Robotics in knee replacement

Sandeep Munjal MD, FAAOS
I do speak English

- Mahatma Gandhi Medical College, Indore India 1982-86 MS (ortho) 1987-90
I speak 3 languages, ….did I mention English?...

- Royal Orthopedic Hospital, Birmingham England  1992-96
I love: Chicago, jazz, running, table tennis, Buddha

- University Hospital Dundee, Scotland 1996-97
- M.Ch. (Ortho)
Favorite surgery: Joint placement

- University of Chicago Joint Replacement Center 1997-98
CAOS RAOS

- University Hospital Buffalo (1999-2005)
Cedar Rapids 2005-
One of the most common causes of joint pain is arthritis. The most common types of arthritis are:
- Osteoarthritis (OA)
- Rheumatoid Arthritis (RA)
- Post-traumatic Arthritis
Treatment Options

- Medication
- Physical therapy
- Arthroscopy - cleaning the joint
- Joint fluid supplements (injections that provide temporary pain relief)
- Partial joint replacement
- Total joint replacement
Medications

- Aspirin-free pain relievers - acetaminophen
- Nonsteroidal anti-inflammatory (NSAIDs)
- Corticosteroids - injection/pill form
Physical Therapy

- Passive range-of-motion exercises may help:
  - Reduce stiffness
  - Keep joints flexible
- Isometric exercises help build muscle strength
Joint Fluid Supplements

Injections that provide temporary relief

- For patients whose joint pain does not improve with medication or physical therapy, "joint grease" injections may provide temporary relief. The joint is injected with a joint fluid supplement that acts as a lubricant for the damaged joint.
Joint Fluid Supplements

Injections that provide temporary relief

• Joint injection schedules and duration of relief vary according to the treatment chosen and the individual patient. *However, these injections do not cure the diseased knee, and joint replacement may be needed as the joint worsens with time.*
Should you limit your activities? If you have knee arthritis, the more you walk the more the knee will hurt. In time, running, tennis, golf and eventually even walking may become impossible. You can minimize the pain by simply cutting back on activities which seem to aggravate the knee.
Whenever possible, use an elevator (or an escalator) instead of stairs, and avoid long walks that leave you in pain. However, “saving the joint” by becoming totally sedentary will not slow down the arthritis. Therefore it is recommended that you remain as active as your pain will comfortably allow.
- The best all-around exercise for you is swimming. The water relieves the stress on your hip as you “walk” about in the shallow end of the pool.

- Bicycling (stationary or mobile) is also well tolerated.
• A cane is an effective pain-reliever for arthritis.

• Two important facts about canes:
  1). Hold the cane in the opposite hand from the side with the hip problem and same side for varus knee
  2). The cane should be the correct height.
Once you have knee arthritis it will never get better. It won’t even stay the same. It will generally progress as time goes by. There are no exercises, diets, vitamins, or minerals (except, perhaps, chondroitin sulfate) which will make any difference.
Weight Plays a Role in Joint Health.

Joints hurting? Lose just a few pounds and you’ll take some strain off your Hips, Knees, and Back.

Every pound you lose takes four pounds of pressure off the knees.④
Exercise May Help Joint Pain.

Did You Know?

Regular, Sensible Exercise May Help Your Arthritis.

Arthritic Joints sometimes need a short period of rest followed by a gradual return to activity. It’s important to maintain your strength & range of motion in your joints.
Copper bracelets will definitely not make any difference!
A mesenchymal stem cell is a primitive cell with the ability to:

- Reduce Inflammation
- Differentiate into Multiple Tissues
- Self Replicate
Stem cells
The rate of further deterioration varies greatly from person to person. The pain may become unbearable within six months for one person, yet drag on at a tolerable level for several years in another person who has the same degree of arthritis.
KNEE Surgery

- May be suitable for patients who:
  - Have a painful, disabling joint disease of the KNEE resulting from a severe form of arthritis
  - Are not likely to achieve satisfactory results from less invasive procedures, medication, physical therapy, or joint fluid supplements
  - Have bone stock that is of poor quality or inadequate for other reconstructive techniques
You will never need a knee replacement if you are willing to live with the pain.
Partial Joint Replacement

Partial joint replacement is a surgical procedure in which only the damaged or diseased surfaces of the joint are replaced, leaving much of the natural bone and soft tissue in place.
Total Joint Replacement

- Total joint replacement is a surgical procedure in which certain parts of an arthritic or damaged joint are removed and replaced with a plastic or metal device or an artificial joint. The artificial joint is designed to move just like a healthy joint.
Implant Technology
Joint Replacement

- Joint replacement is a treatment option when pain:
  - Is severe
  - Interferes with daily activities
  - Interferes with work
Recovery

- Every individual is different and every treatment plan is different. The length of hospital stay after joint replacement varies and depends on many factors including age and physical ability.

