small osteochondral defects. In the case of advanced disease, arthrodesis or total ankle arthroplasty are the surgical options.

Ankle Arthrodesis

Arthrodesis was originally described in the late 1800s. It has been the gold standard for end-stage ankle arthritis for many years and, for most surgeons, remains so today. Despite many reported techniques, the goals have always remained the same: to remove all painful motion from the articulation, restore and maintain alignment, and withstand the significant day-to-day stresses of standing, walking, and even impact activity (in younger patients). Today arthrodesis is performed open or arthroscopically using some combination of plates or screws with bone graft. Using modern methods, roughly 90% of patients are able to achieve bony union and experience significant pain relief. Optimal position of fusion restores the weightbearing axis of the lower extremity (if deformity was present) and places the forefoot in position to be accommodative.[1] Inevitably, some patients will have problems such as infection, delayed or nonunion as well as progressive degenerative changes in nearby joints due to the increased stresses placed on them after ankle fusion. The overall satisfaction rate with ankle fusion in patients remains excellent, although it is clear that walking with a stiff ankle requires certain accommodations and some patients unequivocally dislike the lost ankle motion and never seem to be able to adjust well to that despite an improvement in their pain level.

TOTAL ANKLE REPLACEMENT

Total Ankle Replacement (TAR) was initially introduced in the 1970s as an alternative to ankle fusion for the treatment of debilitating ankle arthrosis. The postoperative limitation in motion, altered gait mechanics, and possibility of gradually progressive arthritic development in nearby foot joints caused by ankle fusion remain the longstanding driving factors in the continued search for a better option.[5,6] Despite the inherent promise, potential advantages, and multigenerational designs associated with replacement of the ankle, ankle arthroplasty has historically never enjoyed the same level of success documented with hip and knee arthroplasty. Early total ankle implant designs were plagued with complications such as implant loosening and subsidence as well as limited function. All of these problems made ankle fusion a more attractive option. Due to recent improvements in design and surgical technique interest in total ankle replacement has returned.

There are currently five commercially available ankle prostheses in the United States today approved by The Food and Drug Administration (FDA), which are considered 3rd generation designs, one of which was designed and patented by one of the authors. Most of the modern prosthetic designs consist of three pieces, two of which are comprised of a metal alloy and the third which makes up an interface composed of a very durable plastic piece made of highly cross-linked polyethylene. The two metal components are usually made of titanium or cobalt-chrome, with one piece designed for insertion into and replication of the distal tibial surface (top of the ankle) and the other designed for replacing the talar dome (bottom of the ankle joint). While all but one of these devices are fixed bearing, two-piece designs that have the plastic piece fixed to the tibial component, one is a three component "mobile bearing" system, whereby the plastic liner is intended to move freely between the two metal components. To date there exists little if any data which definitively supports a difference in survivorship or outcome between these design concepts, and currently the majority of the purported advantages and disadvantages remain theoretical. The short and midterm follow-up data, supporting a survivorship ranging between 80–95% for approximately 5–10 years postoperatively for these 3rd generation designs, remains promising, and foot and ankle surgeons retain a cautious optimism with these implants, given the historically poor track record of earlier (1st and 2nd) generation design technology. [6-9]

Design advances

Early designs of ankle replacements were simple hinge joints and were highly constrained. Constraint refers to the restriction of motion and can be rotational, anterior to posterior or medial to lateral. Increased constraint led to higher forces being transmitted to the bone-prosthesis interface and ultimately implant loosening and failure.[1] The current

generation of implants on the market today incorporate different metallurgy and plastic technology, are more anatomic and less constrained leading to more equal transfer of force to the surrounding bone and subsequently lower rates of implant failure.[6]

