My Robotic Experience

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Conflicts

- **Stefano Alec Bini, MD, FAAOS**
- JOURNALS
  - Arthroplasty Today, Associate Editor: Editorial or governing board
  - Journal of Arthroplasty: Editorial or governing board
  - Elsevier: Publishing royalties, financial or material support
- SOCIETIES
  - Personalize Arthroplasty Society: Board or committee member
- START UPS
  - CaptureProof.com: Stock or stock options
  - Cloudmedx.com: Stock or stock options
  - Gait Science: Stock or stock options
  - InSilicoTrials.com: Stock or stock options
  - Siramedical.com: Stock or stock options
  - Archetype.ai: stock or stock options
- **INDUSTRY**
  - **Stryker: IP royalties**

Proceedings of The Knee Society 2021

The Prevalence and Predictors of Patient Dissatisfaction 5-years Following Primary Total Knee Arthroplasty

David C. Ayers MD [a], Mohamed Yousef MD, PhD [a b], Hua Zheng PhD [a], Wenyun Yang BS [c], Patricia D. Franklin MD, MBA, MPH [d]

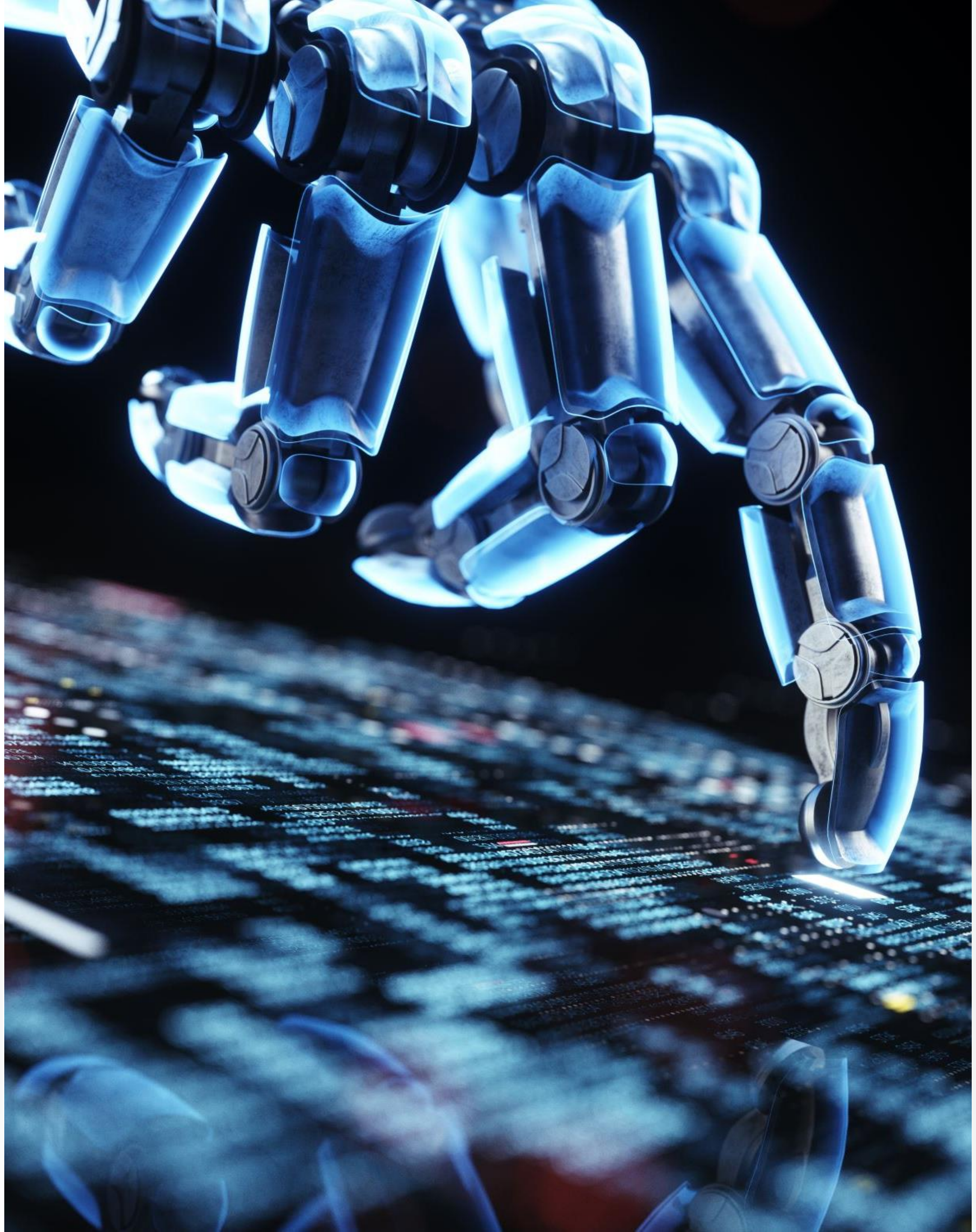
Where we are today: not good.

