ALIGNMENT CONCEPT TKR

Dr Ulhas Sonar,

MBBS, MS (Ortho)

MCh Upper Limb

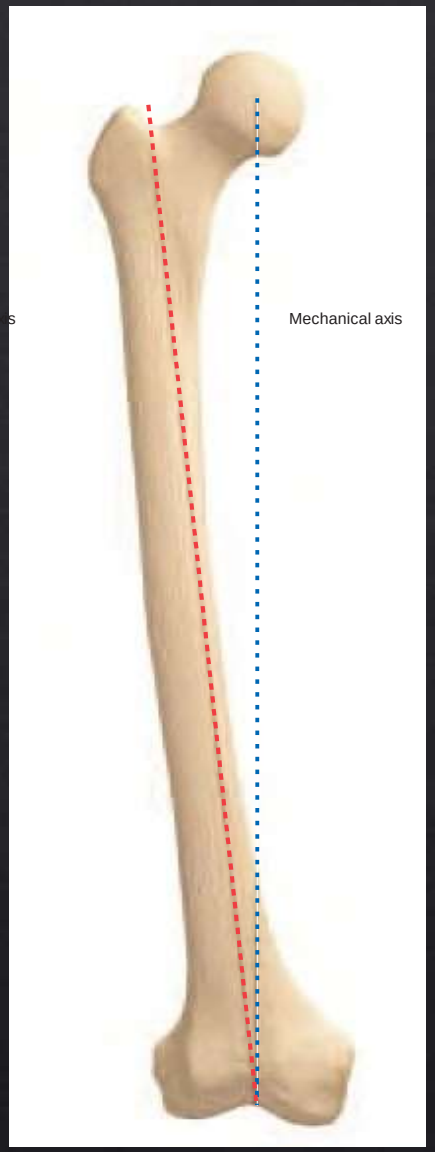
MRCS, FEBOT,

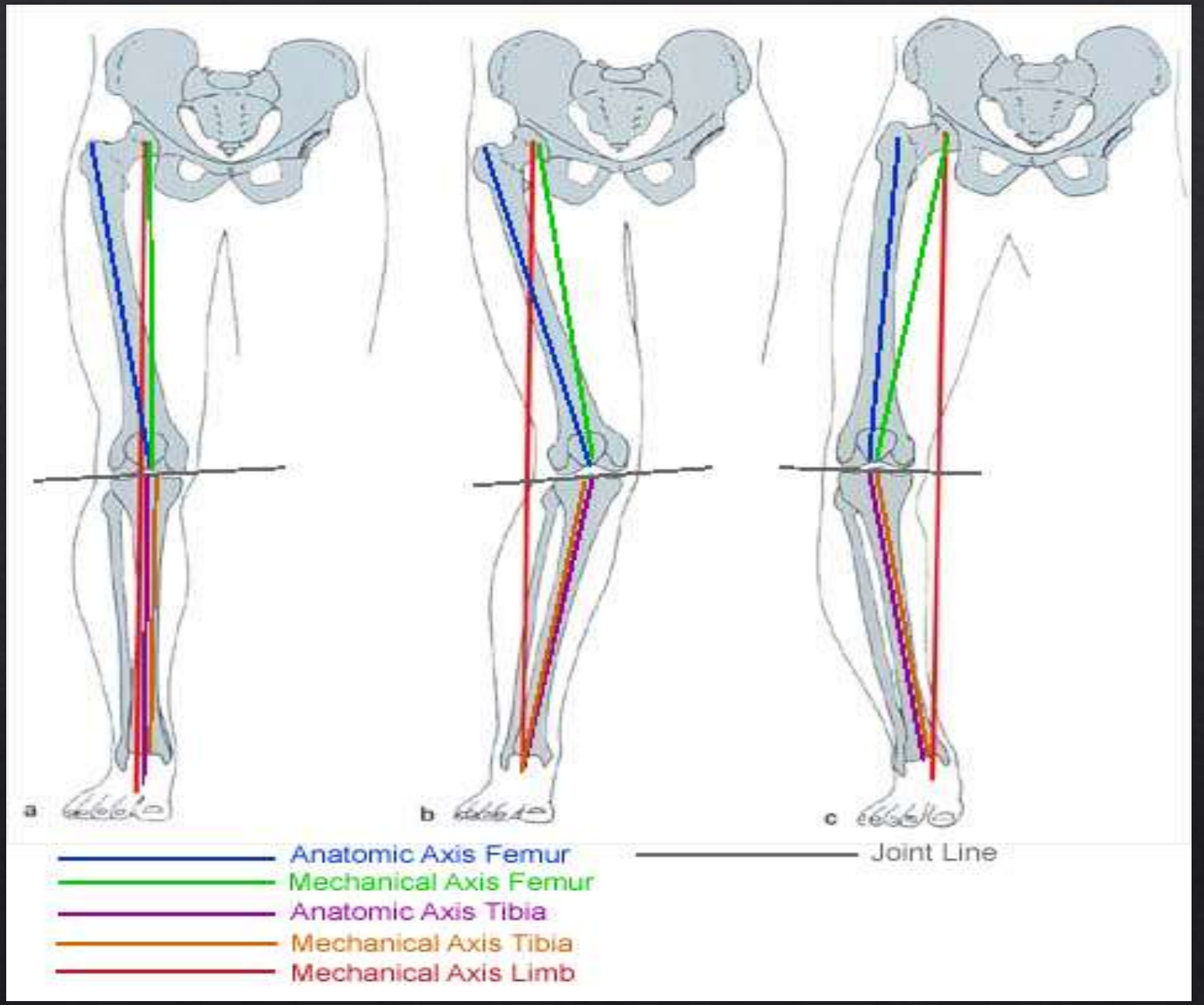
FRCS(JCIE, UK)
PGDip in Computer Assisted TKR