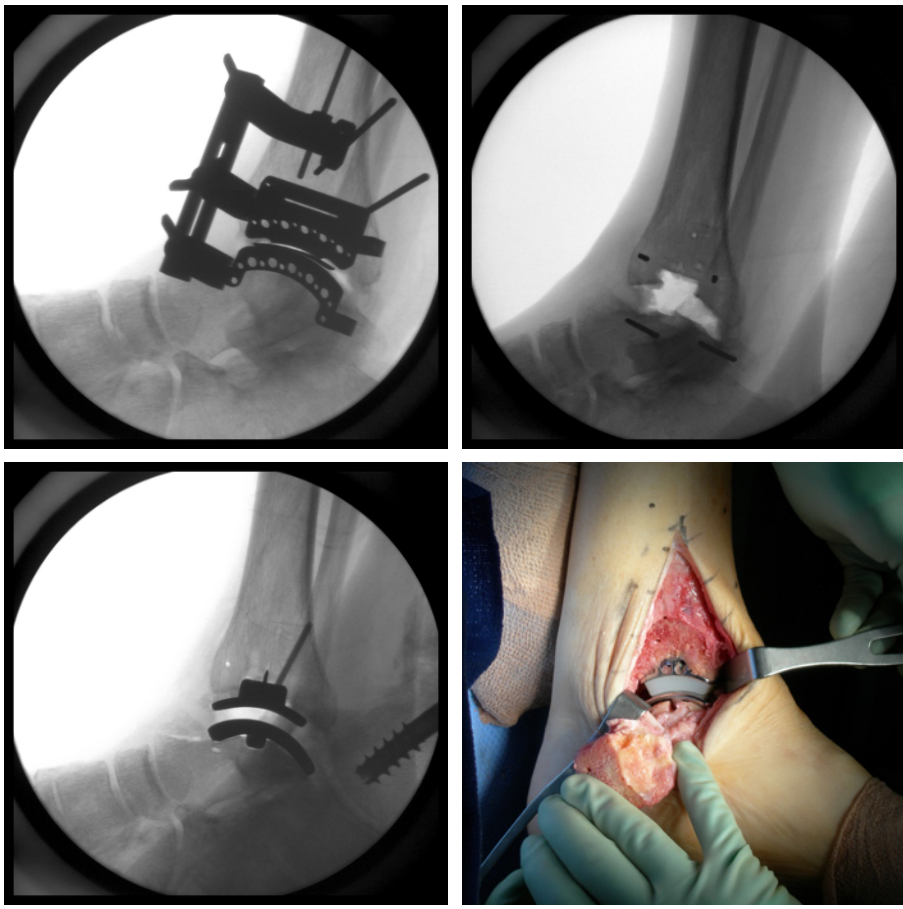
All prosthetic implants must firmly attach to bone. Most early ankle replacement prostheses were cemented in the distal tibia and required a significant amount of distal tibial bone to be removed. The cement provides an additional surface where failure can occur. Additionally, removal of large pieces of bone to fit the prosthesis and cement made future conversion to a fusion (if required) difficult.[7] Current ankle replacement designs, although typically approved for cemented use, are being predominantly utilized as "press-fit" devices, being implanted directly onto the raw bony surface in a process quite similar to many modern hip replacement designs that take advantage of biological bony ingrowth. These prostheses are coated with tiny beads that have intervening spaces as small as 50 microns. The pores allow for the surrounding bone to literally grow into the prostheses and form a potentially life-lasting bond that retains the capability of remodeling over time. This advancement has led to increased survival not only in total hip replacements but also total ankle replacements. Combined, these advances have led to better fixation, better survival, and lower rates of implant loosening and failure in modern total ankle replacement surgery.[6]

While there have been many improved advances and techniques in ankle replacement there is also mounting evidence to suggest that patients are increasingly preferring ankle replacements because they seem to offload adjacent joints and also mimic a more normal gait cycle as compared to ankle fusion patients on a day-to-day basis. It also remains clear (and is important to remember) that the ideal candidate who would benefit most from ankle replacement has yet to be been fully determined. Importantly, there are several agreed upon contraindications to an ankle replacement.

Contraindications

Absolute contraindications include those patients with peripheral vascular disease, active infections, as well as those with neuropathic or Charcot arthropathy. Patients who already have a stiff ankle are less likely to gain motion after joint replacement and should be counseled appropriately. As with any joint replacement surgery infection is always a dreaded complication which can lead to implant failure and necessitate removal and long-term IV antibiotics. If the infection cannot be cleared, below the knee amputation may be considered. Relative contraindications include smoking, young active patients, those with ligamentous laxity about the ankle, overall lower extremity malalignment as well as pre-operative ankle stiffness.