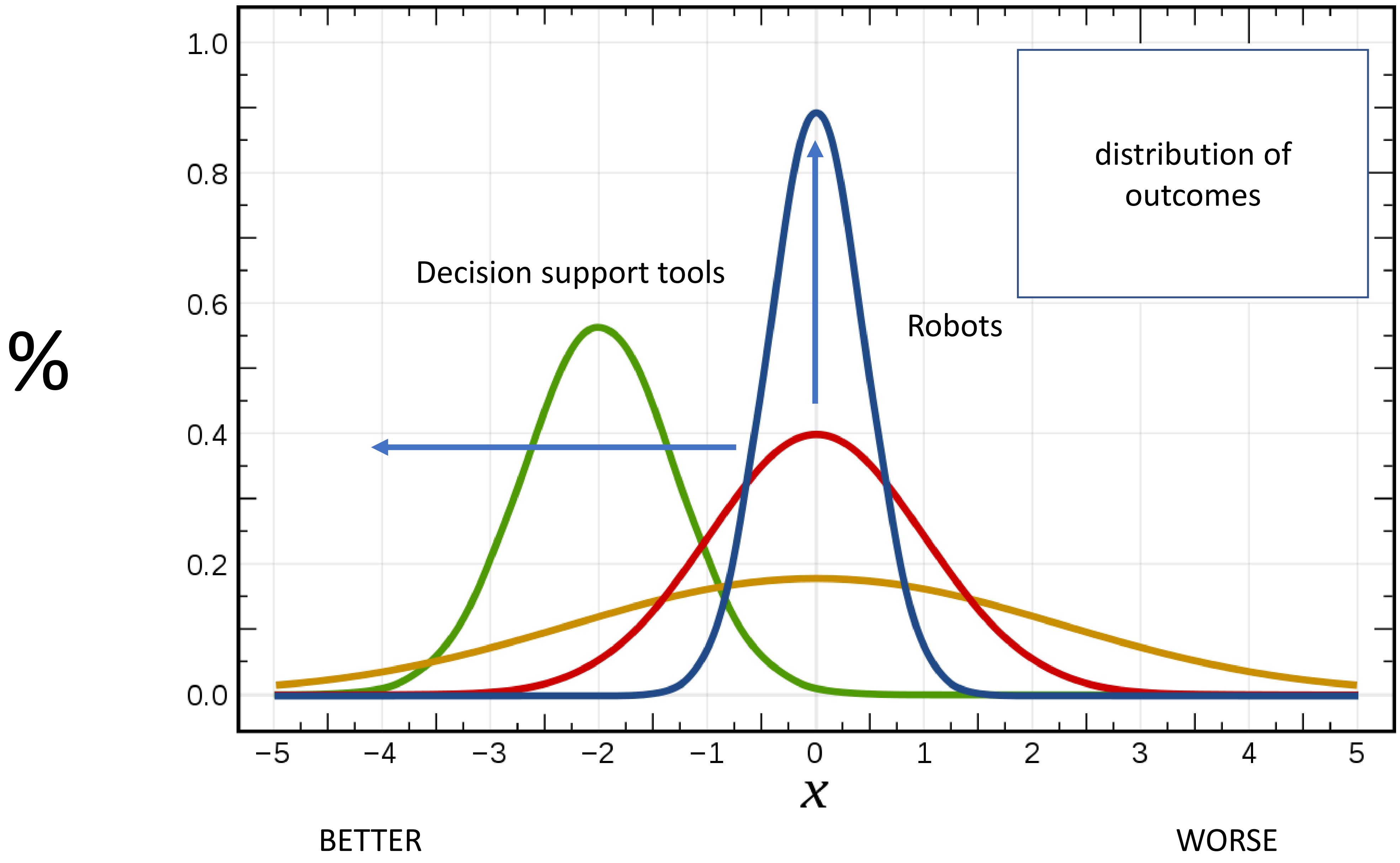
- A total of 12.7% patients (559/4402) reported **dissatisfaction** 5-years after TKA.
  - Increased BMI, higher CCI, higher Owestry Disability Index and increased number of other painful lower extremities (LE) joints were significantly associated with dissatisfaction.
- Surgeons should use these identified risk factors to set realistic expectations for patients at an increased risk for dissatisfaction aiming to optimize their outcomes and increase their long-term satisfaction after TKA.
- Dissatisfaction is a terrible threshold to chose
- Only 35-40% are perfect in other recent studies

Rationale for poor outcomes

- Patients didn't do well it was because of one of the following:
  - Lazy
  - Pain seeking
  - Poor compliance
  - Their Risk factors (socio demographics)
  - Bad implant design
- If it was someone else's patient
  - Poor surgical technique
  - Poor cement job
  - Poor balancing
- We never questioned the alignment
- We focused on implant survivorship as the primary outcome
- We added computers (CAS - navigation): no change in results

Robotics as a solution





%
1.0
0.8
0.6
0.4
0.2
0.0
distribution of outcomes
Decision support tools
Robots
−5
−4
−3
−2
−1
0
1
2
3
4
5
X
BETTER
WORSE

The Role of Technology

- Enable us to do something we could not otherwise do with standard means.
  - Faster
  - Better
  - **Different**
- It also must make things **easier**
  - If it’s more complicated (the “cost” goes up) the outcome must justify the increased effort (“rewards” must be much higher)

Robotic TKA survivorship Australia

- 2021 AOANJRR Annual Report: 2,219 robotic-assisted TKRs performed in Australia between 2015 and 2020.
- The cumulative percent revision rate for these procedures at five years was **2.3%, compared to 3.0% for non-robotic-assisted** TKRs.
- This suggests that robotic-assisted TKRs have similar or slightly better survivorship than non-robotic-assisted TKRs.
- Reference: AOANJRR. Annual Report. 2021. Available at: https://aoanjrr.sahmri.com/documents/10180/69732/Annual%20Report%202021)

Robotic TKA survivorship Australia

- The AOANJRR also published a **specific report on the survivorship of the Stryker Mako robotic-arm assisted TKR system**, which is one of the most commonly used systems in Australia.
- Cumulative percent revision rate at three years was **1.3%**, the overall revision rate for TKRs in Australia during the same time period was **2.6%.**
- Reference: AOANJRR. Supplementary Report: Stryker Mako. 2021. Available at: https://aoanjrr.sahmri.com/documents/10180/70157/Supplementary%20Report%202021%20-%20Stryker%20Mako)

ROBOTIC UKA: England and Wales

- The Journal of Arthroplasty in 2021 compared the survivorship of robotic-assisted UKAs to manual UKAs using data from the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man.
- The study found that the **five-year revision rate** for robotic-assisted UKAs was **3.7%, compared to 4.7%** for manual UKAs.
- The study also found that robotic-assisted UKAs had a **lower risk of revision** due to aseptic loosening.
- Reference: Gwam CU, Mohammed AZ, Thomas M, et al. Comparative survivorship of robotic-assisted and manual unicompartmental knee arthroplasty: A propensity score-matched analysis of 18,465 procedures from the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. J Arthroplasty. 2021;36(5):1637-1644. doi:10.1016/j.arth.2021.01.024

ROBOTIC UKA: Australia

- The Journal of Arthroplasty in 2020 compared the survivorship of Stryker Mako robotic-arm assisted **UKAs** to manual UKAs using data from the Australian Orthopaedic Association National Joint Replacement Registry.
- The study found that the five-year revision rate for Stryker **Mako UKAs was 2.5%, compared to 4.6% for manual UKAs**. The study also found that Stryker Mako UKAs had a lower risk of revision due to aseptic loosening and other causes.
- Reference: Gwam CU, Sardesai N, Egol KA, et al. Comparative survivorship of robotic-arm assisted and manual unicompartmental knee arthroplasty: An analysis of 24,041 cases from the Australian Orthopaedic Association National Joint Replacement Registry. J Arthroplasty. 2020;35(9):2484-2488. doi:10.1016/j.arth.2020.04.060

RTKA and Pain

- Knee: 2022 A systematic review and meta-analysis was conducted to assess the impact of technology-assisted total knee arthroplasty (TKA) **on post-operative** pain and opioid use.
- The analysis included 31 studies with a total of 761,300 TKAs.
- The results showed **no significant difference in pain** scores between manual and technology-assisted TKA cohorts, as measured by various patient-reported pain scales.
- However, the evidence was mixed regarding how opioid consumption differed between the two techniques, particularly in the immediate post-operative period.
- Overall, the study suggests that technology-assisted TKA **does not offer significant advantages in terms of pain management** over manual TKA.