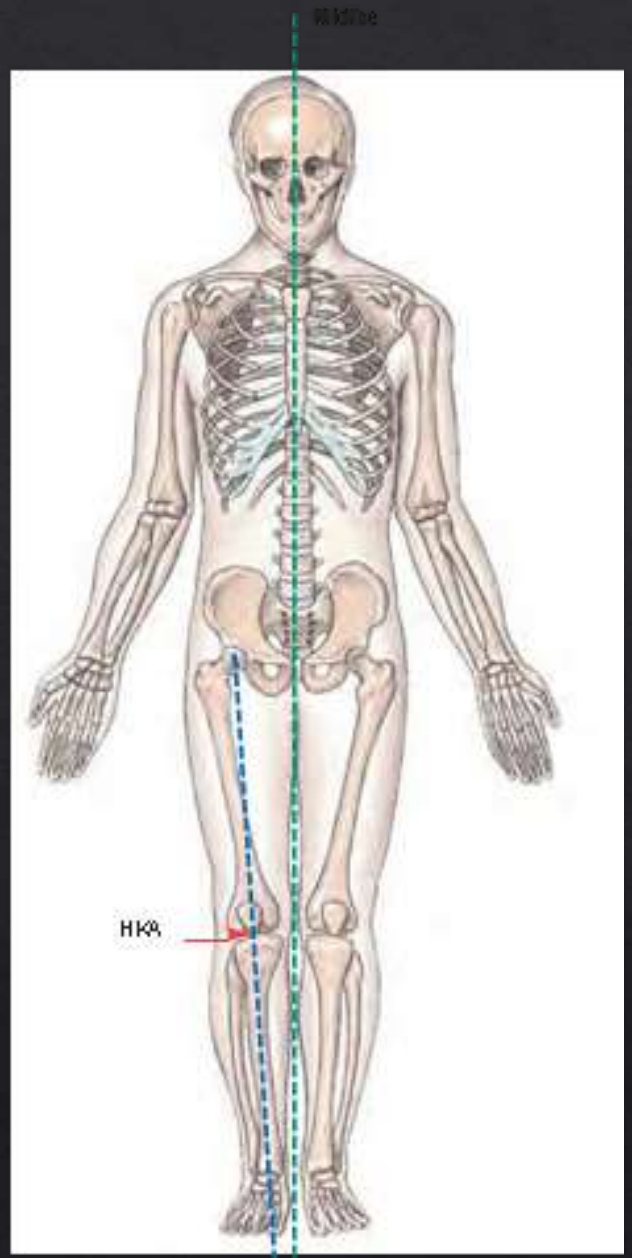
TERMS

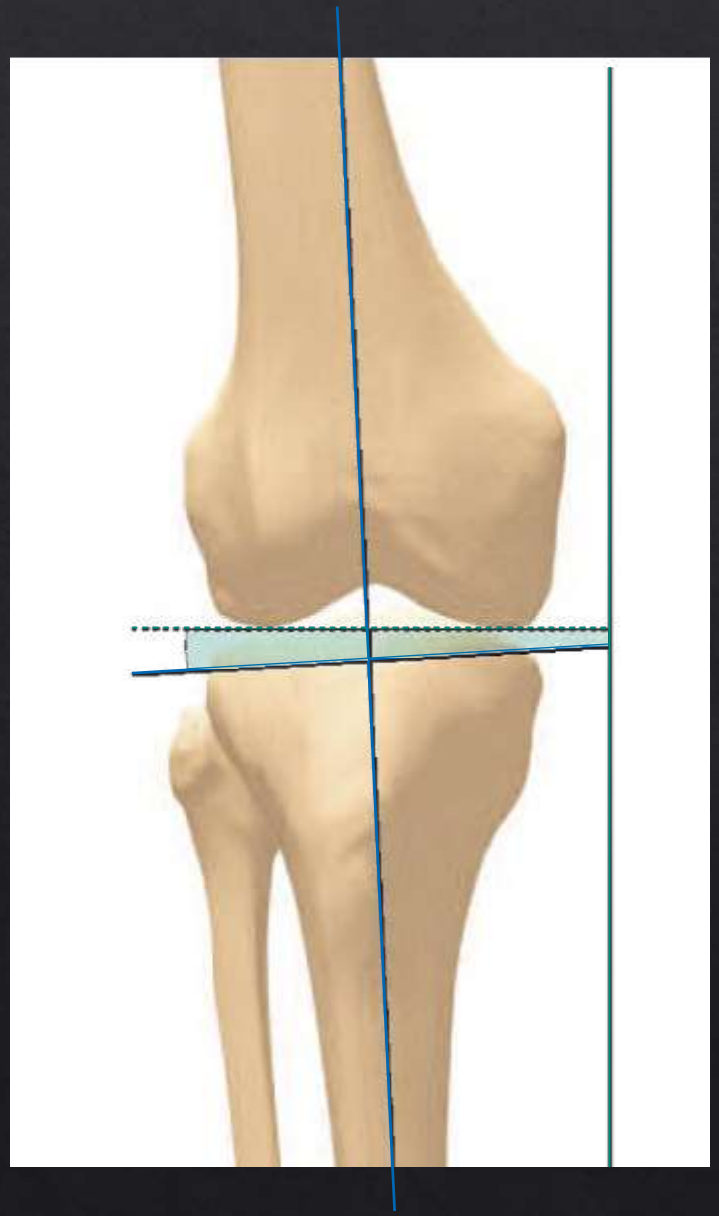
- Alignment
- HKA Axis
- Mechanical Axis
- Anatomical Axis

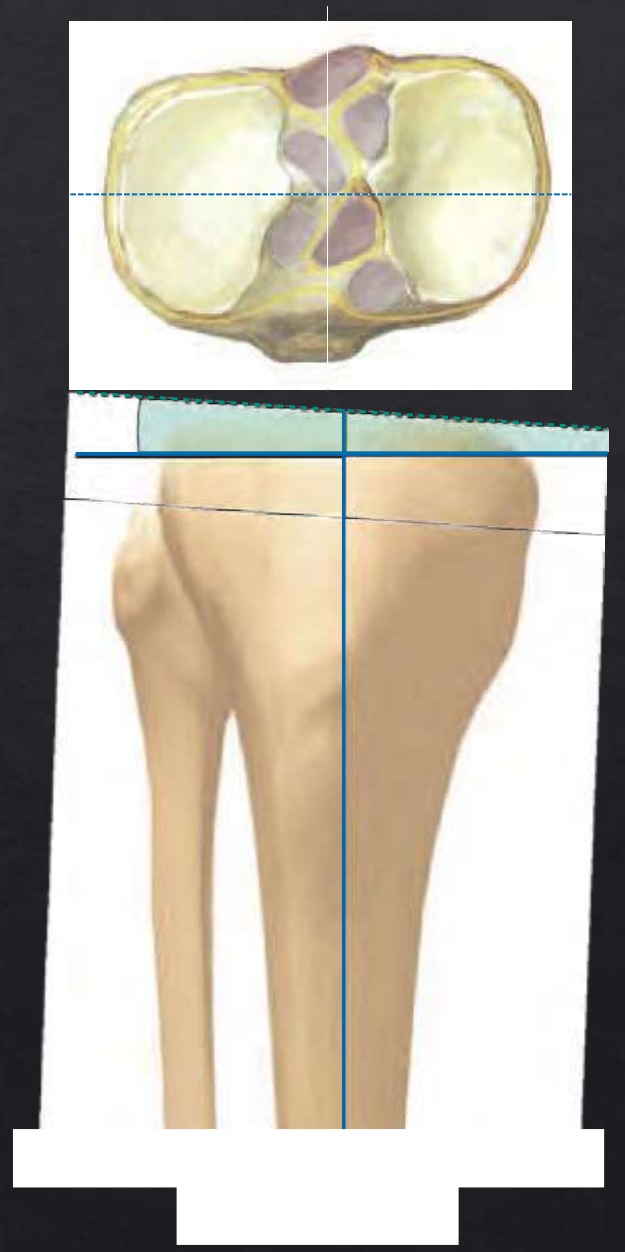
- Measured Resection
- Gap Balancing


Anatomic axis
Mechanical axis

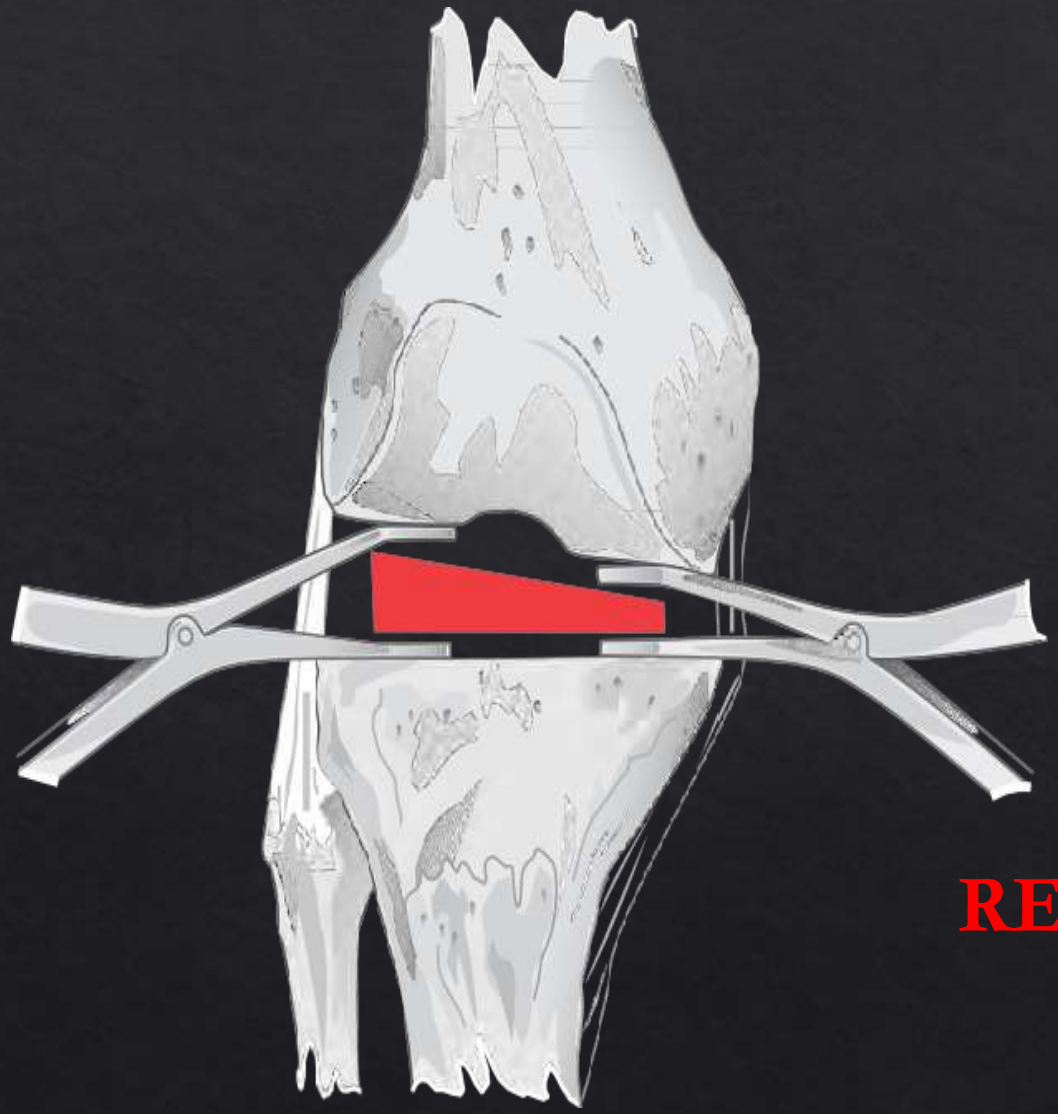

a
b
c
Anatomic Axis Femur
Mechanical Axis Femur
Anatomic Axis Tibia
Mechanical Axis Tibia
Mechanical Axis Limb
Joint Line