- Estimated Recovery Schedule:
  - In-hospital Recovery: 1 - 3 days (most 1-2 days)
  - Significant Functional Improvement: 6 weeks - 3 months
  - Maximal Improvement: 6 - 12 months
After Surgery

Limitations

- For approximately 12 weeks after surgery certain limitations are placed on your activities. When fully recovered, most patients can return to work. However, some types of work may not be advisable for individuals with a joint replacement. These types of work include:
  - Construction work
  - Certain types of carpentry
  - Occupations that involve repeated high climbing
Limitations
After Surgery

Limitations

- Athletic activities that place excessive stress on the joint replacement will need to be avoided. Examples of these activities include:
  - Skiing (snow or water)
  - Basketball
  - Baseball
  - Contact sports
  - Running
  - Frequent jumping
Advances in Knee Replacement and best practices for recovery
What’s New in Knee Replacement?

Choose:

- Less pain
- Smaller incision
- Shorter hospital stay
- New techniques
- Seamless process
What is Partial Knee Replacement?

Partial knee replacement (PKR) is a surgical procedure that helps relieve arthritis in one or two of the three compartments of the knee.

With PKR, only the damaged area of the knee joint is replaced, which may help to minimize trauma to healthy bone and tissue.
Types of Partial Knee Replacement

① **Unicondylar** Knee Replacement is a procedure that replaces only the single affected compartment of the knee, either the medial or lateral compartment.

② **Patellofemoral** Knee Replacement is a procedure that replaces the worn patella (the kneecap) and the trochlea (the groove at the end of the thighbone).

③ **Bicompartmental** Knee Replacement is a procedure that replaces two compartments of the knee, the medial and patellofemoral compartments.
Common Questions About Knee Replacement

- Can I have an allergic reaction to the implant?
- Is the implant heavy?
- Will it set off a metal detector?
Joint Replacement Surgery

- Numbers are increasing overall
- People are living longer
- “Baby Boomers” expectations
- More joints with arthritis in younger populations
- Patients are more educated and have more choices
  - Direct to consumer marketing
  - The internet
  - More pro-active in care decisions and in selecting a provider
Robotics in Knee Arthroplasty

• 25 % of UKA’s in US; rapidly growing TKAs
Why Consider Robotics?
Joint replacement market

- **Primary TKA**: 705,000
- **PKA**: 78,000
- **Primary THA**: 355,000
US joint replacement environment

**Demand for orthopaedic procedures in US:**
- THA: ↑174% by 2030
- TKA: ↑ 673% by 2030
- PKA: Partial knee replacement surgery is currently underutilized, accounting for only 8% of knee replacement procedures

**Drive towards quality enhancements in US:**
- Enhance patient experience
- Reduce per capita cost
- Value based healthcare
- Bundled reimbursement
- Economic burden of OA in the US: $60 billion per year
Several factors, including surgical technique, polyethylene wear, loosening, preoperative comorbidities, and pain levels, have been shown to be associated with failure after TKA.

Surgical technique has been reported to be the most common cause for failure in TKA.
• However, we believe that educating ourselves about new technology will allow us to evolve into better surgeons and provide for better outcomes for our patients.
The importance of mechanical axis alignment in implant longevity has been well documented. **This is a surgical variable that has been reported to have significant variation.**
Evolution

1950s  Static plan

1990s  Navigated execution

2000s  Navigated freehand power tools

2000s  Robotic-arm assisted surgery
Initial interest in computer navigation and robotic systems involved improving known variables that had been demonstrated to limit TKA results, including mechanical axis, joint-line alteration, and surgeon variability. These were the initial motivations that robotic TKA attempted to address.
• **History of Robotic Knee Arthroplasty**

• Robotic systems combined with navigation were initially developed to improve the clinical outcomes and reproducibility of TKA.

• **Passive systems** complete a portion of the procedure under continuous and direct control of the surgeon.

• **Active systems** perform a task independent of any surgeon involvement.

• **Semi-active** systems provide feedback that augments the surgeon's control of the tool, typically with tactile feedback. These systems are also known as *haptic*. Initial robotic systems involved either passive or semi-active systems that restricted motion for the cutting tools.
HAPTIC?

- Derived from Greek word “haptikos” meaning “ABLE TO COME INTO CONTACT WITH”

- Haptics = touch = connection

- Touch is at the core of personal experience

- Of the five senses, touch is the most proficient, the only one capable of simultaneous input and output
HAPTIC?