KNEE | Published: 19 August 2022

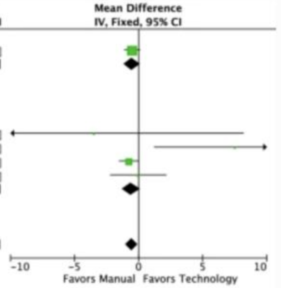
Use of intraoperative technology in total knee arthroplasty is not associated with reductions in postoperative pain

Andrew G. Kim, Zachary Bernhard, Alexander J. Acuña, Victoria S. Wu & Atul F. Kamath

Knee Surgery, Sports Traumatology, Arthroscopy **31**, 1370–1381 (2023) | Cite this article

Fig. 5

	Manual TKA			Technology Assisted TKA				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
4.1.1 Robotic Arm Assisted								
Zak et al. 2021	3.3	2.77	217	3.81	2.58	101	57.3%	−0.51 [−1.13, 0.11]
Subtotal (95% CI)			**217**			**101**	**57.3%**	**−0.51 [−1.13, 0.11]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.60 (P = 0.11)								
4.1.2 Computer Assisted Navigation								
Dyrhovden et al. 2013	78.7	41.9648	95	82.2	41.9648	103	0.2%	−3.50 [−15.20, 8.20]
Gøthesen et al. 2014	19.4	22.0947	94	11.9	22.0947	95	0.6%	7.50 [1.20, 13.80]
Schmitt et al. 2011	2	1.5	28	2.76	2.1	59	37.4%	−0.76 [−1.53, 0.01]
Zak et al. 2021	3.3	2.77	217	3.33	3.32	9	4.6%	−0.03 [−2.23, 2.17]
Subtotal (95% CI)			**434**			**266**	**42.7%**	**−0.58 [−1.31, 0.14]**
Heterogeneity: $Chi^2 = 7.01$, df = 3 (P = 0.07); $I^2 = 57\%$								
Test for overall effect: Z = 1.58 (P = 0.11)								
Total (95% CI)			**651**			**367**	**100.0%**	**−0.54 [−1.01, −0.07]**
Heterogeneity: $Chi^2 = 7.03$, df = 4 (P = 0.13); $I^2 = 43\%$								



Pooled analysis comparing post-operative VAS pain values between manual and technology assisted TKA. *VAS* Visual Analog Scale, *TKA* total knee arthroplasty, *95% CI* 95% confidence interval, *M–H* Mantel–Haenszel

Surgical Training

"Impact of Robotic Assistance on the Learning Curve in Total Knee Arthroplasty by Residents" by Batailler et al. (2019). Residents who were trained using robotic-assisted techniques had **shorter learning curves and improved outcomes** compared to those who were trained using traditional techniques.

Reference: Batailler C, White N, Ranaldi FM, et al. Impact of robotic assistance on the learning curve in total knee arthroplasty by residents. Knee Surg Sports Traumatol Arthrosc. 2019;27(6):1917-1923. doi:10.1007/s00167-018-5289-1

COST EFFECTIVENESS TIED TO VOLUME TO AMMORTIZE COST OF THE ROBOT

- **Methods:**
- - Three institutional case volumes were used to generate average per-case robotic costs: low volume (10 cases, $71,025 per case), mid volume (100 cases, $7,463 per case), and high volume (200 cases, $3,931 per case).
- - Systematic reviews were used to determine early (≤1 year) and late (> 1 year) revision rates
- - Outcomes were total costs and health outcomes measured in quality-adjusted life-years (QALYs). Costs and QALYs were organized into incremental cost-effectiveness ratios (ICERs).
- - A procedure was considered cost-effective if its ICER fell below willingness-to-pay (WTP) thresholds of $50,000 and $100,000/QLY
- Results:
- - Robotic-assisted TKA produced 13.55 QALYs versus 13.29 QALYs for conventional TKA.
- - Total costs per case for robotic-assisted TKA were $92,823 (low volume), $29,261 (mid volume), and $25,730 (high volume) compared with $25,113 for conventional.
- - Average number needed to treat was >42 and >24 robotic-assisted TKAs for cost-effectiveness at the $50,000 and $100,000/QALY WTP.
- - Robotic-assisted TKAs remained cost-effective when annual revision rates <1.6% and quality of life values were >0.85.

- **Conclusion:**
- - Robotic-assisted TKAs potentially offer improved health outcomes, especially when annual institutional case volume >24 cases per year. (Hua paper: 49)
- - Continued prospective investigation will be crucial to demonstrate the value of this new technology.

RESEARCH: RESEARCH ARTICLE

The Cost-Effectiveness of Robotic-Assisted Versus Manual Total Knee Arthroplasty: A Markov Model–Based Evaluation

Rajan, Prashant V. MD; Khlopas, Anton MD; Klika, Alison MS; Molloy, Robert MD; Krebs, Viktor MD; Piuzzi, Nicolas S. MD

Author Information

Journal of the American Academy of Orthopaedic Surgeons 30(4):p 168-176, February 15, 2022. | ***DOI:*** 10.5435/JAAOS-D-21-00309

Literature: Cost and Results

Overall cost

Per case cost at our institution went down and was lower than comparable implants

Lower costs over 3 months if looking at total billing in state-wide databases.