It is clear that the horizon for total ankle replacement looks very promising, but this procedure is still not for every surgeon or every patient. A pooled meta-analysis done several years ago evaluated the intermediate and long-term outcomes of TAR versus fusion and, despite limited and arguably confounding data, confirmed overall comparable results between the groups.[9] Certainly, further investigation is needed in the area of TAR before we truly know who will benefit most from this operation, and for how long. Given the recent promising early results of newer technology there is no doubt that interest in ankle replacement will continue. The ultimate goal for defining a wholly successful total ankle replacement – which would eliminate the need to ever perform an ankle fusion ever again in a manner similar to the evolution of hip and knee replacement surgery supplanting any need for hip or knee fusion surgery – will be to provide our patients with a safe, reliable, durable ankle arthroplasty that 1) preserves ankle motion and function, 2) provides excellent long-term pain relief, and 3) exhibits a 95% 20–25 year survivorship akin to the most successful hip and knee replacements currently available.



Eclipse (Integra Life Sciences) total ankle replacement. Cutting blocks guide the precise bony resection of the distal tibia and talus. The space for the implants is evidence and final implants are placed. Finally before wound closure.[10]

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Brief Report: Total Knee Arthroplasty Performed with Patient-Specific, Pre-operative CT-Guided Navigation

LEE E. RUBIN, MD; KENNETH T. MURGO, BA

ABSTRACT

The clinical success and long-term outcomes of total knee arthroplasty (TKA) are dependent not only on the biomaterials within the prosthetic implant, but also on the surgeon's ability to correctly position the implants onto the bone. Intra-operative computer navigation and robotic surgery have emerged as options to increase the accuracy of implant placement and enhance the outcomes of TKA, with mixed clinical results to date. Pre-operative CT-guided, patient-specific navigation is a unique method for planning TKA surgery to achieving consistent implant positioning, especially for patients with retained surgical hardware or unusual bony anatomy. This technology has been used in Rhode Island in a limited series of patients to assess the utility of the technique and represents an interesting advance for both orthopaedic surgeons and their patients.

KEYWORDS: patient-specific instrumentation, total knee arthroplasty (TKA), CT-guided navigation.

INTRODUCTION

Total Knee Arthroplasty (TKA) is a procedure in which the damaged cartilage surfaces of the knee joint are removed and replaced with smooth articular bearing surfaces. There are many manufacturers who produce TKA implants, and numerous options regarding the design and materials of the prosthetic implants. What is critical across all TKA systems is for the surgeon to place the implants onto the patient's bone in an anatomic fashion. This results in restoration of knee joint biomechanics and optimal longevity of the implants in vivo over many decades of use.

As the manufacturing process for TKA implants has improved over the years, so too has the technology available to surgeons to help place the devices in the most accurate way possible. Advances in surgical cutting jigs, implant designs, sizing options, and bearing surface materials have all been utilized to enhance the outcomes of TKA. More recently, computer navigation and robotic surgery have emerged as intra-operative options to increase the accuracy of implant placement.

Despite the advanced capabilities of these two techniques, their utility is limited by the potentially significant capital investment costs for the relevant technology. Additionally, while some studies have shown improvements in radiographic assessment of implant alignment with computer navigation, no improvements were seen in the long-term implant survival at an average of 10.8 years following computer-navigated TKA compared to conventional TKA.[1] (Studies to date have shown improvements in radiographic implant alignment, but no improvements in short-term knee function or long-term implant survival using computer navigation.)

Preoperative MRI or CT images have been utilized to help plan TKA surgery and generate "patient-specific" custom cutting guides to enhance the accuracy of the procedure. Studies have shown that CT-based navigation can predictably increase the precision of implant placement to within 1.7 degrees of the ideal rotational position[2] but has higher costs compared to "conventional" TKA using standard

