Estimating edge-loading risk in patients with metal-on-metal hip resurfacing

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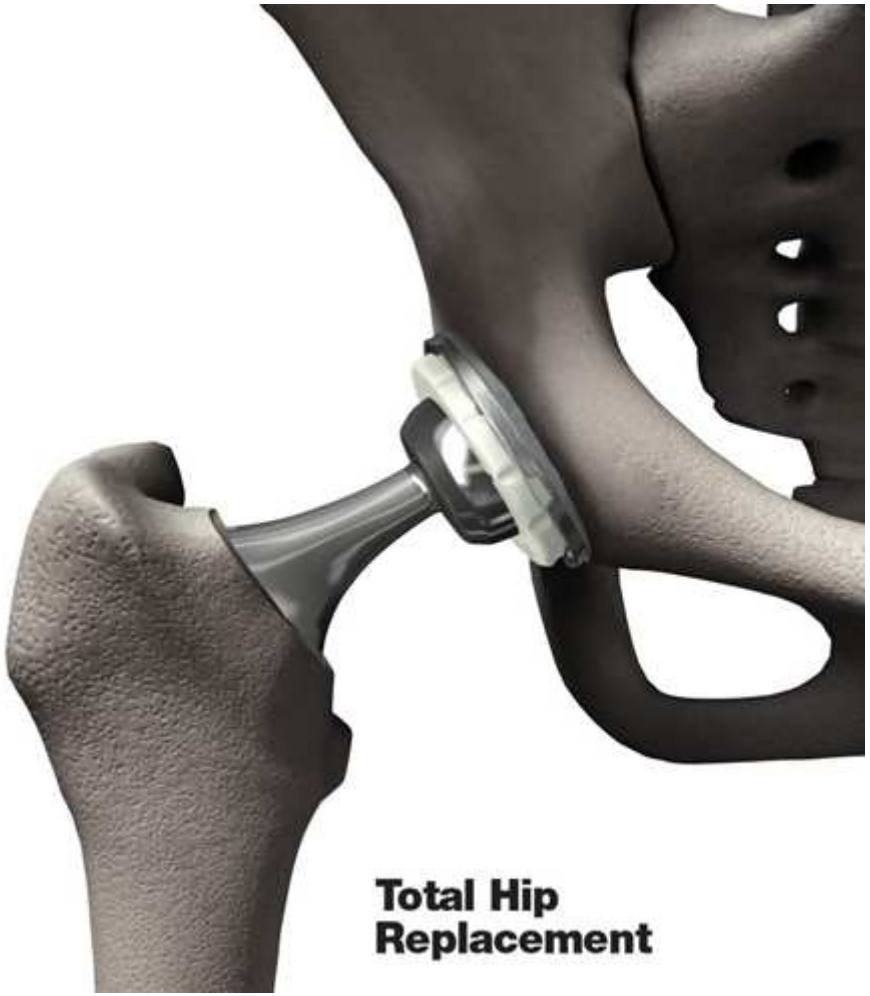
Total Hip Replacement (THR)

- THR is most often carried out to treat advanced osteoarthritis

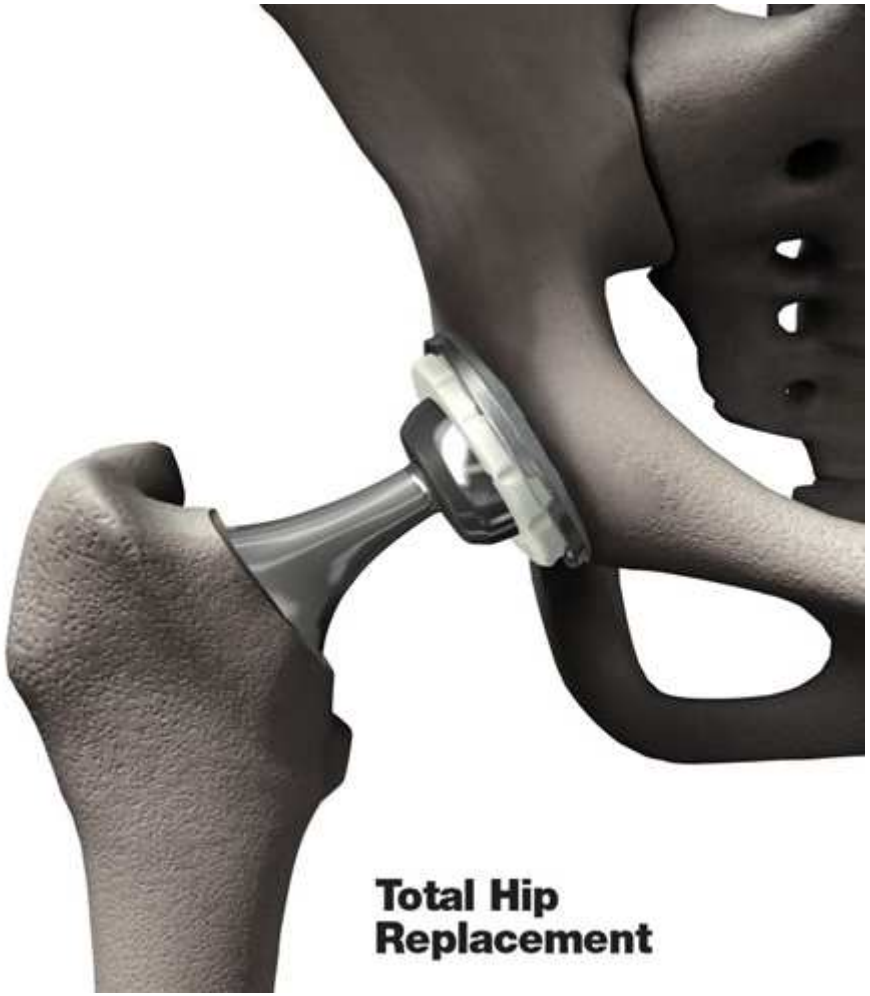
- Majority of patients receive a replacement with a metal-on-polyethylene bearing