• Derived from Greek word “haptikos” meaning “ABLE TO COME INTO CONTACT WITH”

• Haptics = touch = connection

• Touch is at the core of personal experience

• Of the five senses, touch is the most proficient, the only one capable of simultaneous input and output
Computer-assisted navigation uses registration from predefined landmarks to identify where components are placed in space. **Haptics allow these predefined boundaries from navigation technology to allow the robot to become a surgical assistant instead of the surgeon.**
The Robotic Arm is a haptic system available in clinical practice for unicompartmental and total knee arthroplasty. Preoperative CT is used in surgical planning to help determine component sizing, positioning, and bone resection; this is confirmed and adjusted intraoperatively based on the patient's specific kinematics prior to any surgical resection.
The robotic system provides haptic feedback to prevent bone resection outside of the executed template.

Retrospective review of a case series demonstrated extreme precision with almost no radiographic outliers.
UKA:

• Early recovery, high function, normal kinematics, “natural” feel, 94% survivorship at 10-15 yrs in hands of high volume surgeons...
What Impacts the Results of UKA?

- Pathology/Disease
- Patient selection
- Component design
- Polyethylene quality
- Surgeon experience/volume
- Accuracy of implantation
Unicompartmental knee arthroplasty has been controversial since its introduction in the early 1970s. Early reports on the success of the procedure were conflicting.
Early reports of unicompartmental arthroplasty noted failure and revision rates of up to 40%, most related to mechanical alignment, implant design, cemented fixation, and debris from polyethylene wear.
Robotic Assisted Patient-specific Partial Knee Replacement Using Surgeon-controlled Robotic Arm Technology
Total Knee Arthroplasty (TKA) Isn’t Always The Solution

- Considered the Gold Standard for Advanced Knee OA
- However, it has limitations:
  - Addresses ONLY late-stage OA
  - Removes healthy bone, cartilage, and tissue
  - >50% of TKA patients report some degree of limitation in functional activities\(^1\)
  - Only 75% of TKA patients are satisfied with their knee replacement\(^2\)
  - Requires extensive rehabilitation

90% of Patients Actively Decline Joint Replacement Surgery

Duke University Center Survey finds that 92% of men and 88% of women actively decline joint replacement surgery despite safety and long-term positive outcomes.

Prevalence of Partial Knee Osteoarthritis

- **Unicondylar Disease**
  - ≈ 43% of TKA patients may present with unicondylar tibiofemoral disease\(^1\)

- **Patellofemoral Disease**
  - 24% of OA patients may present with isolated patellofemoral disease\(^2\)

- **Bicompartmental Disease**
  - 40-65% of OA patients present with tibiofemoral-patellofemoral disease\(^2,3\)
Mako Fills A Gap For Patients With Mid-Stage Osteoarthritis

Early-Stage Knee Pain

Arthroscopy

Mid-Stage OA

MAKOplasty Partial Knee Arthroplasty Options

Late-Stage OA

Total Knee Replacement

© 2013 MAKO Surgical Corp. 209084 r00 11/13
Limitations of Manual Partial Knee Replacement

Manual PKA Procedure Pitfalls:

- Substantial complication rates persist throughout the learning curve\(^1\)

- Surgical Technique Plays Major Role in Manual UKA Failure\(^2\):
  - 19% failure rate in year one\(^2\)
  - 48.5% failure rate in first 5 years\(^2\)

- Data for Bicompartmental Knee Arthroplasty Using a Manually Placed Monoblock Femoral Component Were NOT Promising\(^3,4\)

---

The Robotic-arm Advantage

• Patient-specific pre-operative 3-D plan enables accurate implant sizing and positioning consistently and reproducibly

• 3-D view improves surgeon visualization

• Proper implant alignment is assessed BEFORE procedure begins

• Optimal soft tissue balancing through entire range of knee motion is enabled
Robotic Assisted Partial Knee Replacement

Mako Robotic-Arm Assisted Technology can be used for partial knee replacement, which is a procedure designed to relieve the pain caused by joint degeneration due to osteoarthritis (OA).

Robotic-Arm Assisted Technology:

- Provides surgeons with a personalized surgical plan based on a 3D model of your knee.
- This allows the surgeon to remove only the diseased bone, preserving healthy bone and soft tissue, and assists your surgeon in positioning the implant based on your anatomy.
How it Works.

1 Have a Plan Personalized for You

It all begins with a CT scan of your joint that is used to generate a 3D virtual model of your unique anatomy. This virtual model is loaded into the Mako System software and is used to create your personalized pre-operative plan.
How it Works.