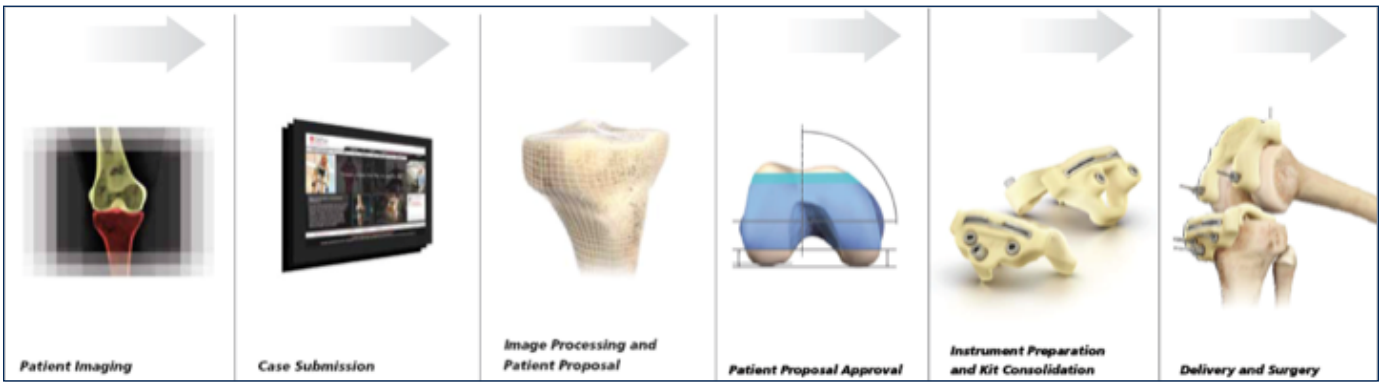
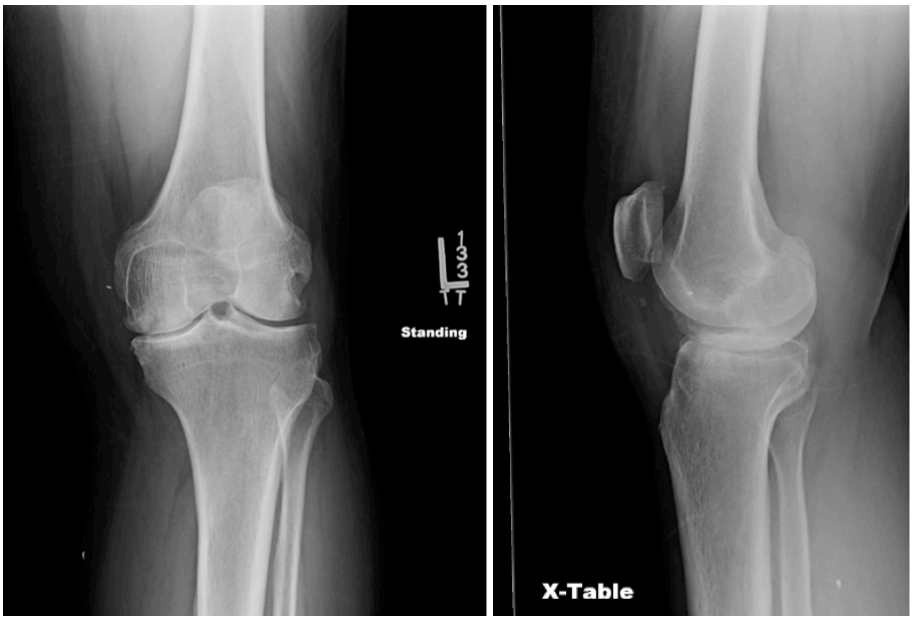


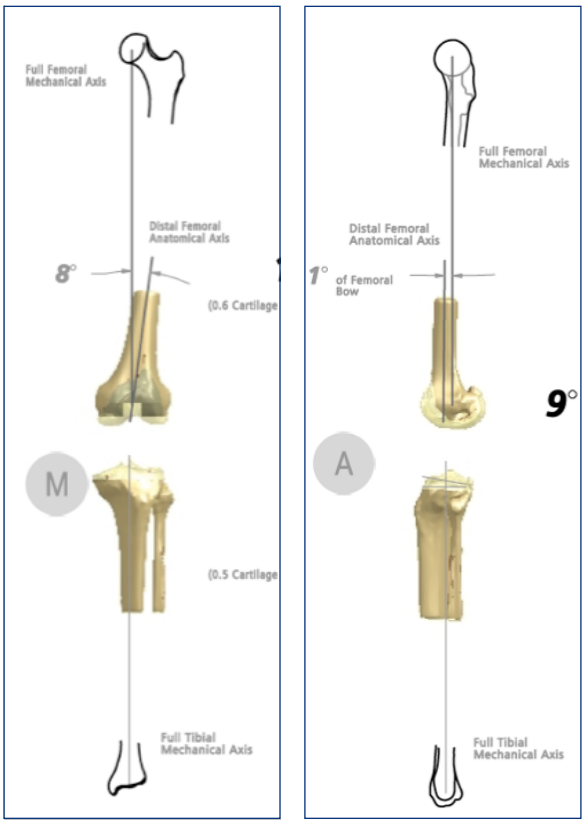
Figure 1. Stepwise method for generating patient-specific cutting blocks using the DePuy TruMatch System.