Total Hip Replacement (THR)

- In England and Wales, the mean age of patients undergoing THR is 67 years

- However, ~8000 operations (12%) each year on people younger < 55 years



Total Hip Replacement (THR)

- Patients > 55 yrs, THR provides:
  - effective pain relief
  - restored function
  - excellent implant survival
- Patients < 55 yrs, THR provides:
  - pain relief
  - functional improvement
  - **However, only approx. 65% of implants last 17 years (Swedish Arthroplasty Registry)**

Total Hip Replacement (THR)

- Aseptic loosening, due to wear, is the most common mode of failure for THR
- Articulation of metal-on-poly generates wear particles of polyethylene with a diameter of 0.3–10 μm
- Immune response to these particles causes resorption of bone around prostheses which leads to loosening - **Osteolysis**

Total Hip Replacement (THR)

- 4% of all THR dislocate
- Early < 6 months after surgery
  - Due to mal-positioned components
- Late
  - Most often a product of bearing wear

Total Hip Replacement (THR)

- Early implant failure is a particular problem in younger patients who are more active and have a longer life expectancy than older patients

- Dislocation remains a risk for conventional THR

THR:Large Heads Hard Bearings

- Desire for alternative bearing surfaces that have lower wear and allow larger head sizes
- Larger heads = reduce risk of dislocation
  - 32mm diameter and above
- Hard bearings – reduce wear
  - Ceramic-on-ceramic (CoC)
  - Metal-on-metal (MoM)

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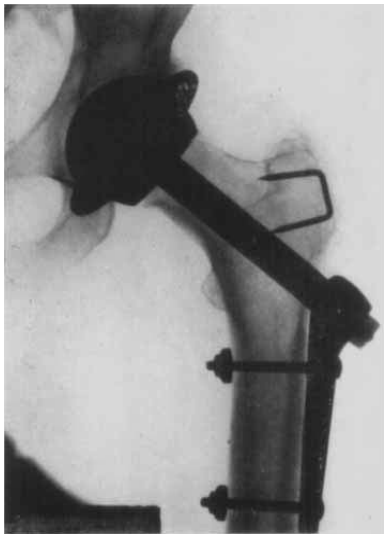
  - **Metal-on-metal (MoM)**

Metal-on-Metal (MoM)

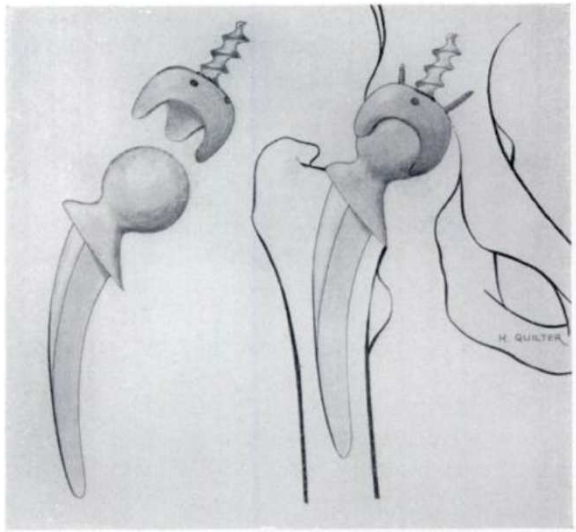
- MoM bearings, made of CoCr alloy, first used for THR in 1938, later re-introduced during the 1950s and 1960s
  - Variable survival results
  - implants that survived exhibited very low wear

