

Domo Arigato, Mr. Roboto

A look into Robotics for Orthopaedic Surgery

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- Undergraduate: University of Wisconsin- Madison
 - Biomedical Engineering
- Medical School: University of Minnesota- Twin Cities
- Residency: University of New Mexico- Albuquerque
- Fellowship: Harvard Medical School – Boston
 - Massachusetts General Hospital – Hip and Knee Reconstruction

Brett Mulawka, M.D.

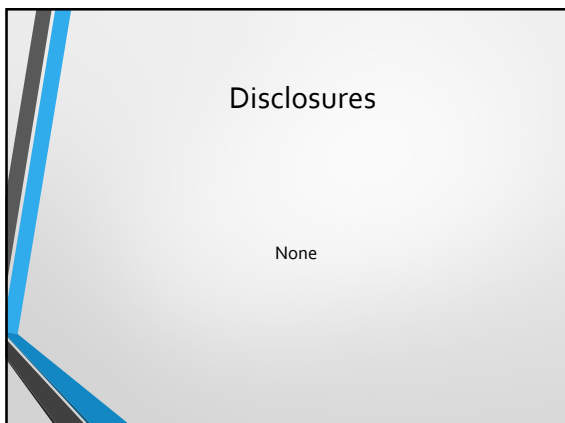


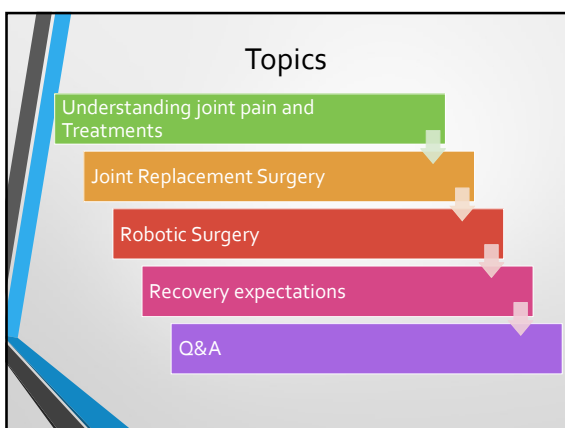
Interests

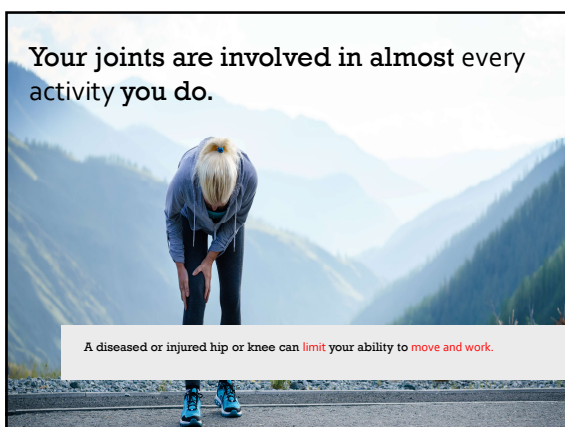
- Enhanced recovery after total joint arthroplasty
- Narcotic minimizing surgery
- Computer and robotic assisted surgery
- Implant design
- Improving arthroplasty

Brett Mulawka, M.D.









Common causes of joint pain

Rheumatoid arthritis (RA), sometimes called inflammatory arthritis, is a condition in which a person's immune system attacks the joints with uncontrolled inflammation, potentially causing joint erosion.

Osteoarthritis (OA) can occur when the cushioning cartilage at the end of the bones may have worn down, making walking painful as bone rubs against bone.

Post-traumatic arthritis is a less common form of arthritis, in which a broken or fractured bone extends into the joint space, causing the surface to become uneven. Over time, friction causes the joint to break down and become arthritic.

Non-surgical treatment options

 **Walking aids** may allow you to put less pressure on the affected joint.

 **Heat or cold therapy** can provide relief to an achy hip or knee joint.

 **Physical therapy** can lessen your pain by teaching better posture or "form" for your day-to-day activities, like getting in and out of a chair.

 **Over-the-counter or prescription anti-inflammatory medicines** may help reduce pain and swelling. Non-steroidal anti-inflammatory drugs (NSAIDs), like ibuprofen, and steroid medications, like corticosteroids injections, may also be helpful.

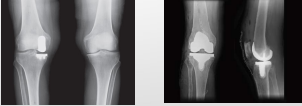
Weight loss and exercise help to relieve stress on joints and pain while providing blood flow and nutrition for joint healing.

When to consider joint replacement

- Does joint pain keep you from doing the things you want to do?
- Are you less active because of joint pain?
- Are you less mobile because of joint pain?
- Are you happy with nonsurgical treatments for joint pain?
- Is joint pain affecting your ability to sleep?