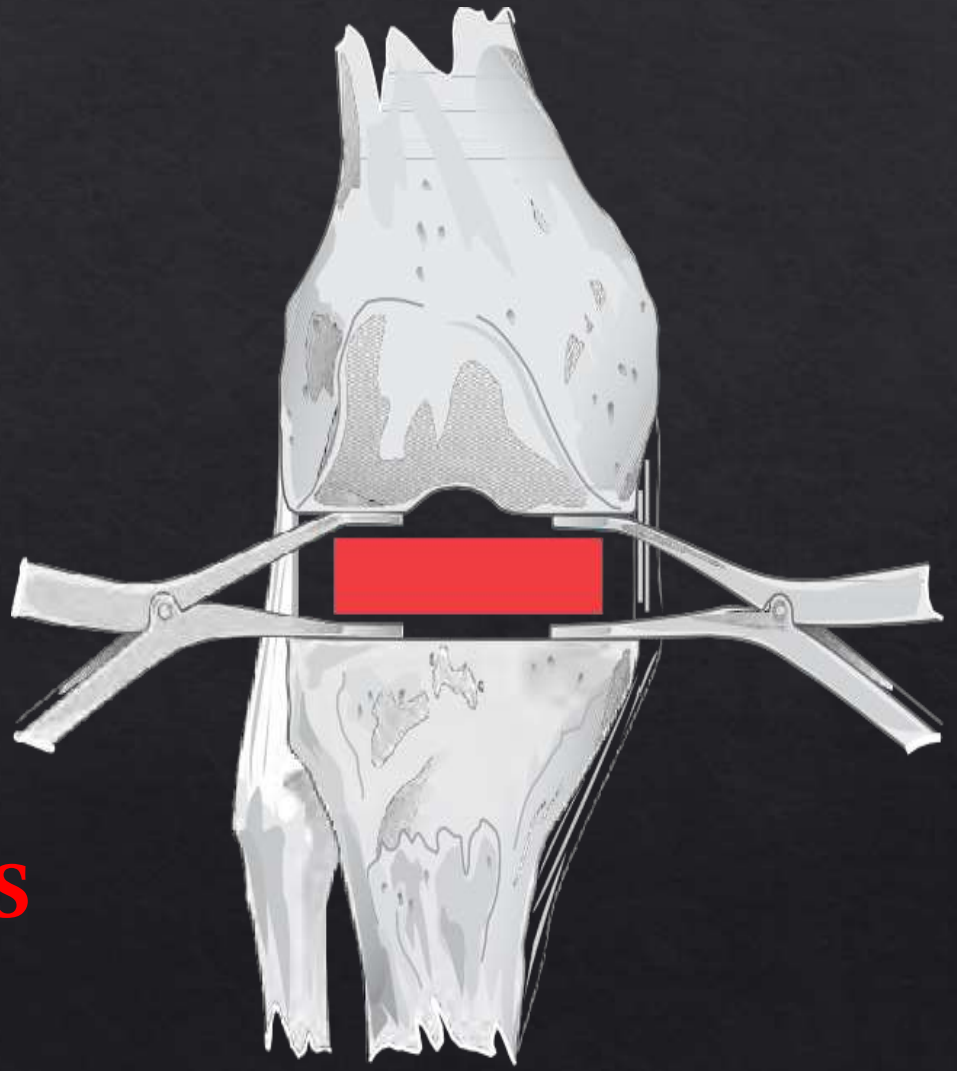

HKA
3°





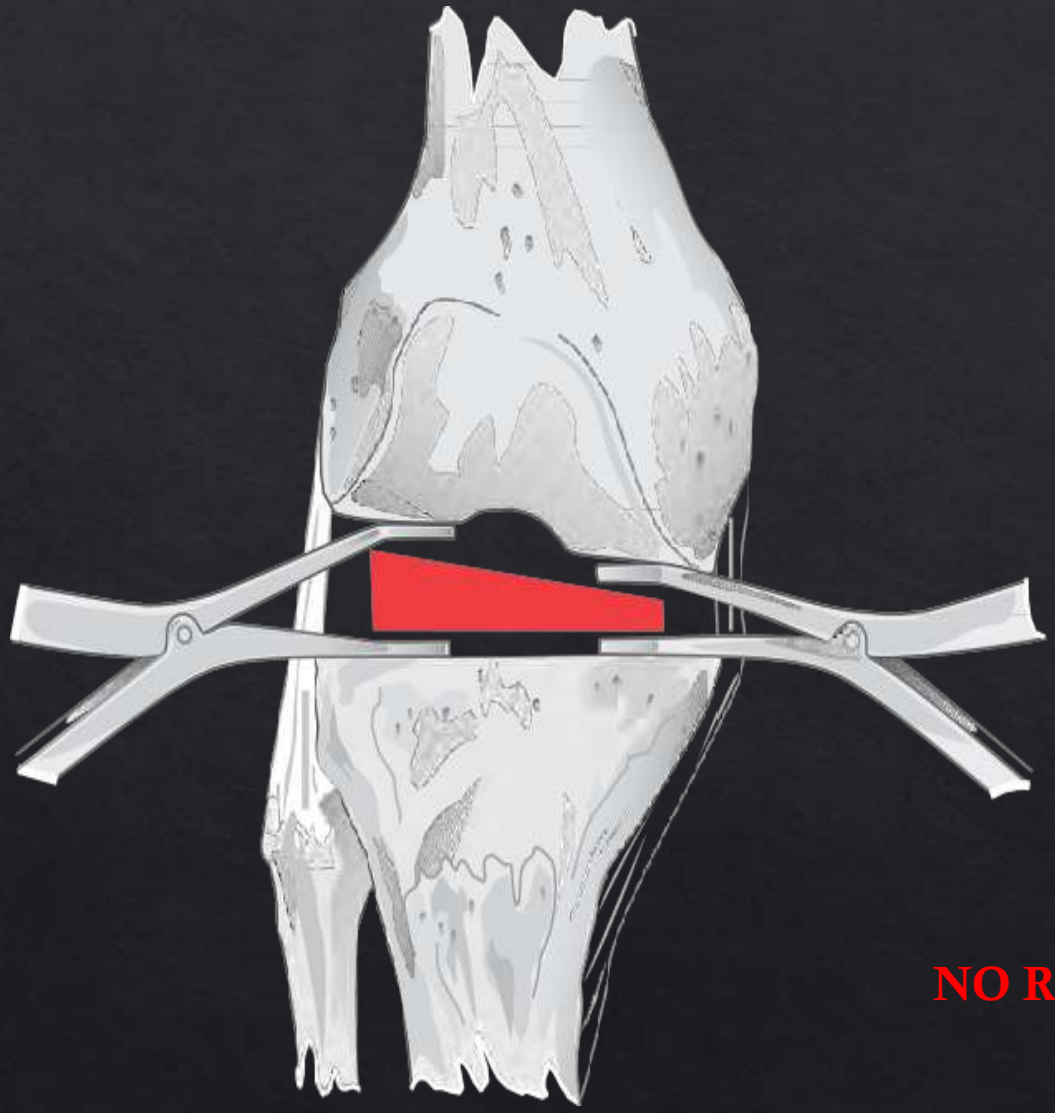
MEASURED RESECTION

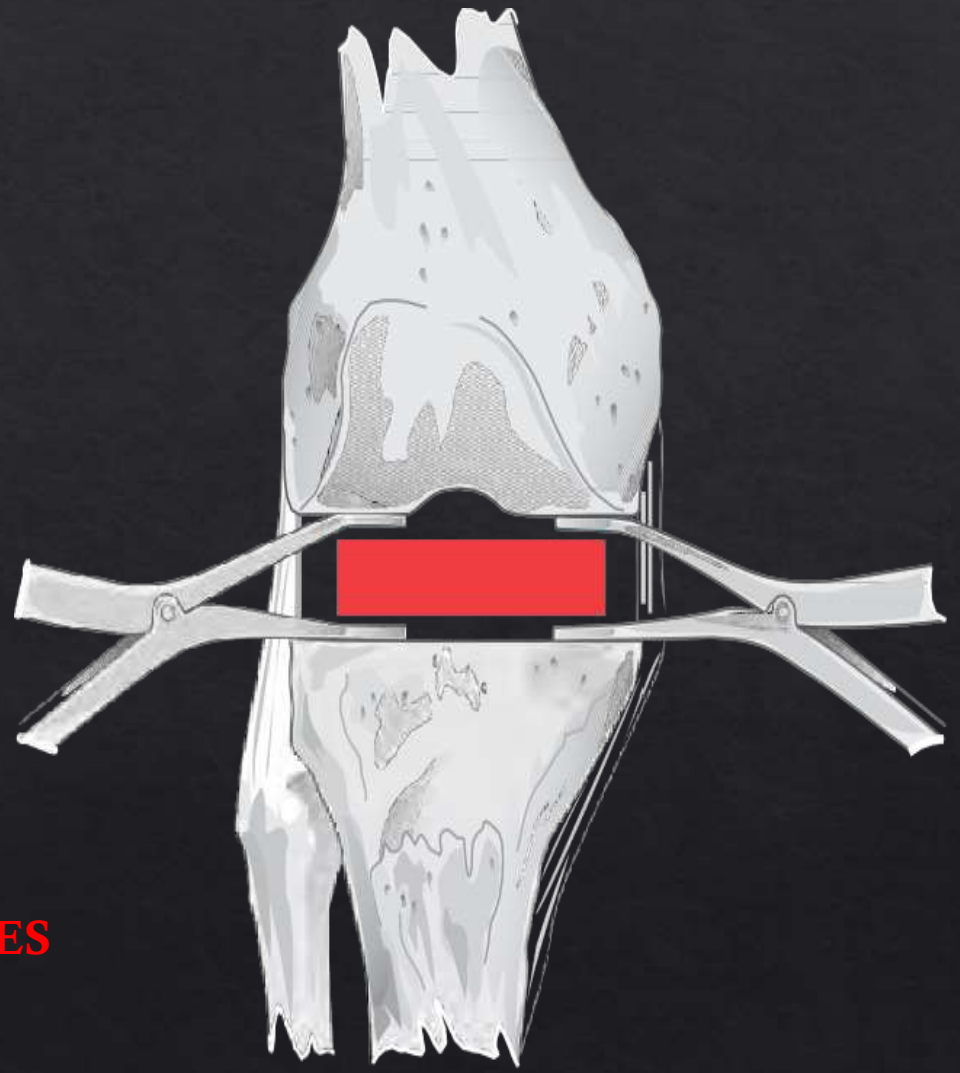




RELEASES

GAP BALANCING





NO RELEASES

APPROACHES

- MECHANICAL ALIGNMENT
- CURRENT PERSONALIZED APPROACHES
  - KINEMATIC
  - INVERSE KINEMATIC
  - RESTRICTED KINEMATIC
  - FUNCTIONAL.

INTRODUCTION

- Restitution Of Pre-arthritic Anatomy
- Kinematic:
  - *Maintaining The Native Femoral Joint Line Obliquity.*
  - The Flexion And Extension Gaps Balanced with extra tibia resection.
- Inverse Kinematic Alignment:
  - *Keep The Native Tibial Joint Line Obliquity.*
  - Gap Balancing Is Performed By Adjusting The Femoral Resections.
- Restricted Kinematic Alignment
  - Compromise.
  - Defined Safe Zone Of Alignment.

FUNCTIONAL ALIGNMENT

- Evolution of kinematic alignment
  - Robotic-assisted system
  - Releases, and/or implant positioning, manipulating alignment, bone resections, soft tissue releases
  - Optimize TKA function
- Patient's specific alignment
- Personalizing alignment
  - Restore native knee kinematics
- A long-term follow-up remains crucial

1. MECHANICAL ALIGNMENT

- 90° to the tibial and femoral mechanical axis
- Equalizing load
- Decrease wear and loosening
- Good long-term implant survival