~1938



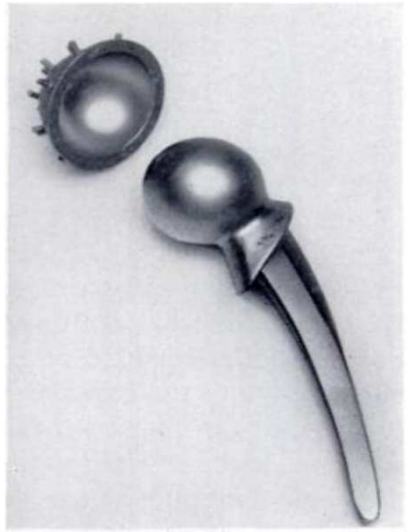
Wiles' "ball-and-cup athroplasty"

~1956



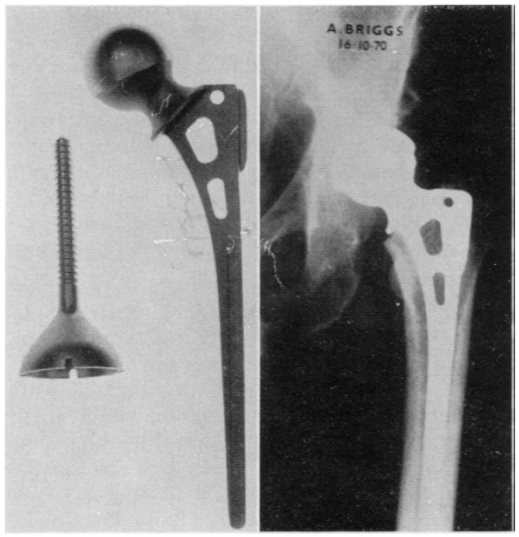
McKee's "three-claw" cup with Thompson stem

~1960



McKee's cemented cup

~1964

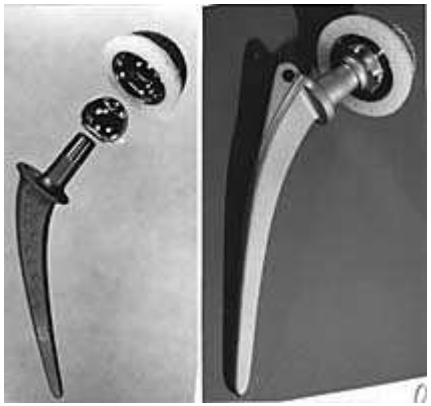


Ring's design with cementless cup

Metal-on-Metal (MoM)

- MoM bearings, made of CoCr alloy, first used for THR in 1938, later re-introduced during the 1950s and 1960s
  - Variable survival results
  - implants that survived exhibited very low wear

- The “second generation” of MoM articulation devices was introduced in the early 1990s - MoM prostheses with a conventional THA head diameter (28–32 mm)
  - exhibited good survival and low wear



Metasul 2nd generation MoM

Metal-on-Metal (MoM)

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  - Variable survival results
  - implants that survived exhibited very low wear
- The “second generation” of MoM articulation devices was introduced in the early 1990s - MoM prostheses with a conventional THA head diameter (28–32 mm)
  - exhibited good survival and low wear
- Introduction of “third-generation” MoM bearings in the 1990s
  - Wear simulator studies showed up to 100 times less wear than MoP bearings

3rd Gen MoM

- Manufactured with larger femoral component diameters (38–64 mm)