In the Operating Room

In the operating room, your surgeon will use Mako to assist in performing your surgery based on your personalized pre-operative plan. The Mako System also allows your surgeon to make adjustments to your plan during surgery as needed. When the surgeon prepares the bone for the implant, the Mako System guides the surgeon within the pre-defined area and helps prevent the surgeon from moving outside the planned boundaries. This helps provide more accurate placement and alignment of your implant.
After surgery, your surgeon, nurses and physical therapists will set goals with you to get you back on the move. They will closely monitor your condition and progress. Your surgeon may review an x-ray of your new partial knee with you.
Robotic-Arm Technology Does Not:

- PERFORM SURGERY
- MAKE DECISIONS ON ITS OWN
- MOVE IN ANY WAY WITHOUT THE SURGEON GUIDING IT
Robotic assisted Partial Knee Overview
Clinical Value to Patients

• MAKOplasty PKA Offers The Following Potential Benefits:
  - Improved surgical outcomes
  - Less implant wear and loosening
  - Bone-sparing and soft-tissue preserving
  - ACL and PCL preservation
  - Less invasive and less scarring
  - Shorter hospital stay
  - Rapid recovery

• Attractive Treatment for Patients Seeking Rapid Return of Knee Function

• Feels More Natural When Compared to Total Knee Replacement

Mako Provides More Accurate And Reproducible Implant Placement Than Conventional UKA Techniques

- Robotic arm assisted PKA leads to:
  - 2-3 times more accurate implant placement than manual UKA\(^1,2,3,4,5\)
  - At least 3 times more reproducible implant placement than manual UKA\(^1,2,3,4,5\)
  - Fewer outliers than manual UKA\(^6\)


© 2013 MAKO Surgical Corp. 209084 r00 11/13
Robotic assisted PKA Has Lower Revision Rate Than Manual UKA Procedures

Key Result:
- 1.1% Revision Rate at 2 Years Compared to Manual UKA Procedures

Robotic PKA demonstrates Less Post-Operative Pain Versus Manual UKA

Early Post-operative Pain

Conclusion: MAKOplasty Patients Had Significantly Less Pain than Oxford Patients Day 1 To Week 8


Oxford® is a registered trademark of Biomet, Inc.
RPKA Demonstrates Improved Function Versus Manual UKA

Conclusion: MAKOplasty patients showed improved function at 3 month follow-up based on AKSS.


Oxford® is a registered trademark of Biomet, Inc.
Who Are Good Candidates For A Robotic assisted partial knee Procedure?

Typical MAKOplasty Patients Share the Following Characteristics:

- Knee pain with activity, on the inner knee (Medial UKA)
- Start up knee pain or stiffness when activities are initiated from a sitting position (PFA)
- Failure to respond to non-surgical treatment such as rest, weight loss, physical therapy and non-steroidal anti-inflammatory medication

- Best treatment option for each patient will be determined individually
Mako Radiographic Outcomes
Patients Have Reported Dissatisfaction with Traditional TKR

1 in 5 patients are **not satisfied** with the results of their total knee replacement.
Although current total knee arthroplasty (TKA) is considered a highly successful surgical procedure, patients undergoing TKA can still experience substantial functional impairment and increased revision rates as compared with those undergoing total hip arthroplasty.
Total knee arthroplasty has been associated with a higher incidence of persistent postoperative pain than THA.

Patient satisfaction following TKA ranges from 75% to 89% using a variety of patient-reported outcome measures.

Patients undergoing TKA still experience substantial functional impairment.

More than half of all patients undergoing TKA report some degree of limitation in normal activities of daily living, and the absence of functional impairment is an important predictor of overall satisfaction.
Although appropriate expectations are important, functional impairment secondary to biomechanical deficiencies of TKA implants severely limit TKA outcomes.

Total knee arthroplasty implants do not consistently reproduce the kinematic patterns of a normal knee. In particular, patients undergoing TKA have significantly less axial rotation during normal gait and activities of daily living.
TKA Dilemma

- Number of TKAs performed increasing exponentially
  - Revision rate increasing in conjunction
- Patient age decreasing yet expectations/demand increasing
- Failure mode changing
  - Early revisions increasing
TKA: 1 in 5 patients are currently not satisfied with their total knee replacement outcomes.
TKA indicators of revision

- Poor outcome ranges from 7-20%\(^8\)
- Dissatisfaction
- Pain
- Stiffness
- Poor function
- 5.6% of patients reported worse Patient Reported Outcome Measures at 6 months post-operatively compared to pre-op

KSS <70
TKA indicators of revision

- Potential causes
- Aseptic loosening
- Infection
- Patellofemoral pain
- Pain, instability, stiffness
  - increasing failure mode since the start of NJRs as compared to aseptic loosening
  - younger cohort so higher demand/expectations
  - Greater strain through the prosthesis
  - Fehring et al concluded the overall rate of revision could be reduced by 25% by careful ligament balancing alone
TKA indicators of revision

- All registries concur the rate of revision is inversely proportional to age

  Sweden 2x increase <65 vs >75\textsuperscript{10}
  Australia 4.5x increase <55 vs >75\textsuperscript{11}
Can I Do Better?
Do My Patients Deserve Better?