Across the board

Lower pain scores

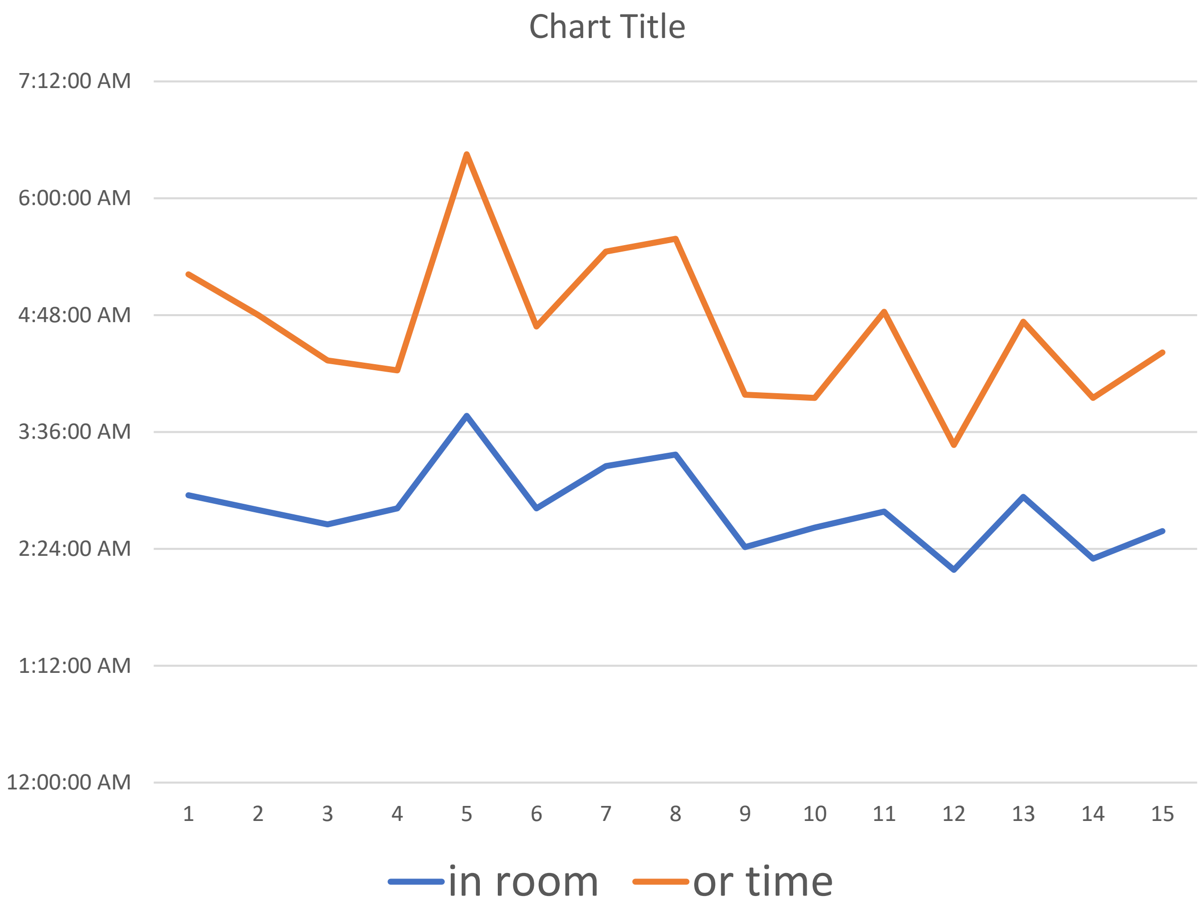
Lower readmission rates

Improved functional outcomes

Some evidence of equal or improved survivorship

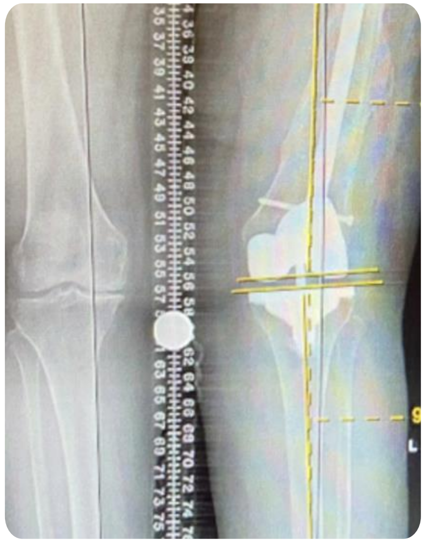
Learning Curve

- Haddad
  - 20 cases
- In Room Time
  - Average 2:48:56
    - High 3:46:00
    - Low 2:11:00
- Surgical Time
  - Average 1:51:24
    - High 2:41:00
    - Low 1:17:00



Complications first 15

- No Surgical Complications in first 15 cases
- LOS 1.2 days
  - 13 patients 1 days
  - 1 patient 2 days (TKA)
  - 1 patient 3 days (THA)
- **16th case had a complication**
  - Primary TKA in patient with Post-traumatic deformity and retained hardware
  - Intraoperative lateral instability after bone cuts
  - Required conversion to semi constrained TKA
  - Achieved desired alignment (see XR)
  - At 4 weeks had excellent recovery and no further complications (see right)



Mako UKA Cut Accuracy

- Results
  - Compared pre and post op CT
- Manual:
  - RMS <5.4 mm, 3.7deg all directions
- Robotic
  - ROMS <1.9 mm, 10.2 deg all directions

ELSEVIER

The Knee
Volume 20, Issue 4, August 2013, Pages 268-271

Unicompartmental knee arthroplasty: Is robotic technology more accurate than conventional technique?

Mustafa Citak [a], Eduardo M. Suero [a], Musa Citak [a], Nicholas J. Dunbar [b], Sharon H. Branch [c], Michael A. Conditt [c], Scott A. Banks [b], Andrew D. Pearle [a]

TKR

- In vivo study
- 37 consecutive cases
- Used Mako measurements
  - **Distal 0.38mm**
  - **Anterior 0.44mm**
  - **Tibia 0.37 mm**
- 94% within 1mm of plan
- Alignment within 1 deg
- **100% within 3deg of plan**

Accuracy of Bone Resection in MAKO Total Knee Robotic-Assisted Surgery

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J Knee Surg 2021;34:745–748.

Reality check on the accuracy data

- Up until **calipered KA** we never REALLY checked our distal resection thickness and happily accepted all kinds variation from the goal, raising joint lines up to 5mm to address contractures.
- **The goal was alignment**
- **The means to get there was soft tissue releases**

Kinematic alignment

- **Designed for use with manual instruments.**
  - In theory, imaging is completely unnecessary other than for knowing the angles pre-operatively
  - Caliper based alignment: **every resection is measured** with calipers and must be within 1 mm of goal.
- **Manual instruments were not as accurate as I wanted.**
  - Hard bone, very soft bone.
  - **Difficult to adjust/restrict.**