MoM THR

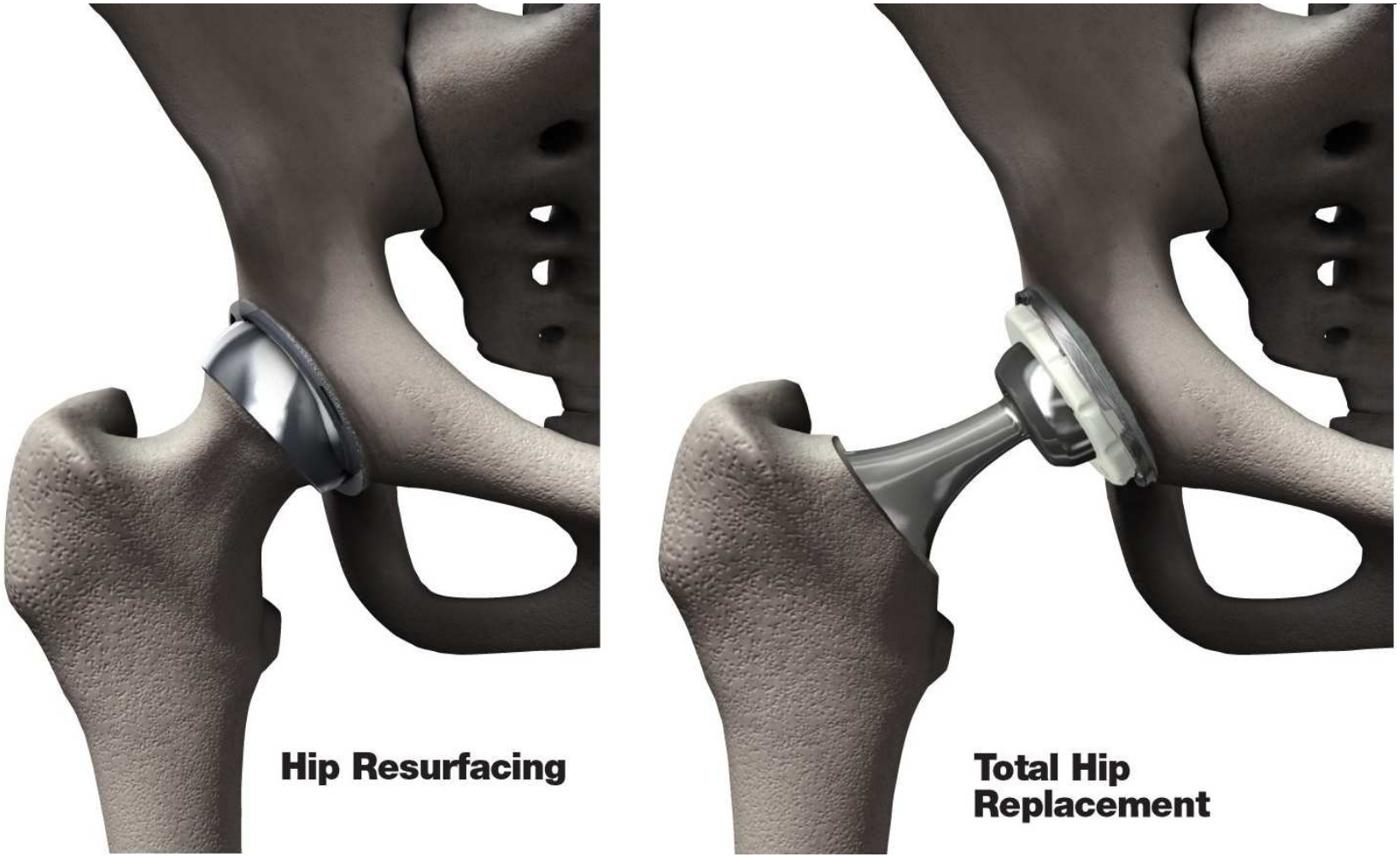
3rd Gen MoM

- Manufactured with larger femoral component diameters (38–64 mm)

MoM Hip Resurfacing

Resurfacing is bone-preserving
i.e. potentially easier to revise to THR

Metal-on-Metal Hip Resurfacing Arthoplasty (MoMHRA)

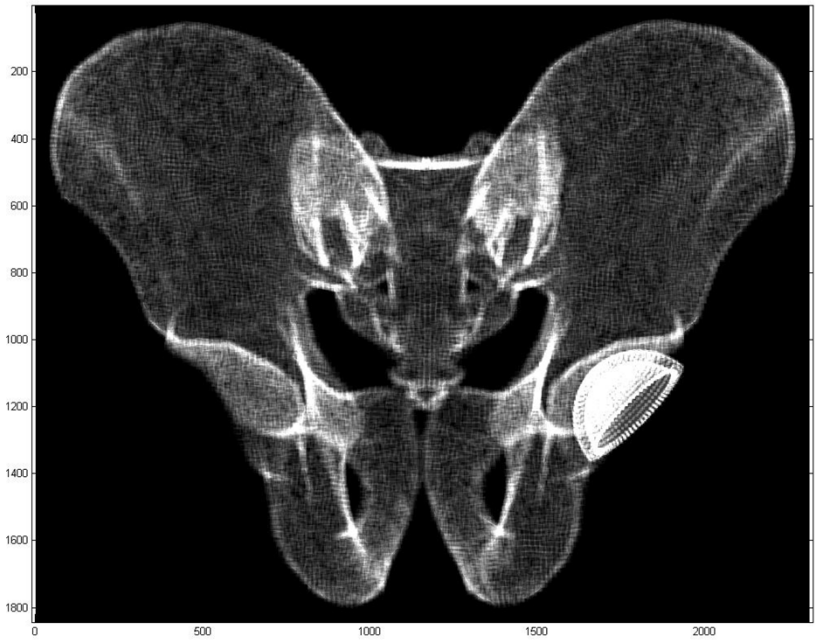


Metal-on-Metal Hip Resurfacing Arthroplasty (MoMHRA)

- 3rd gen MoM bearing surfaces were thought to be ideal for young and active patients:
  - Larger heads - reduced dislocation risk
  - Resurfacing is bone-preserving i.e. potentially easier to revise to THR
  - Low wear