Surgical Treatments: Knee

- Knee arthroscopy
- Partial knee replacement
- Total knee replacement

Knee anatomy

A healthy knee



An arthritic knee

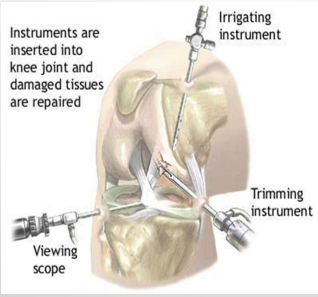


Femur (thigh bone)
 Patella (kneecap)
 Tibia (shinbone)

Diseased cartilage

Knee arthroscopy

Instruments are inserted into knee joint and damaged tissues are repaired



Irrigating instrument
 Trimming instrument
 Viewing scope

Knee arthroscopy

A controlled trial of arthroscopic surgery for osteoarthritis of the knee

J Bruce Moseley¹, Kimberly O'Malley, Nancy J Petersen, Terri J Menke, Baruch A Brody, David H Kuykendall, John C Hollingsworth, Carol M Ashton, Nelda P Wray

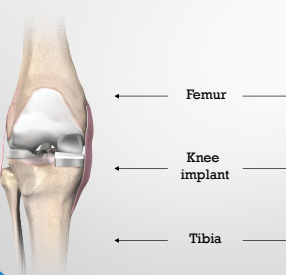
Methods: A total of 180 patients with osteoarthritis of the knee were randomly assigned to receive arthroscopic débridement, arthroscopic lavage, or placebo surgery. Patients in the placebo group received skin incisions and underwent a simulated débridement without insertion of the arthroscope.

Conclusions: In this controlled trial involving patients with osteoarthritis of the knee, the outcomes after arthroscopic lavage or arthroscopic débridement were no better than those after a placebo procedure.

- Rarely useful
- May be helpful for mechanical symptoms
- Easy recovery, low long term benefit for knee OA

Types of knee replacement

Partial knee replacement



Total knee replacement



Femur
Knee implant
Tibia

“Bone on bone”

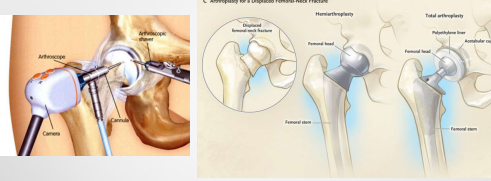
A healthy knee



An arthritic knee



Surgical Treatment: Hip



- Arthroscopy
- Partial hip replacement (hemiarthroplasty)
- Total hip arthroplasty



Robotics

- Design, construction, operation and use of robots/computer systems for their control, feedback and information processing.
- Dictionary.com:
 - The use of computer-controlled robots to perform manual tasks, especially on an assembly line
- Robot according to Webster:
 - A machine capable of carrying out a complex series of actions automatically
- Robot:
 - Reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks [4]

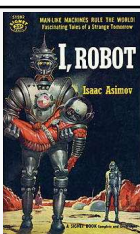
Computer-assisted vs Robotics

- Computer Assisted Orthopaedic Surgery (CAOS)
 - Navigation
 - C-arm (xray)
 - No constraints in surgical capability
- Robotic surgery
 - Provides feedback and constraints
 - Haptics can be provided by auditory, tactile and visual
 - Alerts surgeon and prevents over-resection



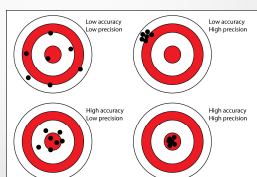
Isaac Asimov - 1942

- Science-fiction author given credit for 1st person to use robotics in short story
- Asimov's **Three Laws of Robotics**
 - 1) A robot may not injure a human being or, through inaction, allow a human being to come to harm.
 - 2) A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
 - 3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws [2]



Why Robots

- Accuracy
 - Industrial standards 2014: 0.05mm
- Precision
- Execution
- Reproducibility
 - Decreased variability
- Clinical Utility
 - Research?
- Increase or decrease cost?
- Truly minimally invasive?



Robotic Uses

- Manufacturing
- Aviation
- Military
- Entertainment
- Agriculture
- Vacuuming




"Over the long term, no industry has ever seen robotic technology be introduced and ultimately not shown an increase in production capacity, improved accuracy and precision and lower cost [1]" – Jacofsky 2014

Outside of Medicine

- 1961 – Fully autonomous industrial robot at General Motors installed "Unimate" [3]
 - Carried hot die castings
 - Tonight show with Johnny Carsons
 - Golfed
 - Conducted Orchestra
 - Touched an accordion

"A Gentleman is someone who can play the accordion, but doesn't."

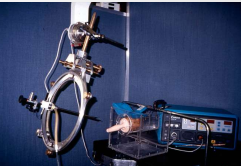
Tom Waits



Robots In Medicine

- PUMA 560 – Used with CT during neurosurgical biopsies in 1985 [5]
- 1988- PUMA used in urology for prostate resection
 - Led to development of ProBot





Da Vinci Surgical System

- Approved in 2000 by FDA
- 200,000+ surgeries since 2012
 - Prostate/hysterectomies
- 3803 Units worldwide
- 2 million + yearly maintenance
 - "A couple hundred thousand a year"




The Issue with Tissue

- Robotics has been developed for both hard and soft tissue
- Soft tissue
 - Da Vinci Surgical system
 - Used in cardiac, colorectal, general, gyn, urology
 - Remote, telemanipulator
 - Passive
- Hard Tissue
 - Bone does not meaningfully deform during procedures
 - Utilizing bony landmarks allows for reliable and precise anatomic positioning of bone removal
- Challenges remain in soft tissues
 - Balancing tissues