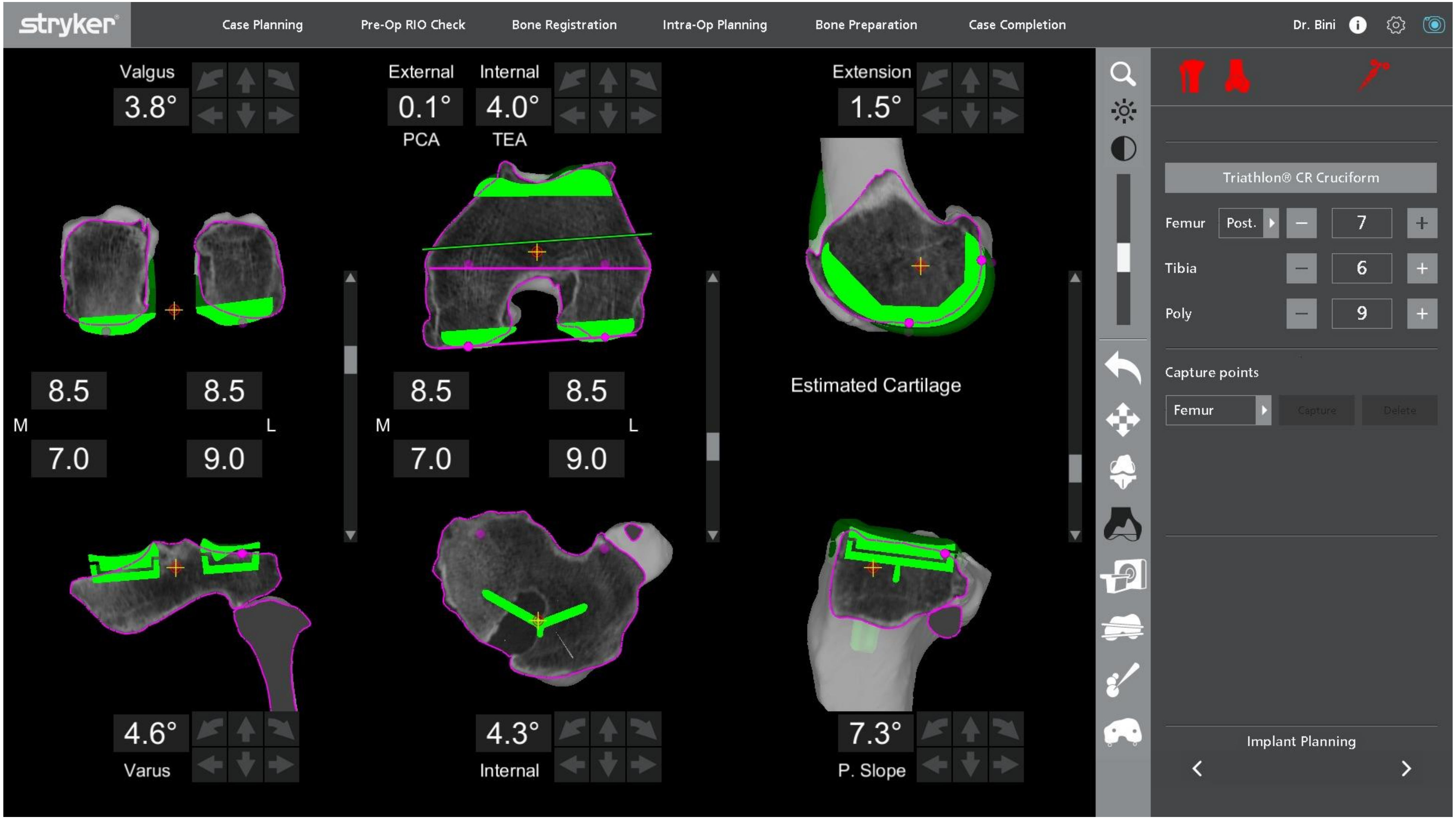
MAKO: The promise of perfect cuts

MAKO TKA 1.0 was designed for MA.

- In M.A. the actual resection depth is irrelevant and asymmetric
- The goal is neutral alignment
- Shoots for a rectangular Flexion gap.
- REALITY: the MAKO TKA platform is really good at alignment-based outcomes.

MAKO used in KA shoots for equal resections on both sides on the femur

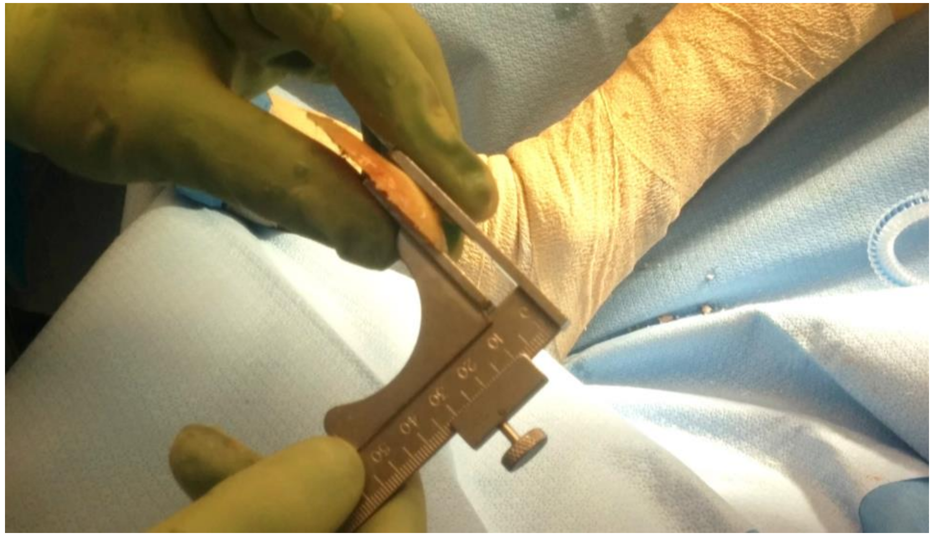
- The most distal point on the femoral condyles.
- The midpoint of the tibial plateaus.
- Goal restore joint line in Extension, **asymmetric native flexion gaps**
- **HKA Alignment variable**