MoMHRA Procedure

- Recommended orientation is 40° inclination and 20° anteversion



MoMHRA Procedure

- Recommended orientation is 40°inclination and 20°anteversion
- Acetabular component is less than hemispherical
  - coverage varies between manufacturers
- Diametrical mismatch between bearing surfaces
  - clearance varies between manufacturers
- All implants are Co-Cr alloys

MoMHRA

- Well functioning MoMHRA wear rates of < 5µm/year

- Under optimal lubrication conditions tribochemical reaction of metallic bearing surfaces with synovial fluid
  - Organic layers formed at bearing surfaces
  - Prevents metal-on-metal contact
  - Limits wear

MoMHRA – Wear & Metal Ions

- Systemic levels of chromium (Cr) and cobalt (Co) ions in whole blood, serum, or urine correlate with the linear and volumetric wear of the femoral component

- Once running-in phase is completed, i.e. ~12 months, systemic Cr and Co concentrations are considered surrogate markers of *in vivo* wear

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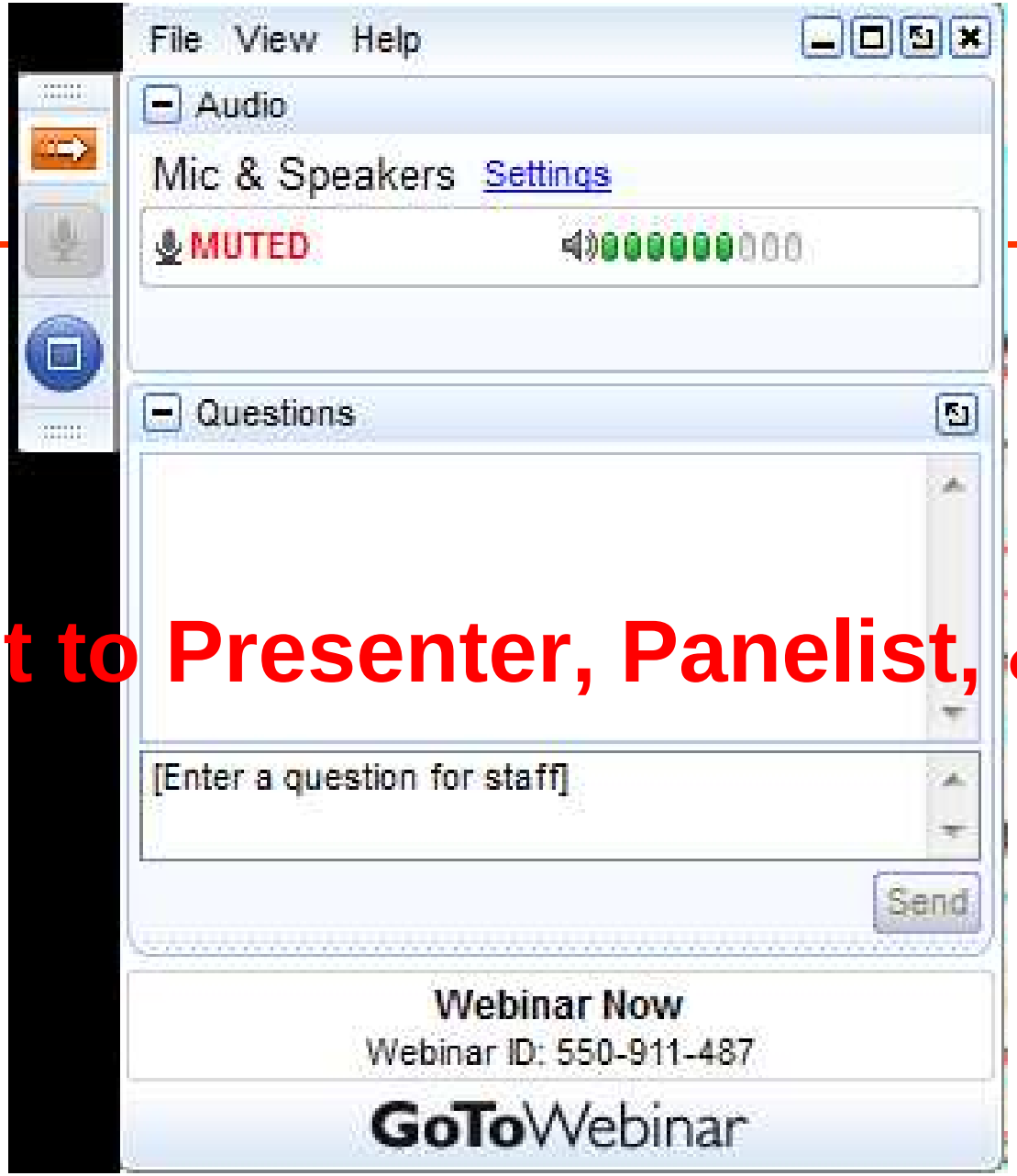