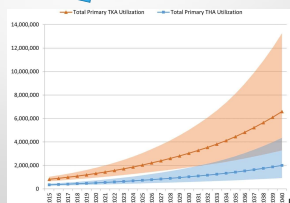
Means robotics in orthopedics can allow for planned and premeasured resection

Robotics in Ortho

- 159 robotic systems are under development for use in surgical fields [9]
 - 30 Robotic systems for ortho @ 2004
 - 15 TJA
 - 7 Spine
 - 3 Trauma
- 23% in North America
- 70% specifically designed for medial use
- 67% have not been tested on humans
- 9% commercially available in at least 1 country [9]

Arthroplasty

- One of the most common and "successful" surgeries in orthopaedics
- Product development interested in value
 - Aka clinical outcomes and survivorship of prosthesis
- Common cause of failures
 - Recurrent instability
 - Impingement
 - Aseptic loosening
 - Material Wear
 - Pain



Common causes of arthroplasty failures

[27]

Contents lists available at ScienceDirect
The Journal of Arthroplasty
journal homepage: www.elsevier.com/locate/jarth

Why Are Total Knee Arthroplasties Failing Today—Has Anything Changed After 10 Years?
Peter F. Sharkey MD, Paul M. Lichstein MD, MS, Chao Shen MD, Anthony T. Tokarski BS, Jared Fayet MD, FRCSC
The Arthritis Institute at Pennsylvania State University, Hershey, Pennsylvania

ARTICLE INFO ABSTRACT

- Aseptic loosening (most common + most common late)
- Infection (most common early)
- Instability
- Fracture

Total hip arthroplasties: What are the reasons for revision?

Sif D. Ulrich · Thorsten M. Seyler · Derek Bennett · Ronald E. Delmonico · Khalid J. Saleh · Isanda Thangtragoon · Michael Kuskowski · Edward Y. Chang · Peter F. Sharkey · Javad Parvizi · James B. Stohr · Michael A. Mont

Received: 9 February 2007 / Revised: 2 March 2007 / Accepted: 6 March 2007 / Published online: 19 April 2007
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[28]

- Aseptic Loosening (51%)
- Instability (16.9 %)
- Infection (5.5%)
- <5 years
 - 33% Instability
 - 24% infection

Conclusion
"The success of hip arthroplasty is likely to be compromised if the technical aspects of the surgery for appropriate component position is not given the proper attention"

Blast from the Past

J Bone Joint Surg Am. 1978 Mar 56(3):317-29.

Dislocations after total hip-replacement arthroplasties.

Leinonen SE, Lehto JA, Törr B, Campese CL, Zimmemann JB

Abstract
In a series of 300 total hip replacements, nine (3 per cent) dislocated. Precise measurements of the orientation of the acetabular cup were made and it was found that anterior dislocations were associated with increased acetabular-component anteversion. There was no significant correlation between cup-orientation angle and posterior dislocation. The dislocation rate for cup orientation with anteversion of 15° ± 10 degrees and lateral opening of 40° ± 10 degrees was 1.5 per cent, while outside this "safe" range the dislocation rate was 6.1 per cent. Other factors that were documented include time after surgery (with the greatest risk in the first thirty days) and surgical history (with a greater risk in hips that have had prior surgery).

Accuracy of intraoperative assessment of acetabular prosthesis placement

Douglas M. Hassan MD, FRCSC, Geoffrey H.F. Johnston MD, FRCSC, FACS, William N.C. Dust MD, FRCSC, FACS, Glen Watson PhD, PEng, Allan T. Dolovich PhD

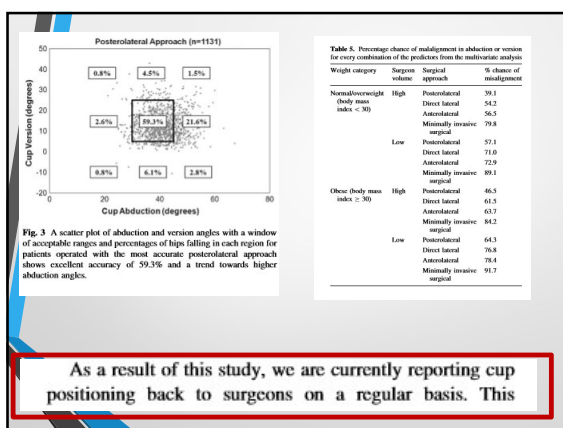
Division of Orthopaedic Surgery and the Department of Mechanical Engineering,
University of Saskatchewan, Saskatoon, Saskatchewan, Canada

The John Charnley Award
Risk Factors for Cup Malpositioning
Quality Improvement Through a Joint Registry at a Tertiary Hospital

Mark C. Callanan MA, Bryan Jarrett BS, Charles R. Bragdon PhD,
 David Zarakowski PhD, Harry E. Rubash MD, Andrew A. Freiberg MD,
 Henrik Malchau MD, PhD

Published online: 18 August 2010
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- Review of 2061 patients THA 04-08
- Safe zone: 30-45 abduction, 5-25 anteversion
 - 63% abduction
 - 79% version
 - 50% nailed both
- Low volume surgeon: 2x
- Minimally invasive approach: 6x
- Obesity: 1.3x