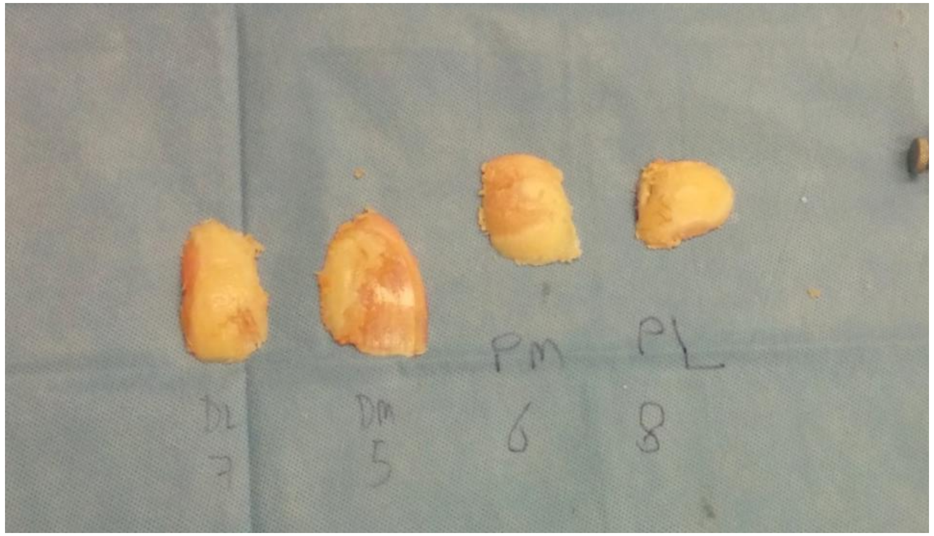


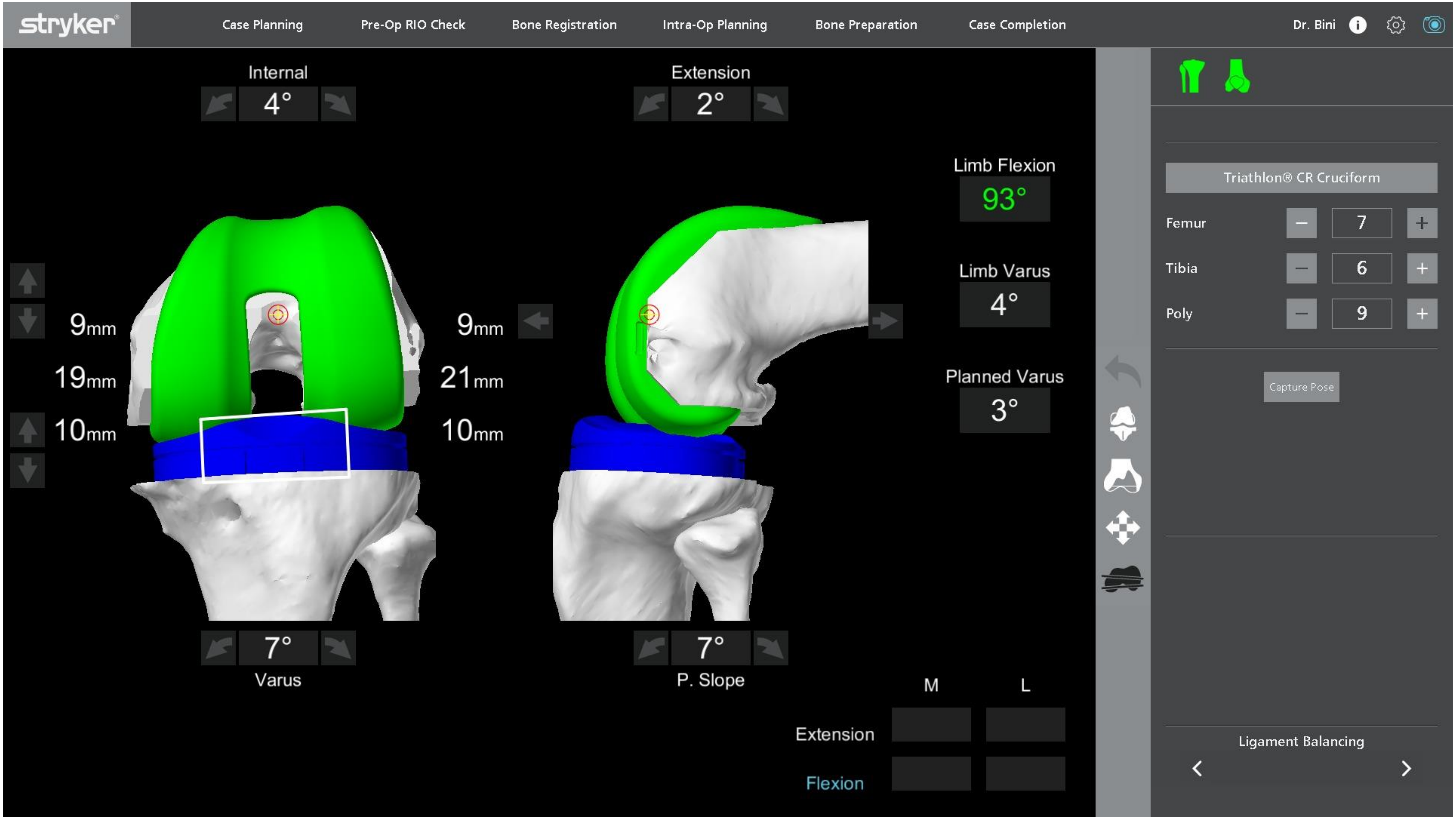
stryker
Case Planning
Pre-Op RIO Check
Bone Registration
Intra-Op Planning
Bone Preparation
Case Completion
Dr. Bini
Valgus
3.8°
External
0.1°
PCA
Internal
4.0°
TEA
Extension
1.5°
8.5
8.5
M
L
7.0
9.0
8.5
8.5
M
L
7.0
9.0
Estimated Cartilage
4.6°
Varus
4.3°
Internal
7.3°
P. Slope
Triathlon® CR Cruciform
Femur
Post.
7
Tibia
6
Poly
9
Capture points
Femur
Capture
Delete
Implant Planning

MAKO 1.0 workflow for KA

- **Plan KA cuts on plain XRs and Robot**
- Performa KA cuts in extension and flexion on femur
- **Measure resected femoral bone cuts**
    - Adjust plan to increase bone resection as needed to match your desired bone resection
    - Resect bone again
    - Test depth of resection with planer probes
- **Proceed to tibia**
    - Measure bone fragment
    - Resect bone again
- **Check planes one more time**
- **Check knee balance with spacer blocks**
- Trial

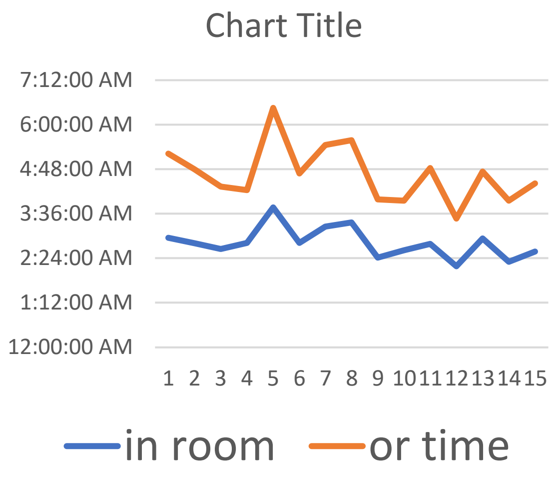




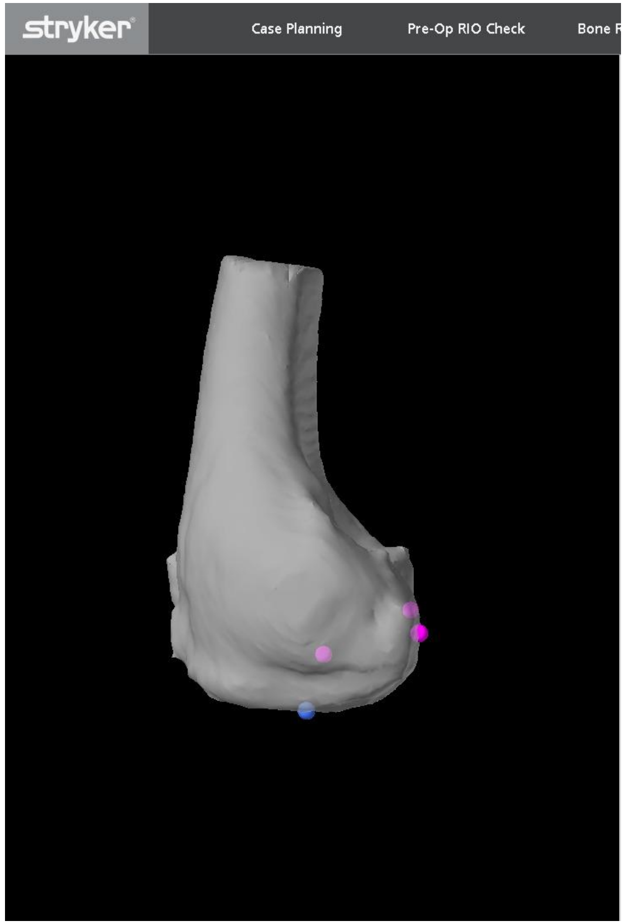

stryker
Case Planning
Pre-Op RIO Check
Bone Registration
Intra-Op Planning
Bone Preparation
Case Completion
Dr. Bini
Internal
4°
Extension
2°
Limb Flexion
93°
Limb Varus
4°
Planned Varus
3°
9mm
19mm
10mm
9mm
21mm
10mm
7°
Varus
7°
P. Slope
M
L
Extension
Flexion
Triathlon® CR Cruciform
Femur
7
Tibia
6
Poly
9
Capture Pose
Ligament Balancing