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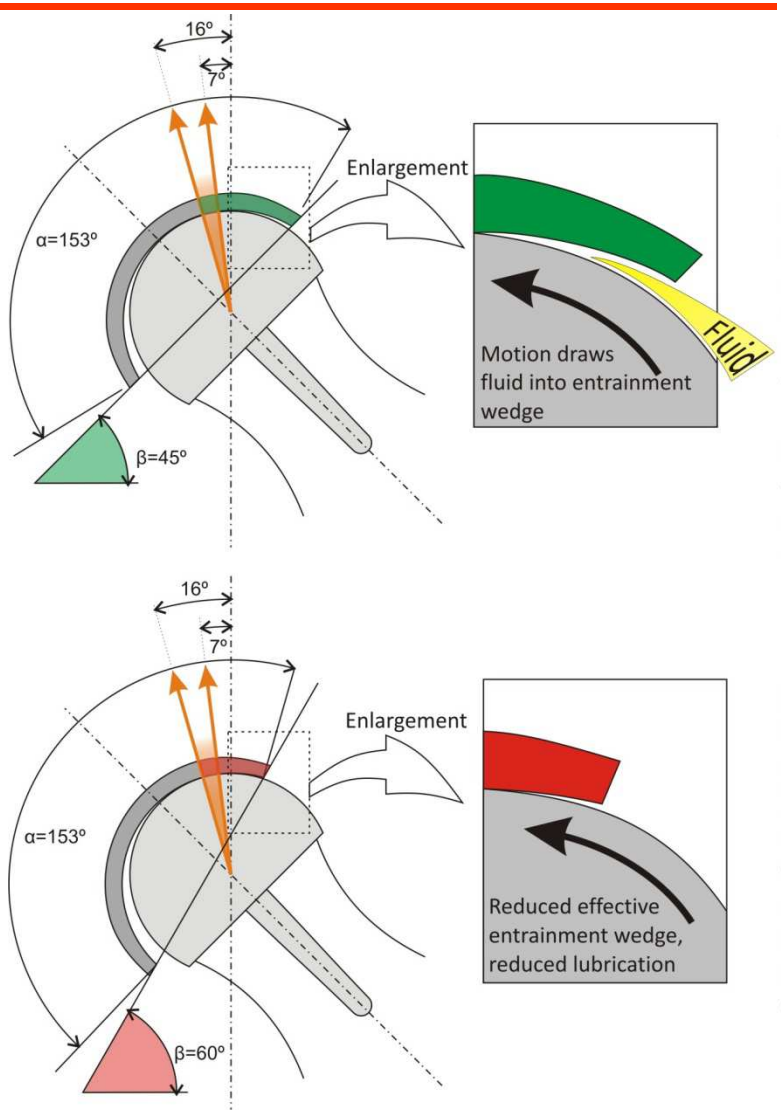
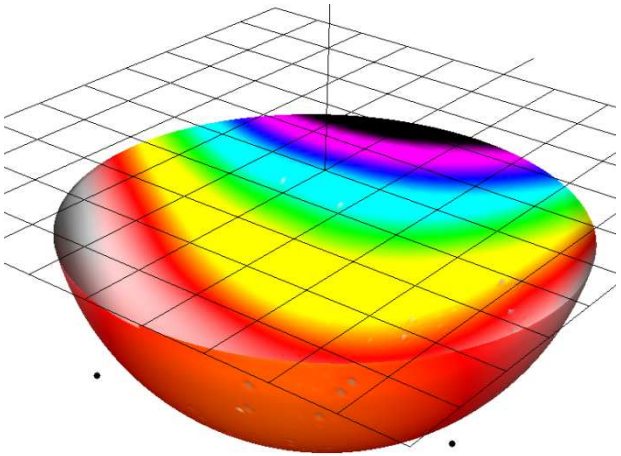
WEAR OF MoMHRA

- Increased wear – Disturbance of fluid film lubrication – Edge loading
- Edge-loading occurs when the hip reaction force passes through the edge of the acetabular component
- Acetabular component orientation is a factor influencing edge-loading risk



WEAR OF MoMHRA

- Increased wear is associated with failure of hip resurfacings and the pseudotumour development
- Increased wear follows disturbance of fluid-film lubrication under edge-loading conditions
- Acetabular component orientation is a factor influencing edge-loading risk



Metal Wear & Soft Tissue Reactions

Soft tissue reactions associated with abnormally high levels of wear to the MoM bearing

- Extensive tissue necrosis
- Bone loss
- Pain

- **Pseudotumours associated with metal-on-metal hip resurfacings.** Pandit *et al.* (2008) JBJS - British Volume, Vol 90-B, Issue 7, 847-851