equipment.[3] Another study showed a 12-minute savings per case in operative time when using the CT-based cutting guides (125.1 minutes versus 137.2 minutes) but also cited cost as potential limitation.[4]

To assist the arthroplasty surgeon with implant choice, sizing selection, and the accuracy of implant placement, a novel technology has been developed for patient-specific instrumentation using pre-operative CT-guided navigation. With this system (TruMatch, DePuy Orthopaedics, Warsaw, IN), a stepwise process is utilized in advance of the TKA surgery (Figure 1). Of note: while a number of other major orthopaedic implant manufacturers (including Smith and Nephew, Biomet, and Stryker) offer the option for pre-operative MRI of the knee joint to create patient-specific cutting guides for TKA surgery, the TruMatch system from DePuy Orthopaedics is currently the only one that utilizes a CT scan from the hip to the ankle to assess and re-create the limb's mechanical axis in a 3-dimensional plane.



Figures 2A and 2B. Preoperative AP and Lateral radiograph of a patient with knee osteoarthritis.

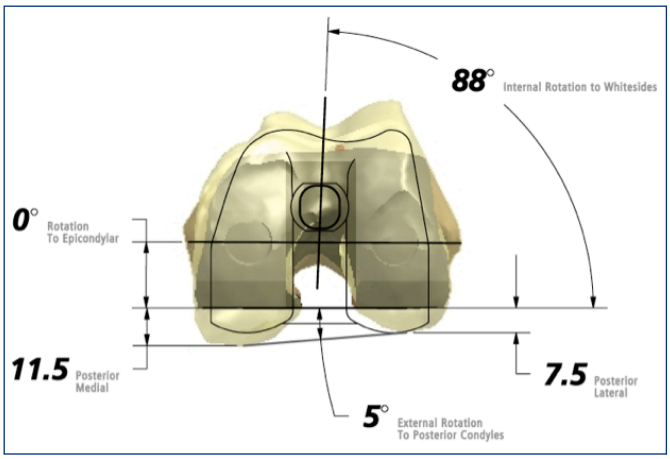


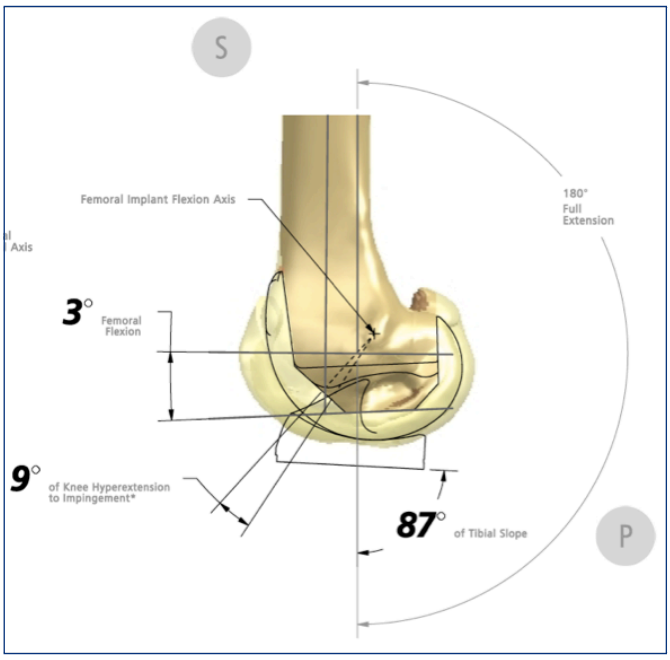
Figures 3A and 3B. CT-scan models determining the AP and Lateral mechanical weight-bearing axis of the operative limb.