- Functional outcomes are inconsistent.

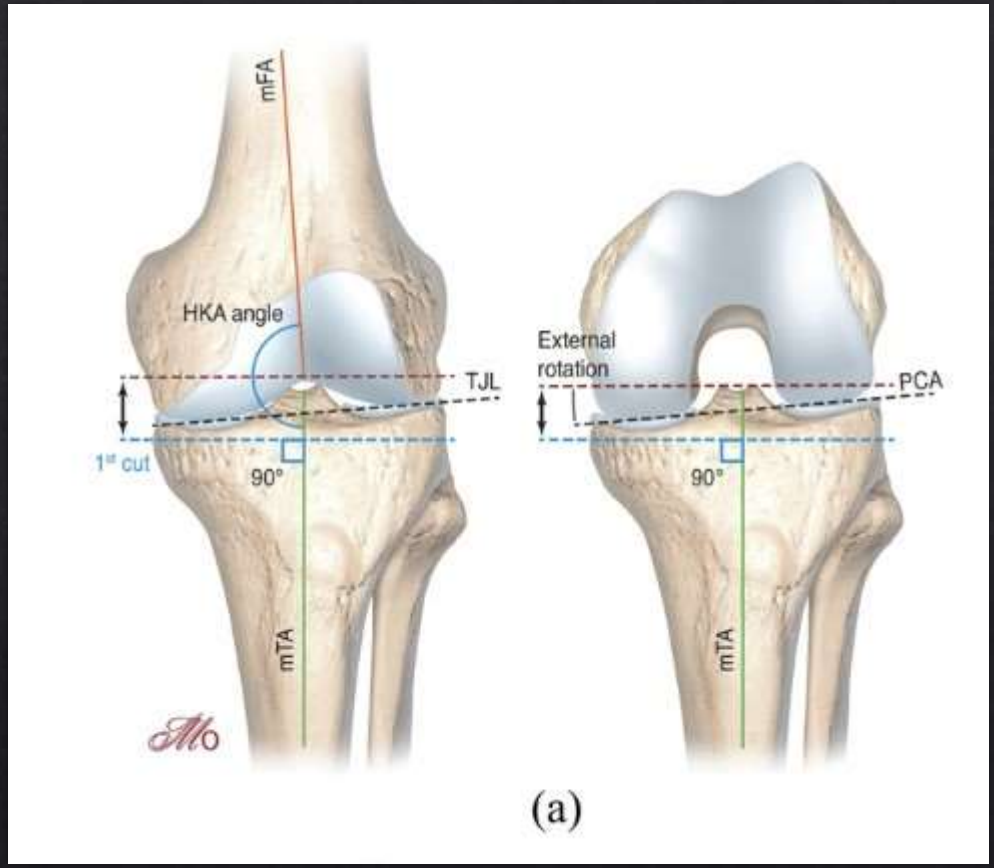
MECHANICAL ALIGNMENT

- Mean hip knee ankle angle (HKA) ranged from 176.7 to 180.7°
- Majority of studies : no neutral native limb alignment of 180°
- Raises the question of a limb alignment of 180° is “normal”

MECHANICAL ALIGNMENT

- Hess et al.
  - Reviewed femorotibial alignment in osteoarthritic knees and concluded there were a large variation in overall coronal limb alignment as well as isolated tibial and femoral coronal alignment
- Bellemans et al.
  - In an asymptomatic Cohort of 250 adults described a neutral alignment as 180° ± 3°, constitutional varus inferior to 177°, and constitutional valgus superior to 183°
- Hirschmann et al.
  - In more recent studies further classified the HKA alignment to include the femoral and the tibial mechanical angles FMA and TMA, respectively
  - This classification is more useful and is an explanation of how current concepts of alignment variations in both femoral and tibial cuts will affect the final alignment.

MECHANICAL ALIGNMENT,



2. PERSONALISED ALIGNMENTS

- Concept of MA was questioned in the 1980 s
- Anatomical alignment was described by Krackow and Hungerford
- Aim to improve functionality by closer reproducing the native knee alignment