Accuracy of Acetabular Component Position in Hip Arthroplasty

Robert L. Barrack, MD, Jeffrey A. Krempke, MD, John C. Chahay, MD, Douglas J. McDonald, MD,
 William M. Ricci, MD, Erin L. Buh, MS, and Ryan M. Stanley, MD

Investigation performed at the Department of Orthopaedic Surgery, Washington University School of Medicine, St. Louis, Missouri

25

- Review of 1549 THA
- Using Callanan safe zone
 - 38% met both version and abduction targets
 - Low-volume 2x more likely to miss

Knees

- Malalignment of total knees > 3 degrees leads to early loosening
- Up to 20% of total knees remain dissatisfied
- 40% of knees not within axis within 3 degrees of neutral
- Current hypothesis of improved component positioning and alignment will influence long term clinical outcomes

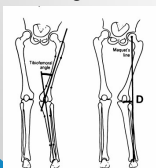


Fig. 7
Measurements on an alignment radiograph.

CORONAL ALIGNMENT AFTER TOTAL KNEE REPLACEMENT

ROBERT J. JEFFERY, RICHARD W. MORRIS, ROBIN A. DENHAM
From Queen Alexandra Hospital, Portsmouth

Magnum's line passes from the centre of the femoral head to the centre of the body of the tibia. The distance of this line from the centre of the knee on a long leg radiograph provides the most accurate measure of coronal alignment. Malalignment causes abnormal forces which may lead to loosening after knee replacement.

We report a series of 117 DePuy knee replacements performed between 1978 and 1981 using the earliest design of components, inserted with intramedullary guide rods. Patients were assessed clinically and long leg standing radiographs were taken before operation, soon after surgery and up to 12 years later.

In two-thirds of the knees (80%), Magnum's line passed through the middle third of the patella on postoperative films and the incidence of subsequent loosening was 7%. When Magnum's line was medial or lateral to this, a mean of approximately $\pm 2^\circ$, the incidence of loosening in a median period of eight years was 24%. This difference is highly significant ($p < 0.001$).

Accurate coronal alignment appears to be an important factor in prevention of loosening. Means of improving the accuracy of alignment and of measuring it on long leg radiographs are discussed.

[11]

Conclusions

Component positioning is important

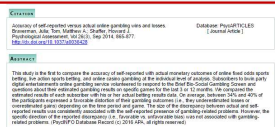
Correct component positioning is challenging

Stakeholder: The patient

- Not concerned with cost
 - Insurance
- OUTCOMES
 - Different measures/perceptions
- Inherent fear of robots?
- Patients want to believe their surgeon is the best
 - Tendency to dislike thinking of the surgeon making errors [10]

Stakeholders: The surgeon

- Surgeons follow Harris Hip Score and WOMAC, SF-36
- Surgeons concerned with performance
 - Focus on success and not failures
 - Post-analysis: tend to gloss over mistakes and remember success
 - Makes it difficult to determine the value of technology designed to reduce human error [10]

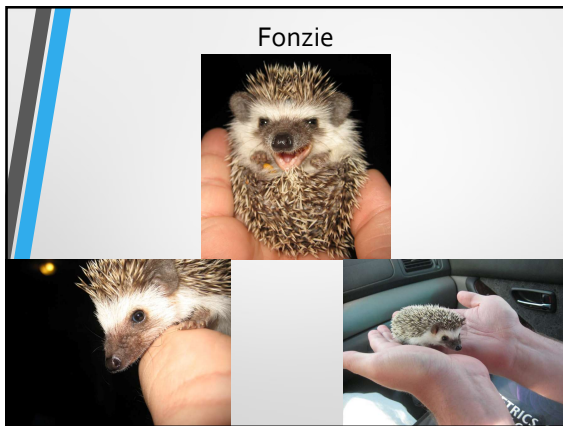


Stakeholder: Hospital

- Decreased go day complications
- Attracting new patients
- "Halo effect"
 - New technology attracts patients with other health problems requiring tests and/or admissions [10]

Image based or Imageless

- "The presence of a plan to execute is one aspect of robotic ortho surgery that differentiates it from other specialist that speak about robotic use [1]"
- Register patients anatomy via mapping points on bone so computer knows special relationships between bone and instruments
 - Image based: registration directly tied to preop imaging (CT/MRI)
 - Imageless: Rely on registrations of patients anatomy after exposure to create virtual model
 - Relies on surgeon's accuracy