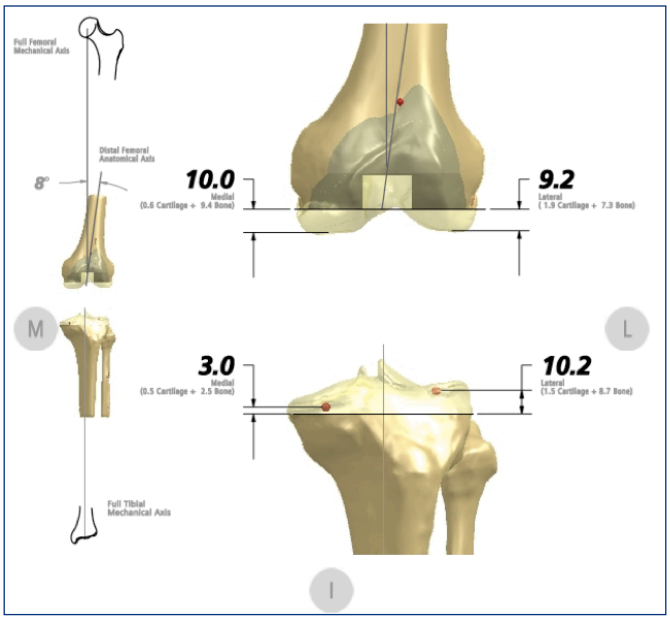
First, a patient is initially assessed with standing knee radiographs to evaluate the severity and location of the osteoarthritis (Figure 2 A and 2 B). Next, a CT scan is obtained from the hip to the ankle, including fine-cut images at the knee joint. A 3-dimensional model of the patient's arthritic knee joint is constructed and reviewed by the surgeon in conjunction with the TruMatch engineering team. This generates a highly detailed rendering of the patient's native bony anatomy and precisely establishes the mechanical weight-bearing axis from the center of the hip to the center of the ankle (Figure 3A and 3B). The program generates a virtual model of how the knee replacement implants will fit the native bone and calculates angular measurements that enable the surgeon to precisely reconstruct the knee before the surgery takes place (Figure 4 A-C). The surgeon interacts with the engineers via a secure web portal; the CT scan images are reconstructed and interpreted by the engineering team remotely in order to create the cutting guides.

The surgeon reviews these images and selects the type of TKA that is optimal, then approves a surgical plan for the patient's operation. The engineers then generate a custom cutting block for both the femur and tibia, which are packaged and sterilized specifically for that individual patient's operation. The cutting guides set the saw blade position during the surgery to allow the surgeon to make bone cuts that align exactly with the pre-operative CT template. Once the bony cuts are complete, the implant is cemented into place, yielding a highly accurate implant position that matches the exact specifications of the preoperative CT scan template (Figure 5A and 5B).

This technology is highly promising as it allows the surgeon to comprehensively understand the 3-dimensional anatomy of a patient's operative knee. By constructing an







Figures 4 A-C. (left) Precise calculation of joint angles, implant position, and bone resections to be used during the surgical procedure.

Figures 5A and 5B. (below) Postoperative AP and lateral views of the left knee following TruMatch TKA showing precise anatomic implant placement.

accurate surgical plan pre-operatively in a virtual environment, changes can be made and problems corrected before reaching the operating room. The TruMatch technology allows for a streamlined operative technique using fewer instruments, and allows for a potentially faster surgical time and operating room turnover.

Importantly, the TruMatch system allows for TKA to be performed in patients with retained surgical hardware in their femur or tibia and for patients with unusual bony deformity, two clinical scenarios that make TKA difficult or impossible using conventional operative techniques.

Patient-specific instrumentation for TKA surgery is an exciting area of advanced technology that will certainly continue to have an impact in the years ahead. Studies will be needed to evaluate the use of this type of technology for conventional knee arthritis surgery, and to compare the outcomes of CT-based versus MRI-based systems for planning customized TKA surgeries in more complex cases.

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