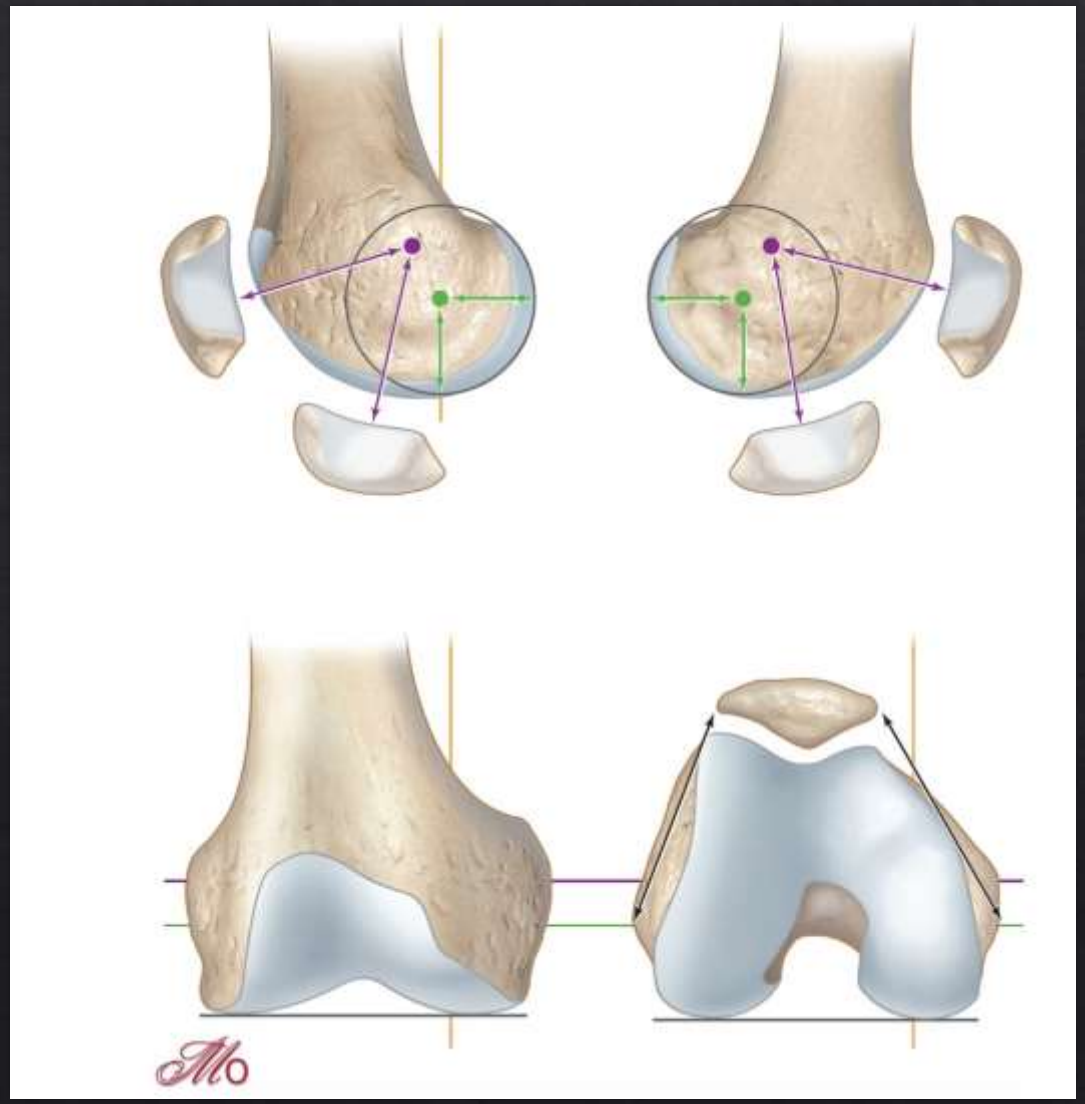
2A. KINEMATIC ALIGNMENT PRINCIPLES

- Howell et al. In 2006
  - “Individualized” / patient-specific technique
  - Restitution of the pre-arthritic anatomy and
  - Preservation of the soft-tissue envelope.

- Three kinematic axis with respect to the joint lines of the posterior and distal femur
  - One transverse axis in the femur about which the tibia extends and flexes,
  - One about which the patella extends and flexes and
  - One longitudinal axis about which the tibia externally and internally rotates on the femur.

- All three axes are either parallel or perpendicular to the joint lines

The femoral transverse axis about which the tibia extends and flexes is the most distal and posterior (green line). The femoral transverse axis about which the patella extends and flexes is more proximal and anterior (violet line). The longitudinal axis about which the tibia externally and internally rotates on the femur passes through the medial femorotibial compartment (yellow line). All three axes are either perpendicular or parallel to the joint lines (blackline).



KINEMATIC ALIGNMENT PRINCIPLES

- Co-align the axes and joint lines of implants with
  - *Three "kinematic" axes*
  - Joint lines of the native joint.

- Resurfaces the femur
- Maintain pre-arthritic *femoral joint line obliquity*
- Adjusts the extension and flexion gaps with the resection of the proximal tibia.
- Complex algorithms to balance the extension and flexion gaps
- More oblique tibial varus resections
- Increased medial tibial cut compared to MA.

KINEMATIC ALIGNMENT PRINCIPLES

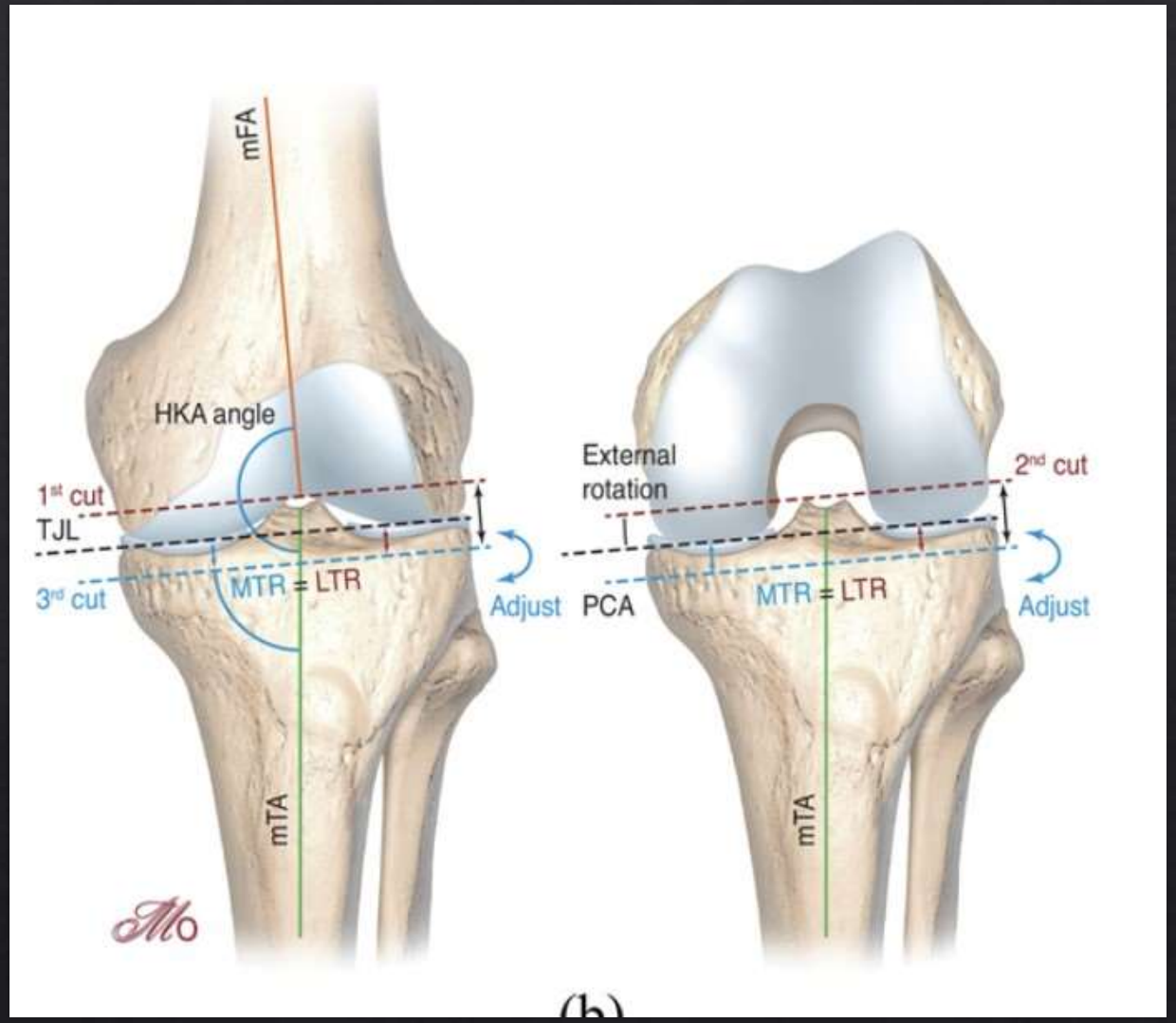
- Caliper measures
- Restores pre-arthritic ligament lengthening
- Does not create gap imbalance
- *Minimal or NO release*
- KA requires an accurate surgical technique

- Performed by multiple methods:
  - Conventional instrumentation
  - Computer navigation
  - Personalized instruments
  - Robotic-assisted

KINEMATIC ALIGNMENT SURGICAL TECHNIQUE

- Measured resection technique ??
- Femur first
  - Estimate the individual physiological knee laxity throughout the range of motion of the knee and the amount of bone loss.
- First cut is the distal femoral cut
  - Parallel to the joint line
  - Correcting for the estimated bone loss.
- Posterior femoral cut is then performed parallel to the posterior condylar plane
  - Usually no wear posteriorly ??
- Cuts the tibia parallel to the joint line.