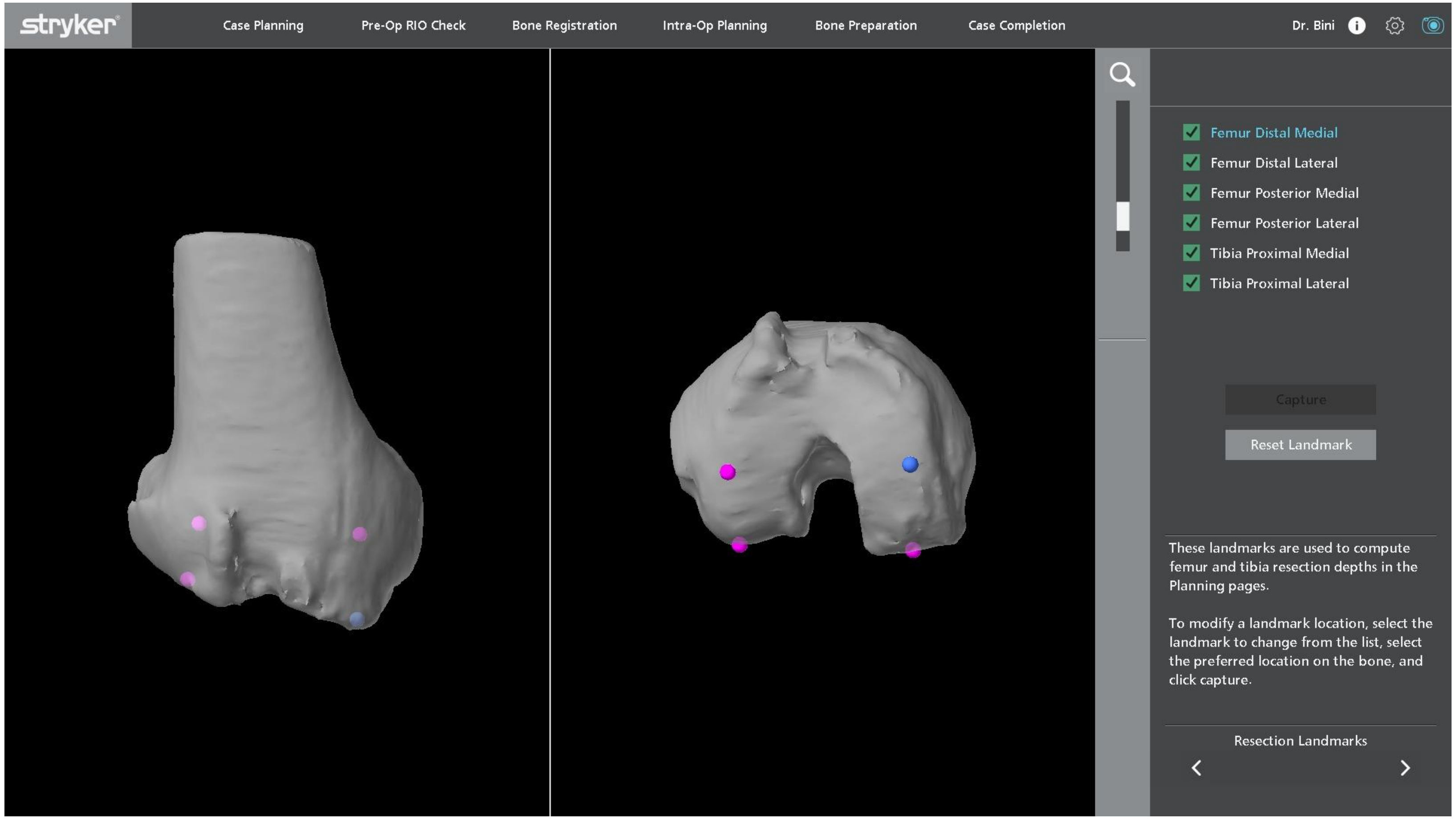
The Problem

- **Resections still inaccurate**
  - The resection height changed with **flexion of the femoral** component
  - When the robot cut, the width considered acceptable is 1mm on either side of the surface of the saw, how was that potential 2mm variance accounted for?
- The **tibia is relatively hard to judge** on cross section coronal CT scans.
- So: we started measuring and recording every single cut very systematically
  - The variance was frequently **1-2 mm**
  - We had to recut frequently
  - Overall surgical times were getting pretty long



Challenges: Resection Point Selection

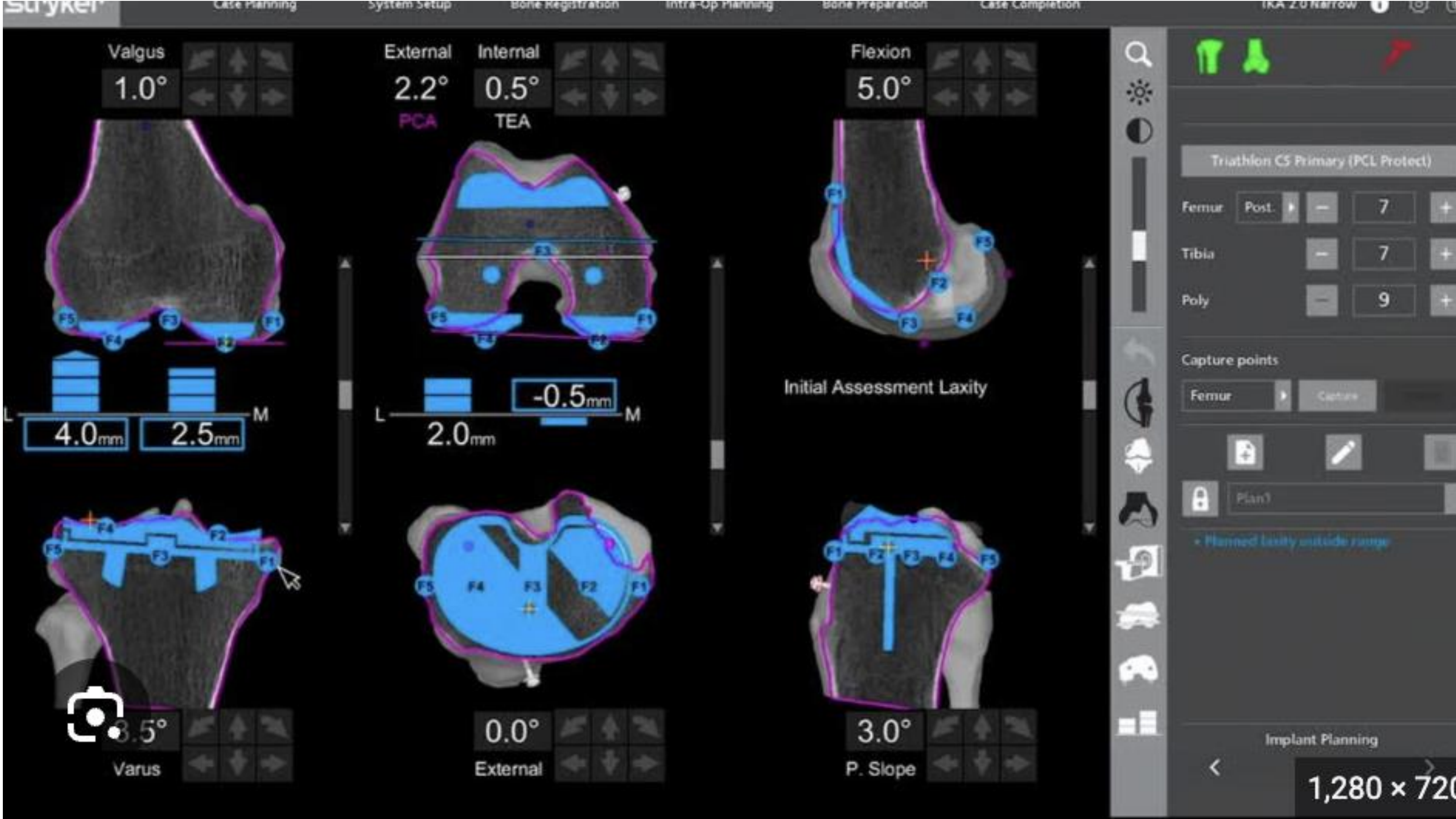




The evolution of the platform. MAKO 2.0

- Mako 2.0 upgrade included **the ability to estimate post resection laxity in mm *prior* to cuts and trials**
- **Navigation (CAS) technology (not new)**
- **Workflow**
  - Create you **KA resection** plan as per prior
  - Open knee and **remove osteophytes** and scarring
  - **Test knee laxity** in ROM
  - **Software calculates** what your post resection laxity will be in Flexion and Extension
    - (NB: UKA allows full ROM laxity testing)
  - **Adjust accordingly**