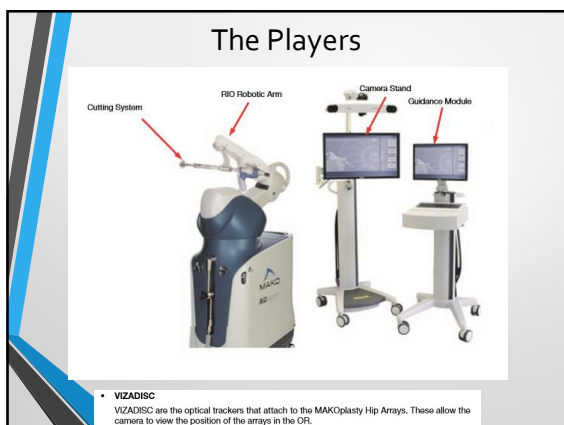


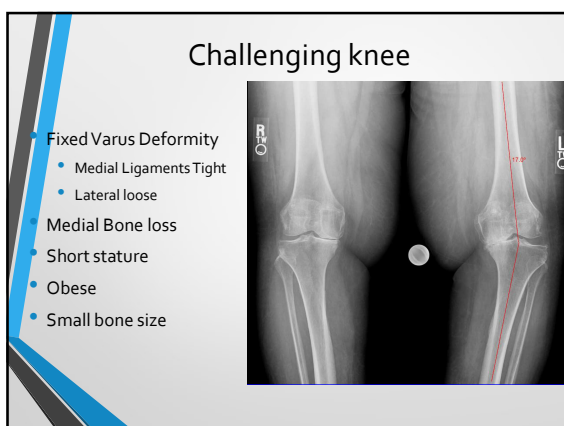
Robotic Arm Interactive Orthopedic System (RIO) [23]

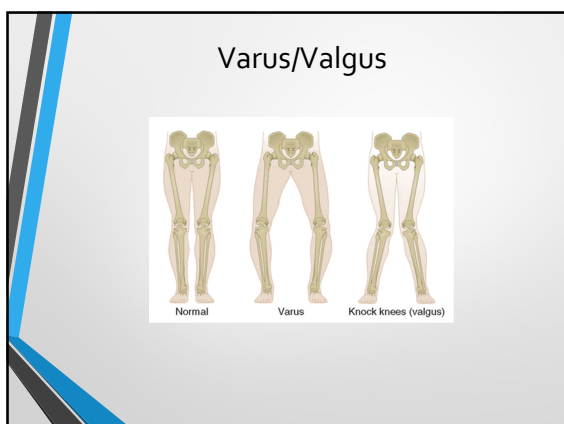
- Mako surgical corp.
 - Merged with Stryker in 2013
 - \$1.6 billion
- Creates 3D model (image-based) of patient's anatomy
- Allows preoperative planning of implant
 - Size
 - Position
 - Alignment
- Provides feedback (haptics) and enforces "safe-zone"

The Basics – 5 steps [14]

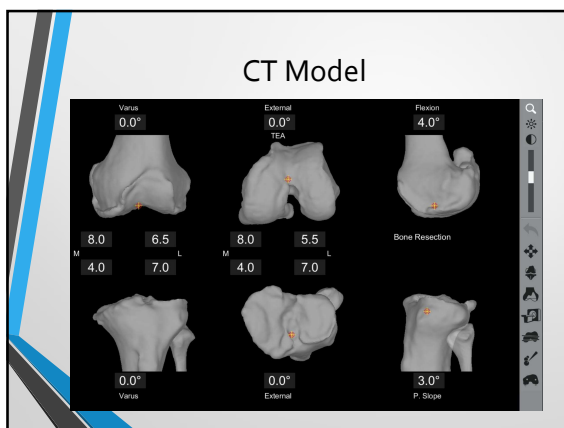
- Digital modeling based on preoperative imaging
- Preoperative implant template
- Intraoperative bone registration
- Execution of plan
- Component positioning and implantation