- **Adverse reaction to metal debris following hip resurfacing: The influence of component type, orientation and volumetric wear.** Langton *et al.* (2011) JBJS – British Volume, Vol 93-B, Issue 2, 164-171

MoMHRA Soft Tissue Reactions

- Pseudotumours can be solid, cystic or mixed in nature
- Various names i.e. cysts, bursae, ALVAL (aseptic lymphocytic vasculitis associated lesions), ARMD (adverse reactions to metal debris), ALTR (adverse local tissue reaction) and pseudotumours
- Regulatory bodies (MHRA & FDA) issued guidance related to the management of MoM patients

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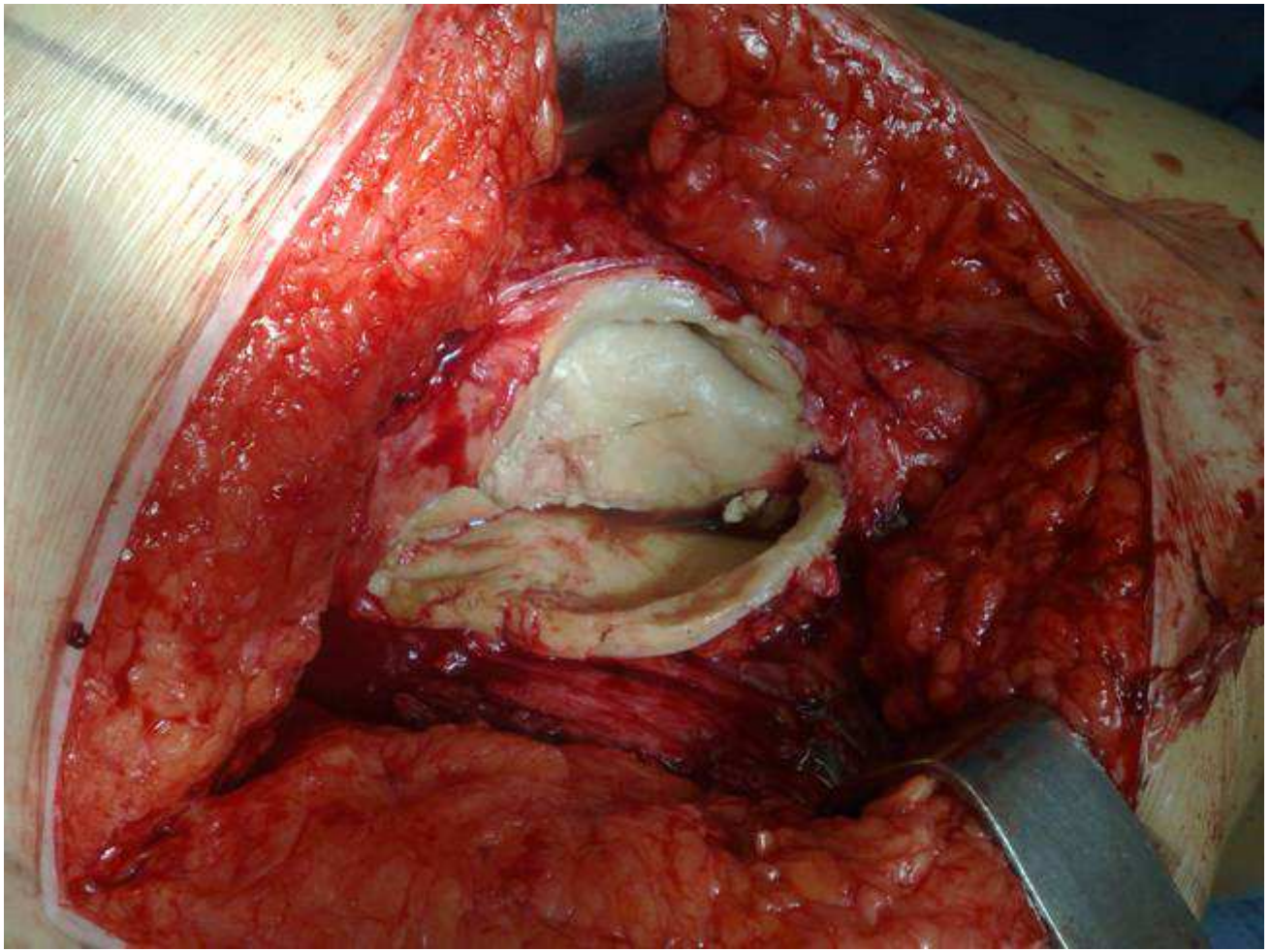
Pseudotumour



Pseudotumour

- Incidence is greater in females with MoM
  - Differences in bone size and native anatomy are thought to be principal factors for this observed difference