KINEMATIC ALIGNMENT



TIPS

- Always measure each bone resection with a caliper
- Adjust:
  - 1 mm saw thickness
  - Cartilage thickness approx 2 mm
- During the trials soft-tissue imbalance
  - Proximal tibia should be recut to compensate
- Summary:
  - Ligament balancing is performed by the bone cuts and adjusted as required by the tibial cut
- Two important limitations
  - Led to the development of restricted KA and inverse KA

RESULTS

- Sappey-marinier et al
  - Systematic review of the clinical and radiological outcomes
  - 2years of follow-up
  - Four of five prospective randomized controlled trial studies did not find any difference for all scores
  - One study reported that kinematically aligned tka had significantly better scores for a range of motion, function, pain than those who underwent mechanically aligned tka [30].

- Young et al
  - Found no difference between kinematic alignment (n = 49) and mechanical alignment (n = 50) in oxford knee score (OKS) (42 ± 6 and 41 ± 6, respectively) at 2-years follow-up.
- Dossett et al
  - Revealed a significant difference (p = 0.005) with KA outcomes (n = 44) greater than MA (n = 44) in OKS (40 ± 10.2 and 33 ± 11.1, resp.)
  - At 2-years follow up. Of note, 90% of knees in the latter study were preoperatively in varus alignment and at 24 months there was no differences concerning the complication and revision rates, postoperative gait analysis, and tibial component migration.

RESULTS

- Shelton et al.
  - Kinematically aligned one and contralateral ma tka
  - 83% of patients were satisfied with the mechanically aligned tka when they were treated with the kinematically aligned tka and 92% were satisfied with the ka tka at the last follow-up.
  - The median forgotten joint score (fjs) for ka tka was higher than ma tka by a significant difference of 15 points ($p = 0.006$).
  - 56% favored the ka tka, 8% favored the mechanically aligned tka, and 36% rated both knees the same ($p < 0.001$).
  - 74% of patients favored the recovery of the kinematically aligned tka, 6% favored the recovery of the mechanically aligned TKA

- Howell et al.
  - Implant survival of 220 (unrestricted) ka tka at 10 years of follow-up of 97.5% for revision for any reason
  - 98.4% for aseptic failure
  - Tibial implant loosening occurred in 1 patient, with a reverse tibial slope.
  - Using ma criteria, the percentage postoperatively aligned in the varus (valgus) outlier range (>3°) was 78% (0%) for the tibial implant, 31% 220 (5%) for the femoral implant knee, and 7% (21%) for the hka (unknown mean varus).

2B) INVERSE KINEMATIC ALIGNMENT PRINCIPLES

- Two difficulties can occur if a tibial recut
  - Firstly, sacrifice medial tibial bone stock.
    - Increased tibial resection depth
    - Significantly greater laxity in valgus between 30 and 90° of flexion,
    - Particularly with a tibial resection ≥ 14 mm
    - Jeopardize the medial collateral ligament
    - Could complicate TKA revision if required
  - Second difficulty concerns gap balancing
    - Majority of “standard” cases the difference between gaps is small.
    - Complex cases where the recut may be asymmetrical, it could lead to laxity.

INVERSE KINEMATIC ALIGNMENT PRINCIPLES

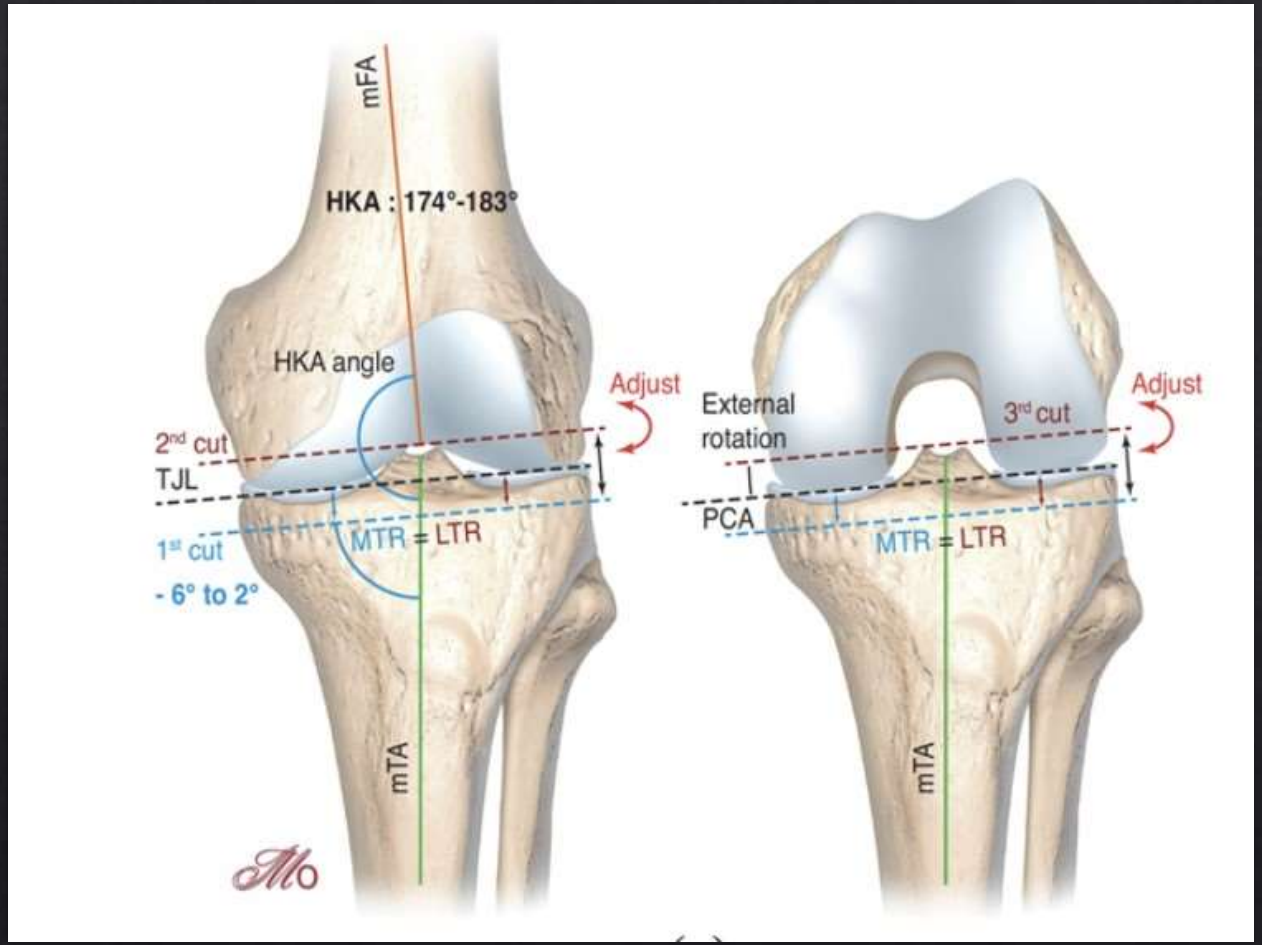
- “Resurface” the tibia maintaining the pre-articular tibial joint line obliquity
- Gap balancing is then performed by adjusting the femoral posterior and distal resections
- Avoid tibial over resection and tibia-related complications
- Manage independently the flexion and extension gaps

- Difficult with conventional instrumentation
- Patient-specific guides is challenging
- Robotic-assisted system enables intraoperative planning of bone resections and gap balancing before the cuts.

SURGICAL TECHNIQUE

- Winnock de Grave et al.
- Robotic-assisted system
- Resection of equal amounts of bone lateral and medial on the tibia
- Correcting for bone wear.
- Restore the native medial proximal tibial angle, within a safe zone of 84–92
- Tibial slope pre-arthritic medial tibial slope.
- Femoral implant is positioned to restore the medial joint line height both in flexion and extension
- The extension and flexion gaps are balanced by adjusting the posterior and distal femoral resection levels.
  - Flexion gap, residual laxity of 1–3 mm in the lateral compartment
  - 1–2 mm in the medial compartment.
  - Extension gap residual laxity of 1–2 mm in the two compartments.
  - Target HKA angle=safe zone between 174 and 183°.
  - Readjustment cuts a second time difficult with a conventional resection guide.
- The robotic-assisted system estimates gap balancing

INVERSE KINEMATIC ALIGNMENT



RESULTS

- Winnock de Grave et al.:
  - No significant difference in clinical results at 12 months between inverse KA and adjusted MA
  - Higher rate of satisfaction and significant improvement in postoperative OKS for restricted inverse KA, compared to adjusted MA.
  - Preoperative varus deformity improved functional score and satisfaction
  - No complication or revision was reported in both groups in the short term.
  - Early results require further studies with increased patients and longer follow-up.

2C) RESTRICTED KINEMATIC ALIGNMENT PRINCIPLES

- KA without restriction controversial
  - Increased stress on the implants as the knee deformity increases and alignment deviates from MA increasing the risk of aseptic loosening

- Nakamura et al.
  - KA increases the contact stress on the tibial insert, medial tibial cortex, and bone resection surface. For moderate (10°) and severe (15°) varus knees, the maximum stress in kinematically aligned TKA increased by 24.8 and 32.2%, compared with mechanically aligned TKA.