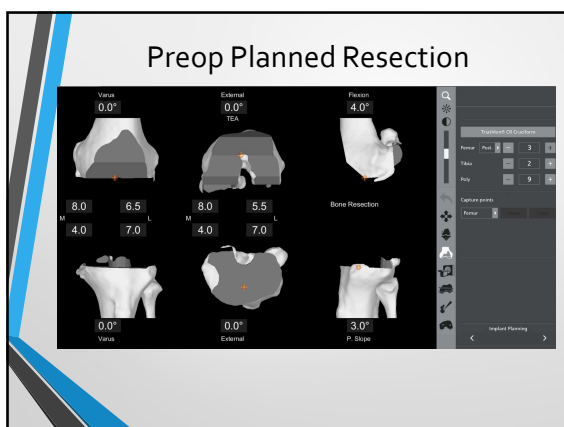


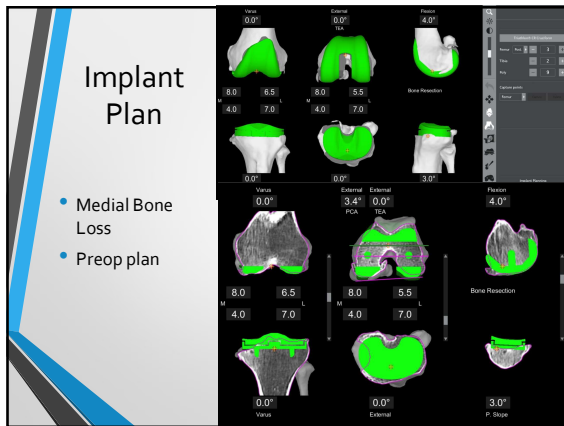


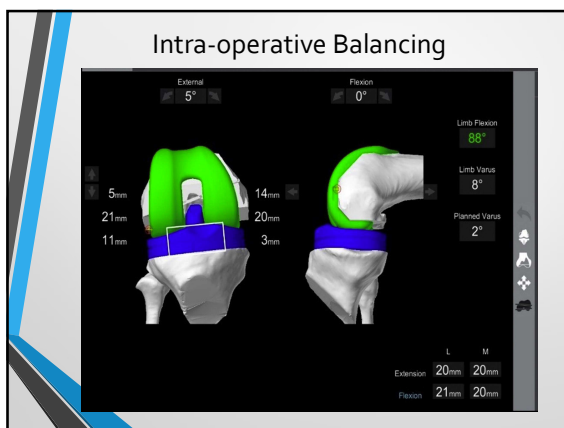


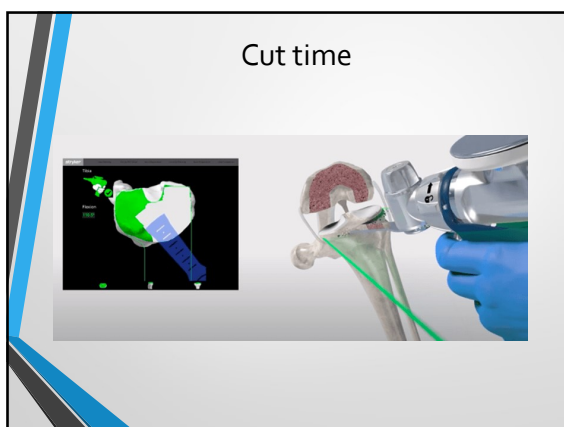






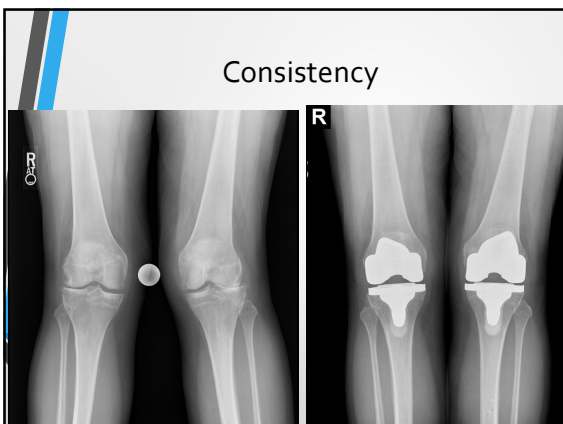






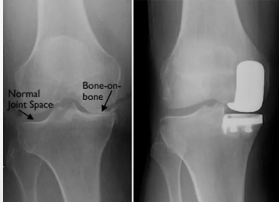






Partial knee replacement

- My favorite surgery
- Bone sparing
 - Preserves anatomy
- Minimally invasive
- Faster recovery
- Less infection risk
- Avoids risk of total knee



Partial knee problems

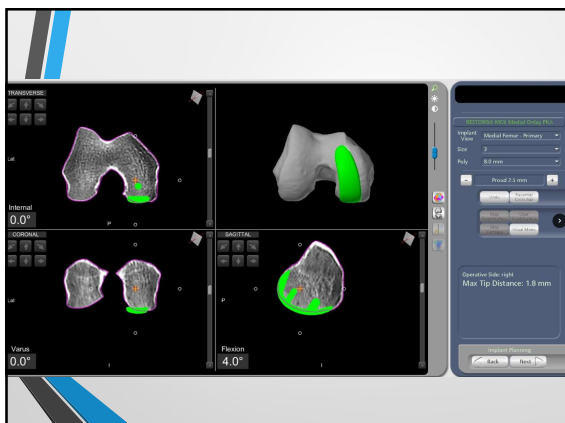
- Technically difficult
 - Preserves more bone
 - Preserves ALL ligaments
 - Alignment/balancing problems
- ==>>> Earlier failure!

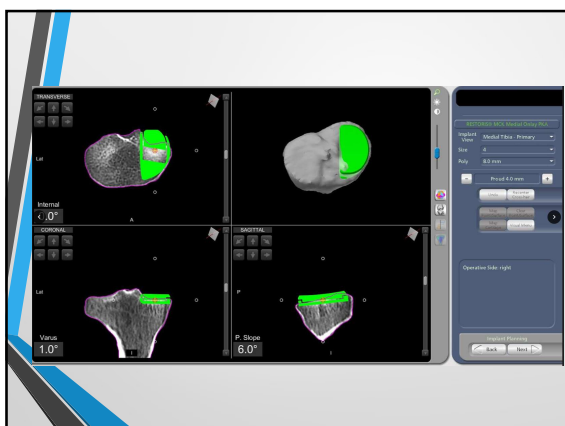


Patient case

- Active skier and hiker
- Track coach
- Medial knee pain
- No instability
- Wants fast recovery
- Wants to remain active!