Gap assessment



Case Planning
System Setup
Bone Registration
Intra-Op Planning
Bone Preparation
Case Completion
Valgus
1.0°
External
2.2°
PCA
Internal
0.5°
TEA
Flexion
5.0°
Initial Assessment Laxity
L
4.0mm
2.5mm
M
L
2.0mm
-0.5mm
M
Varus
0.0°
External
3.0°
P. Slope
Triathlon CS Primary (PCL Protect)
Femur
Post.
7
Tibia
7
Poly
9
Capture points
Femur
Implant Planning
1,280 × 720

Results = change in strategy

- **Calipered Resection was the best solution pre-robotics** for restoring a balanced knee with native kinematics through bony cuts and restoration of "normal anatomy"
- You could add **navigation to adjust the ligaments post hoc**, but not the bony cuts
- With this system you have a very good idea of your final outcome <u>before</u> you cut.
    - Gamechanger

New protocol: Functional KA

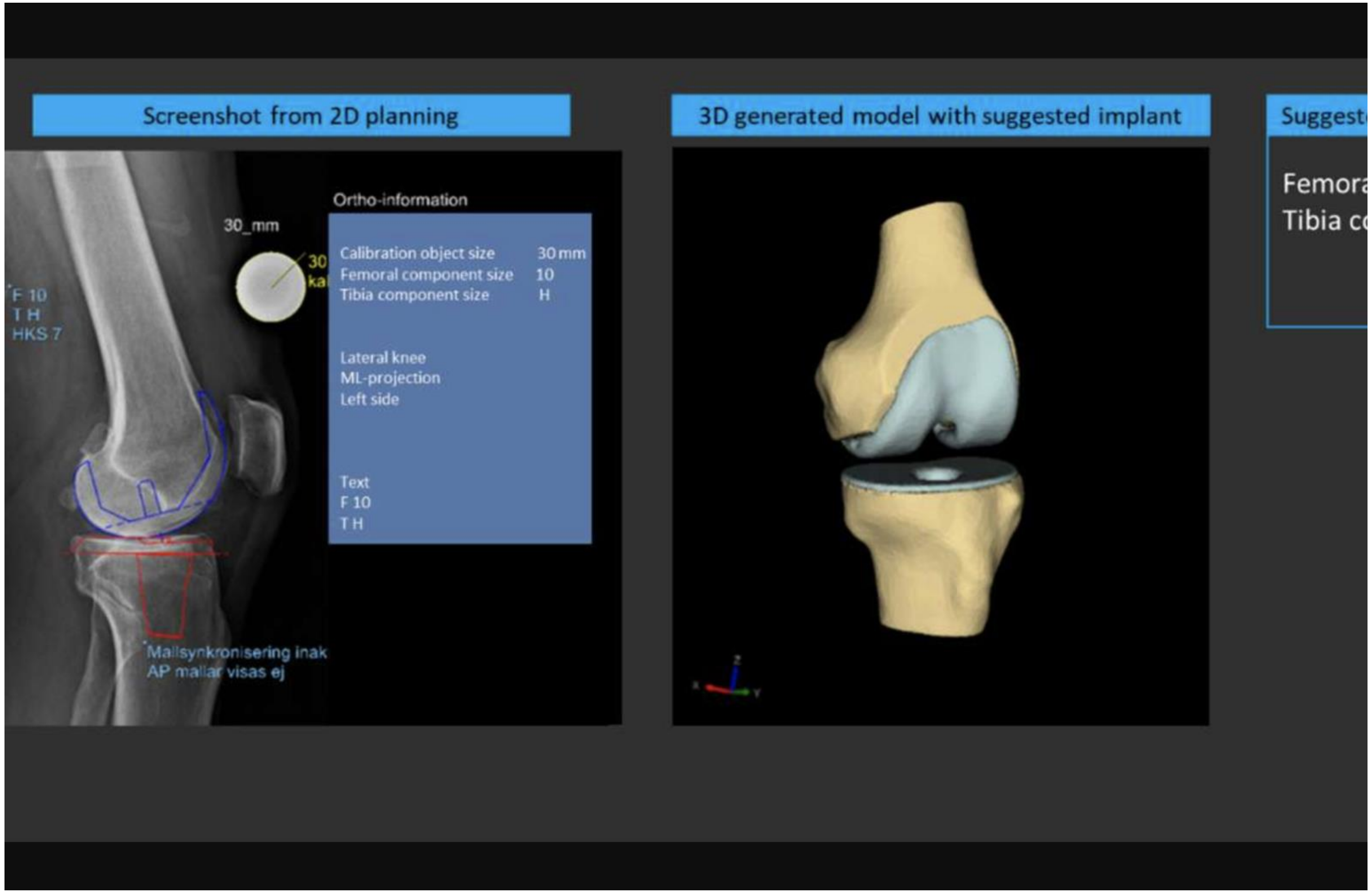
- **Plan: KA protocol**
- Arthrotomy and pin placement: obtain baseline data
- **Free collaterals**: resect all osteophytes ACL and scar if any
- Release around tibia okay (deep collaterals) to level of bone cut
- **Test laxity (gaps)**
- **Adjust plan** to approximate the following:
  - Equal gaps in full extension
  - Medial Flexion gap 1-2 mm > than medial gap in extension
  - Lateral gap: >2 mm than extension … up to any number, just not =
- **Adjust rotation** to trochlear groove if necessary

Robots are meeting their promise

- Robotic JR is showing **better** or equivalent results
- The overall PROM data is lagging
  - too blunt of an instrument and even the FKS and the Adaptive scores have ceiling effects. Plus the robotic surgery is getting better and better
- **full three-dimensional control of how they are implanting their joint**
- built in, **intraoperative feedback loops**

Courtesy Linus Bystroem
Ortona AB

2D to 3D to Generative AI based Modeling



Intraoperative Guidance

ISTA 2023 New York

#8224 - Real-Time AI Surrogate Simulation Model for Enhanced TKA Outcomes: Validation and Applications in the Operating Theatre

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Type Abstract

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Presenting

- Qipeng Shen

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- Joshua

The Personalized Arthroplasty Society (PAS)

THE END
Thank you