- Vendittoli recommended “safe zones” for TKA alignment.
- Restricted KA protocol
- Hybrid option between MA and KA
- “Safe range” :
  - Within ± 5° of the mechanical axis
  - HKA angle must fall within ± 3° of neutral.

SURGICAL TECHNIQUE

- There are two situations:
- Tibial and femoral mechanical axis are inferior or equal to 5°, or superior to 5°.
- In the first case with femoral and tibial axis inferior to 5°, if the femorotibial axis (hka angle) is equal or inferior to 3°, the surgeon can perform the tka with a ka technique. If the femorotibial axis is superior to 3° of varus, the tibial varus will be reduced until the HKA is equal to 3° of varus. If the femorotibial axis is superior to 3° of valgus, the tibial varus will be reduced until the HKA is equal to 3° of valgus.

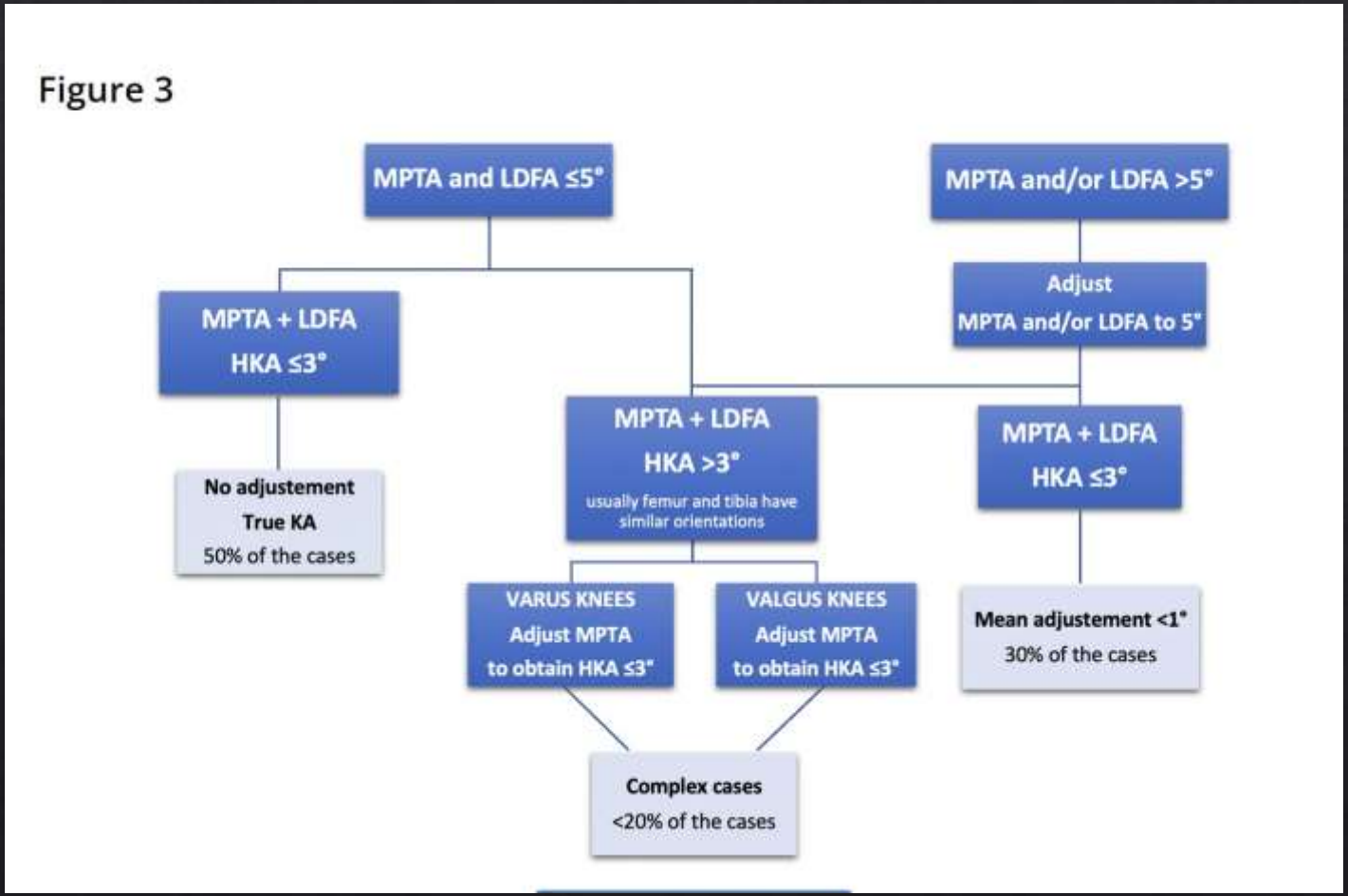
- In cases where the femoral and tibial axis is superior to 5°, the surgeon will correct the tibial and/or the femoral bone cuts to stay within the 5° limit. This will correct the overall HKA to within ± 3° of neutral. If the patient maintains an HKA superior to 3°, the surgeon will further adjust the tibial cut as in the first situation.

- We prefer to modify the tibia to preserve as much as possible the native femoral anatomy and the flexion axis, as in the ka technique. Releases of the ligaments are not needed in cases with anatomic modifications inferior to 3°. In larger corrections, minimal releases can be added (to a much lesser degree compared to MA).

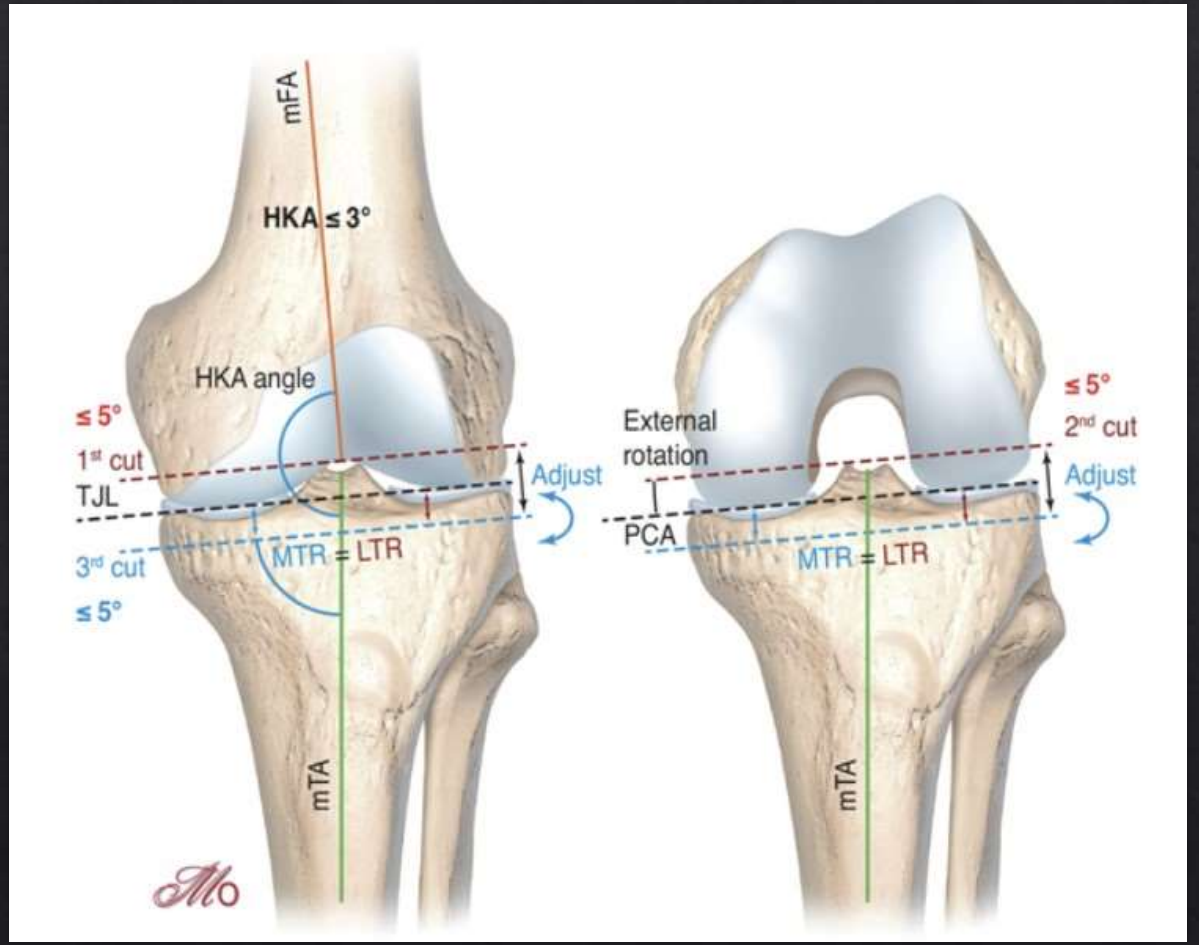
- As with the unrestricted ka technique, it is important to measure the bone resections after each cut. Computer navigation and robotic-assisted systems facilitate intraoperative operative adjustment in complex cases.