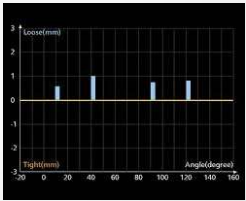


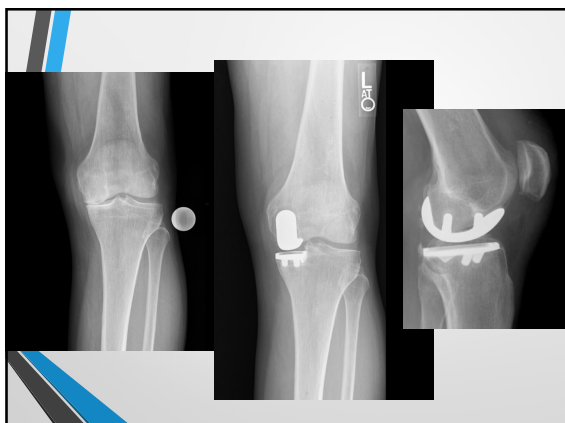


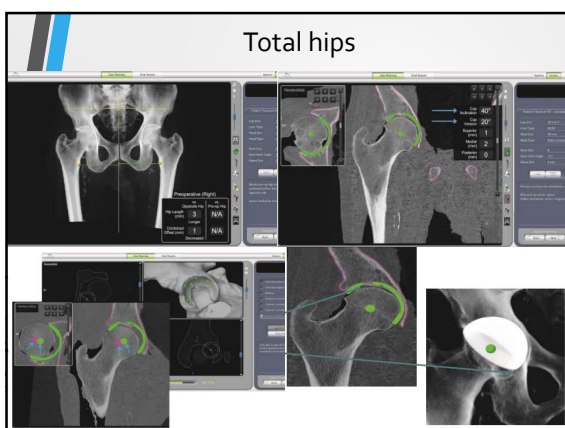


Balance and burr

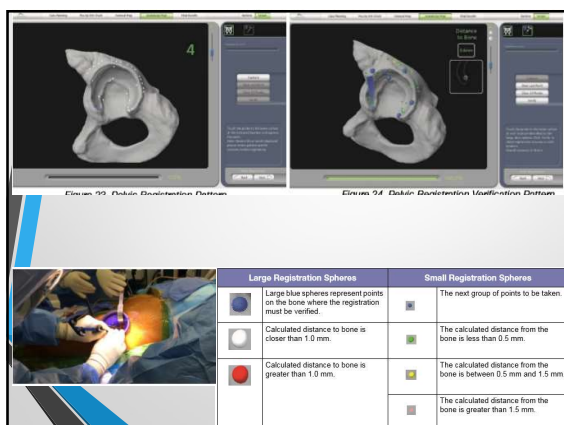
- 4 Ligaments
 - Vs 2 with total knee
- Smaller working window
- Match intra-op feel to pre-op plan

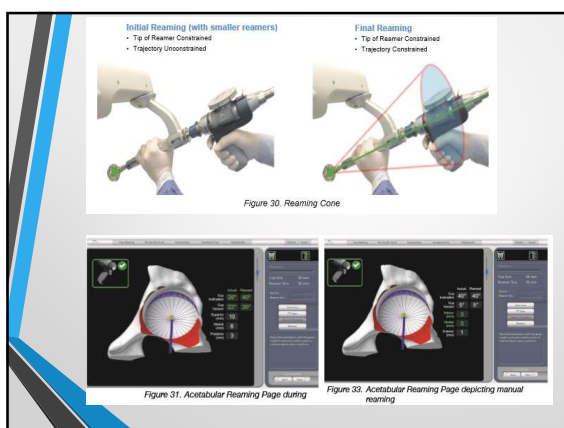



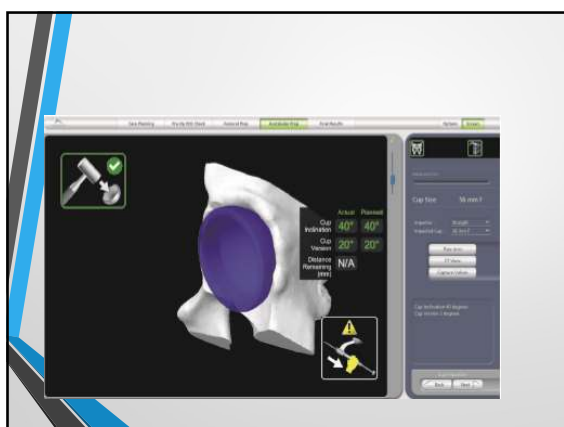


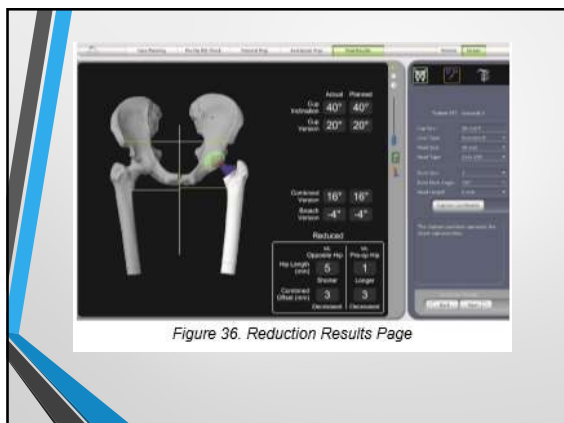














Perioperative Plan

- Preoperative: Same
- PACU: same treatment algorithm
 - Multimodal anesthesia
 - Perioperative blocks
 - Intraoperative peri-articular injections
- Post operative visits: Same
- Early discharge
 - Same day surgery