- Why waste time proving over and over how great you are, when you could be getting better?

- Why hide deficiencies instead of overcoming them?
The Solution

- Restore the mechanical axis
- Individual fit and coverage
Allow yourself the uncomfortable luxury of challenging your mind.

- Ours is a culture that measures our worth as human beings by our efficiency, our earnings, our ability to perform this or that. The cult of productivity has its place, but worshipping at its altar daily robs us of the very capacity for joy and wonder that makes life worth living.
Robotic Assisted Total Knee

- Enhanced Planning
- CT based segmentation into a 3D based model of the patient's bony anatomy
- Ability to manipulate the implant in 6 separate degrees of freedom based on key anatomic landmarks
Robotic assisted Total Knee

- Dynamic joint balancing
- Real time/ dynamic assessment of the patient’s ligament tension, flexion/extension gaps, limb alignment
- Surgeon controlled intra-operative adjustments can be made to the preoperative plan in both flexion and extension before bone preparation
RTKA

- Robotic-arm assisted bone preparation
- Stereotactic boundaries are created that assist the surgeon in executing the femoral and tibial resections to plan
- These boundaries also help protect the essential anatomic structures of the knee
Instead of an autonomous system where the robot is in control of the cuts with no dynamic assistance from the surgeon, the robot provides resistance when the surgeon attempts to deviate from the preoperative plan.

A challenge in haptic feedback surgery includes keeping the feedback stable and transparent. The use of haptics allows precision with efficiency and accuracy. Intraoperative sensors will quantify forces across the joint to verify restoration of normal kinematics. The dynamics of trialing components will be redefined with real time in vivo measurements that will allow kinetic optimization through refinements of bony cuts and soft tissue balancing. Robotics allow precise intraoperative adjustments based on an optimized kinematic profile of the individual patient’s knee.
Laboratory data
Robotic-arm assisted total knee arthroplasty demonstrated greater accuracy to plan compared to manual technique\textsuperscript{14}
SAFETY

Robotic-arm assisted total knee arthroplasty demonstrated soft tissue protection

Figure 2. Examples of A) robotically performed TKA with bone island preparation in front of PCL and B) manually performed TKA with arrow pointing to PCL with no bone island. Black arrow points to PCL. White arrows outline bone island.
Early cases

- Initial 40 cases TKA
- US launch January 2017 TKA
- No soft tissue complications
- Alignment within 1 degree
- LOS: 1.7 days
• Early cases UNI
• 120 cases 2013-2017
• (60 Mako)
• No soft tissue complications
• Same day discharge 75%
• Alignment within one degree
The great equalizer
Technology makes it easier to be a small fish in a big pond
The great equalizer
Technology makes it easier to be a small fish in a big pond

<table>
<thead>
<tr>
<th>RMS Error</th>
<th>NavioPFS</th>
<th>Mako Rio</th>
<th>Acrobot</th>
<th>Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flex/Ext (°)</td>
<td>1.6</td>
<td>2.1</td>
<td>2.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Varus/Valgus (°)</td>
<td>2.3</td>
<td>2.1</td>
<td>1.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Int/Ext (°)</td>
<td>1.7</td>
<td>3.0</td>
<td>3.1</td>
<td>6.3</td>
</tr>
<tr>
<td>Prox/Dist (mm)</td>
<td>1.3</td>
<td>1.0</td>
<td>1.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Ant/Post (mm)</td>
<td>1.3</td>
<td>1.6</td>
<td>1.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Med/Lat (mm)</td>
<td>0.9</td>
<td>1.0</td>
<td>0.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Rationale for Robotics

- Simplify the procedure
  - Eliminate surgical steps
  - Make reproducible
  - Reduce the amount of instrumentation
- Enhance accuracy
- Balance soft tissues
- Improve durability
Downside of Robotics Program

- Capital costs:
  - $400,000-$1 million
- Learning curve
- Need for volume
- Surgical time
- Some require preop CT scan
Upside of Robotics Program

- Precision
- Reduced inventory
- Reduced sterilization costs
- Reduced turnover time
- Safety (semi autonomous)
- *Expanding applications*
- *Enhanced outcomes*