RESTRICTED KINEMATIC ALIGNMENT PROTOCOL.

Figure 3



RESTRICTED KINEMATIC ALIGNMENT,



RESULTS

- Almaawi et al. reported 2475 TKA cases
  - 49% required restricted KA TKA and 51% unrestricted KA TKA

- Blakeney et al. simulated the extension and flexion gaps on 1000 lower limb CT scan according to the restricted KA or MA protocols. An “imbalance” was defined as a difference between lateral and medial gaps. In extension, there were significantly fewer cases having an imbalance ≥ 3 mm with restricted KA (8.3%) versus MA (33%), and ≥ 5 mm with restricted KA (1.5%) versus MA (11%). With restricted KA, the percentage of knees with space imbalances inferior to 3 mm in both flexion and extension was 92% versus 63% with MA with posterior condylar reference and 49% with MA with trans epicondylar reference.

- MacDessi et al. have reported encouraging results after TKA with restricted kinematic alignment in a randomized controlled trial. They found that the mean intraoperative intercompartmental pressure difference at 10° of flexion in the kinematic group was significantly lower than in the mechanical group, using an interoperative pressure sensor. Overall, participants in the kinematic group were more likely to obtain optimal knee balance (80% vs. 35%).

- Currently, no study has assessed the mid- or long-term clinical outcomes after restricted KA TKA.

2D) FUNCTIONAL ALIGNMENT PRINCIPLES

- Functional alignment has similar aims and was developed for similar reasons as KA
- It constitutes an evolution and increased precision of the KA concept
- Patient-specific implants and 3D printed cutting blocks were used pre-operatively to achieve KA in total knee arthroplasty.
- Functional alignment is obtained by manipulating alignment, bone resections, fine-tuning component positioning, and/or soft tissue releases at the surgeon's discretion intraoperatively with robotic-assisted systems to achieve balanced extension-flexion gaps and soft tissue tension while maintaining the patient's native alignment
- These new and constantly improving technologies enable quantifiable measurement and precision adjustment of femoral and tibial cuts, implant positioning, or tissue release in three planes, of one or two degrees, to obtain optimal functional alignment
- The precision offered by robotic assistance may make achieving non-neutral alignment targets more reproducible reducing the risk of missing the target and producing significant outliers of the limb alignment. Theoretically, functional TKA reduces the need for periarticular soft-tissue releases if not desired by the surgeon while restoring the patient's native knee kinematics

SURGICAL TECHNIQUE

- Planning preoperatively on a 3D
- Completed during the surgery prior to bone cuts.
- Once the bone cuts have been made and the trial is in place the robotic system, soft tissue sensor or surgeon may discover a soft tissue imbalance.
- Adjustments can then be assessed with software 3D manipulation virtually and then recut guidance or releases performed with the robotic-assisted system if indicated.

- Aim of functional alignment:
  - To position the implants in the position that least compromises the knee ligaments envelope in 3D
  - Hence to restore the obliquity and plane of the joint to that which the ligaments dictate.
  - If the deformities are fixed, the soft-tissues release is required to balance the gaps, although the extent and frequency of such releases are smaller when compared with the MA technique.

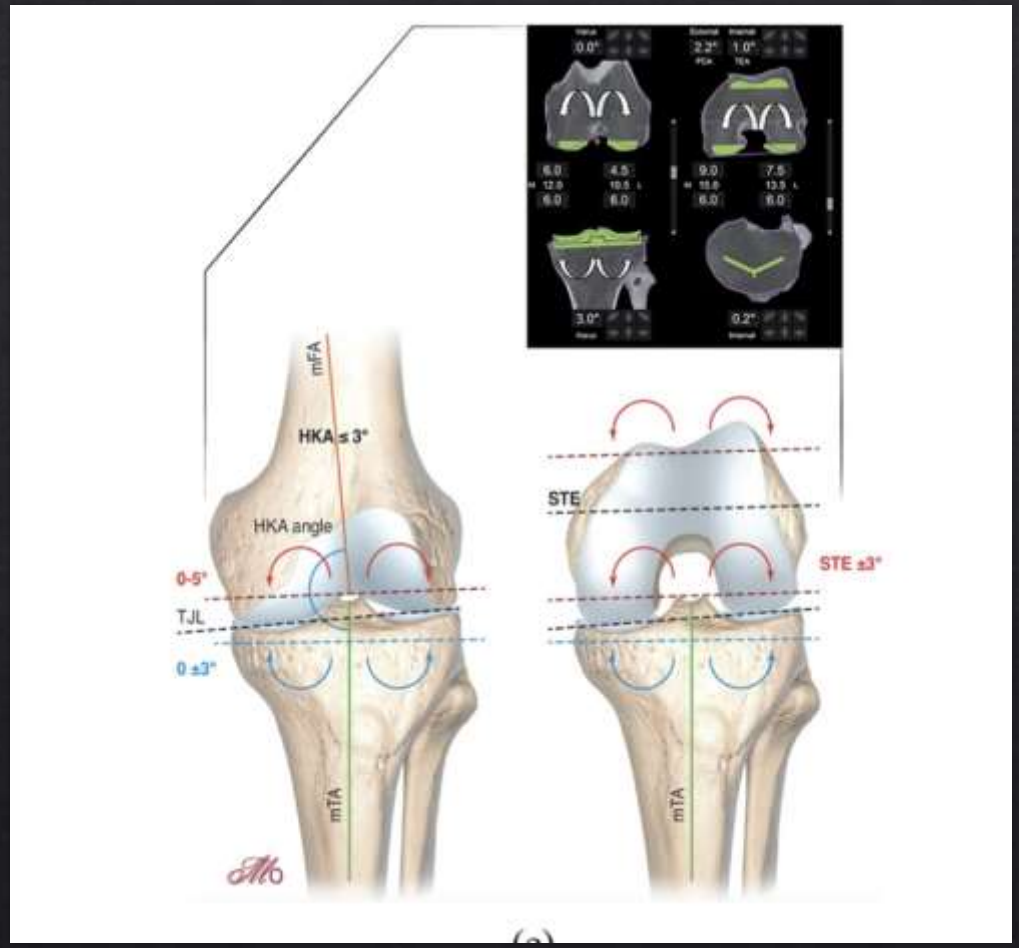
SURGICAL TECHNIQUE

- Femoral component
  - Coronal plane, positioning is modified from a starting point of 0° to the mechanical axis to balance the extension gap.
  - Sagittal plane, the femoral component is positioned to optimize the component sizing and to avoid femoral notch by flexing up to 5°.
  - Axial plane, the femoral implant is aligned to the transepicondylar axis with 3° of freedom to balance the flexion gap.
  - The size of the femoral component is selected using posterior referencing with the smallest size that does not overhang the femur, notch the anterior femur, or overhang mediolateral bone edges, and avoids overstuffing the patellofemoral joint.
  - The femoral component is positioned at the center of the mediolateral cortical bone edges, with a small lateral position if necessary.

SURGICAL TECHNIQUE

- Tibial Component:
  - Coronal plane the tibial component position is aligned to the tibial mechanical axis and modified to balance extension and flexion gaps by up to 3° of varus.
  - Valgus tibial position should be avoided.
  - Sagittal plane, the tibial component position is set to match the patient's pre-arthritic posterior tibial slope, modified to balance the flexion gap if necessary.
  - Axial plane, the tibial component is positioned using the line of Akagi.

FUNCTIONAL ALIGNMENT



RESULTS

- Several studies assessed the accuracy and the reproducibility of robotic-assisted surgery
- Sires and Wilson performed CT scans postoperatively to assess the precision of the image-based robotic-assisted TKA and found that 93% of the surgical measurements were ≤ 3° of the CT measures postoperatively.
- The use of preoperative CT scanning and the planning accuracy of robotic-assisted TKA resulted in well-balanced knees.
- Nevertheless, no study has assessed the functional and clinical outcomes of this alignment technique, nor the implant survivorship.

CONCLUSION

- Several concepts and evolving surgical techniques continue to develop personalized alignment in TKA.
- Personalized alignment aims to restore native knee alignment and improve functional outcomes after TKA.
- New technologies have increased the ability to restore native knee kinematics with TKA.
- A long-term follow-up is crucial to determine clinical outcomes and implant survivorship of these current alignment concepts.

THANKS GN