Advantages

- Less soft tissue damage
- Better preoperative planning
- Precise, accurate, reproducible results
- Less implant trialing
 - Decreases OR sterile processing
- Increased information
 - Improve the future

Surgeon Energy Expenditure During Total Joint Arthroplasty

Peter F. Sharkey, MD, Jonathan R. Davoff, BA, S.1
Gregg Kiers, MD, I and Javad Parvizi, MD

The Journal of Arthroplasty Vol. 30 No. 2 2015

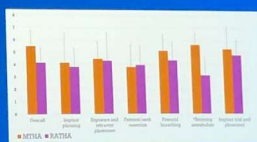
- Energy expenditure during THA is similar to moderate exercise
- Physical fatigue decreases mental alertness and impair performance
- THA – 340 kcal/hour
- TKA – 320 kcal/hour
- Running – 15 min miles = 400 kcal/hour



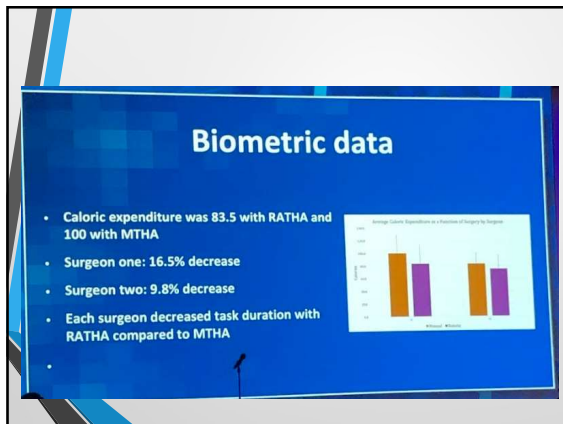
2021 AAHKS annual meeting

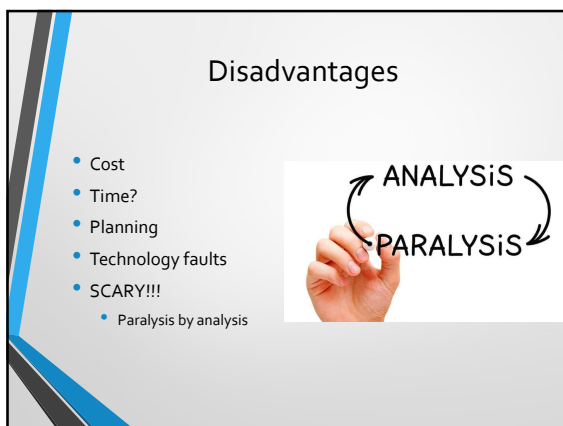
Mental demand

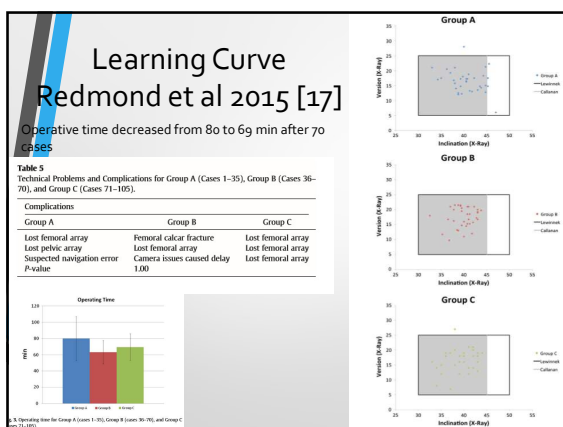
- Overall mental demand was: 5.5 for MTHA vs 4.2 for RATHA
- Mental demand during acetabular reaming significantly higher with manual ($p < 0.01$)
- Beside femoral neck resection, lower mental demand during RATHA for all other tasks



2021 AAHKS annual meeting







The waiting game...

- Current studies show improvement in component positioning
- Accurate and precise implant placement immediately
- Studies show decreased soft tissue damage
- Current studies have survivorship for THA's as 94% at 14 years [26]
- Modern orthopedic robotics only 10-12 years old

Future Applications

- Geometry changes
 - Enabling new resection techniques and bearings
 - Possibility to increase bone in-growth
 - Fixation options
 - Creation of "Biomimetic" implant to recreate native kinematics
- Integrated sensors for soft-tissue balancing
 - Reduction of trialing
- Post-surgical analysis
 - Ability to accurately reflect upon component positioning and techniques
- Minimally invasive techniques
 - Ability to resect "blindly"

Tissue balancing: Force sensors

- Currently balance on mm level
- Detects force and locations of force
- Aids with rotation
- Fine tune of balance



Improve the future

- Provides feedback for component positioning
- Allows "novice" surgeon to place components accurately
- Decreases "new surgeon" practice faults
- DATA for the future

My Ultimate Conclusion

Robots are cool*

*maybe as cool as lasers

...but really

- Shown the variability in surgical implantation
- Evolution of improved conventional techniques remains static
- Ability to conventionally detect component position poor
- Component position important for implant function and longevity
- Improved surgical accuracy and precision with robotics