MoM in the Media

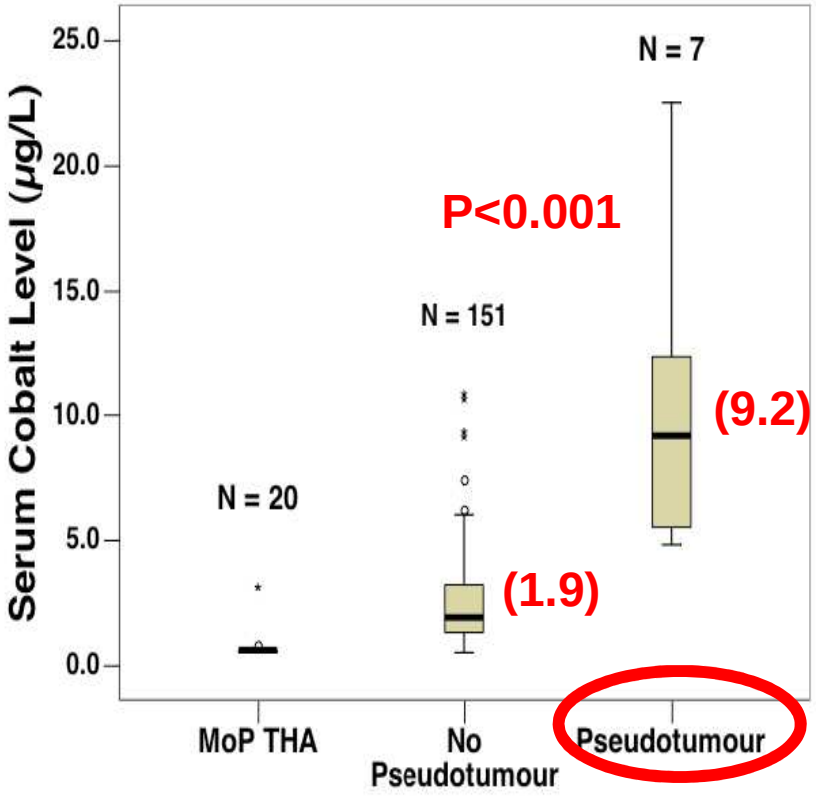
Revision

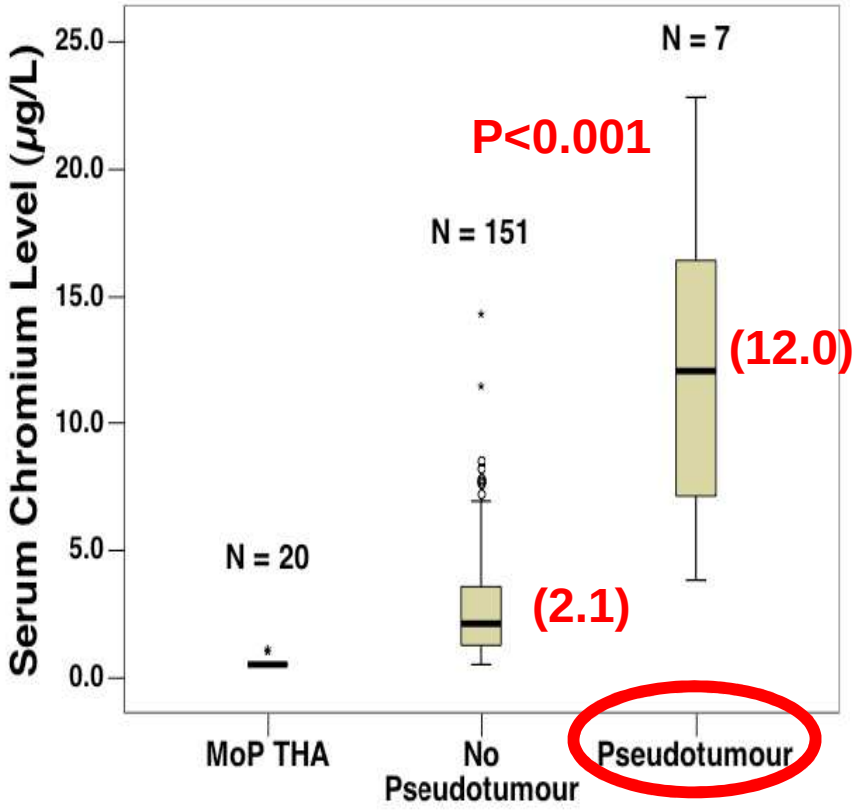
- MoM hips with pseudotumour are most often revised to MoP or CoC THR
- Outcome of revision for pseudotumour is poor
- Revision is more difficult surgery
- Revision is costlier to the healthcare provider

MoM Cohort

- Investigated 201 asymptomatic resurfaced hips:
  - 4.4% prevalence pseudotumour

Serum Metal Ion Levels



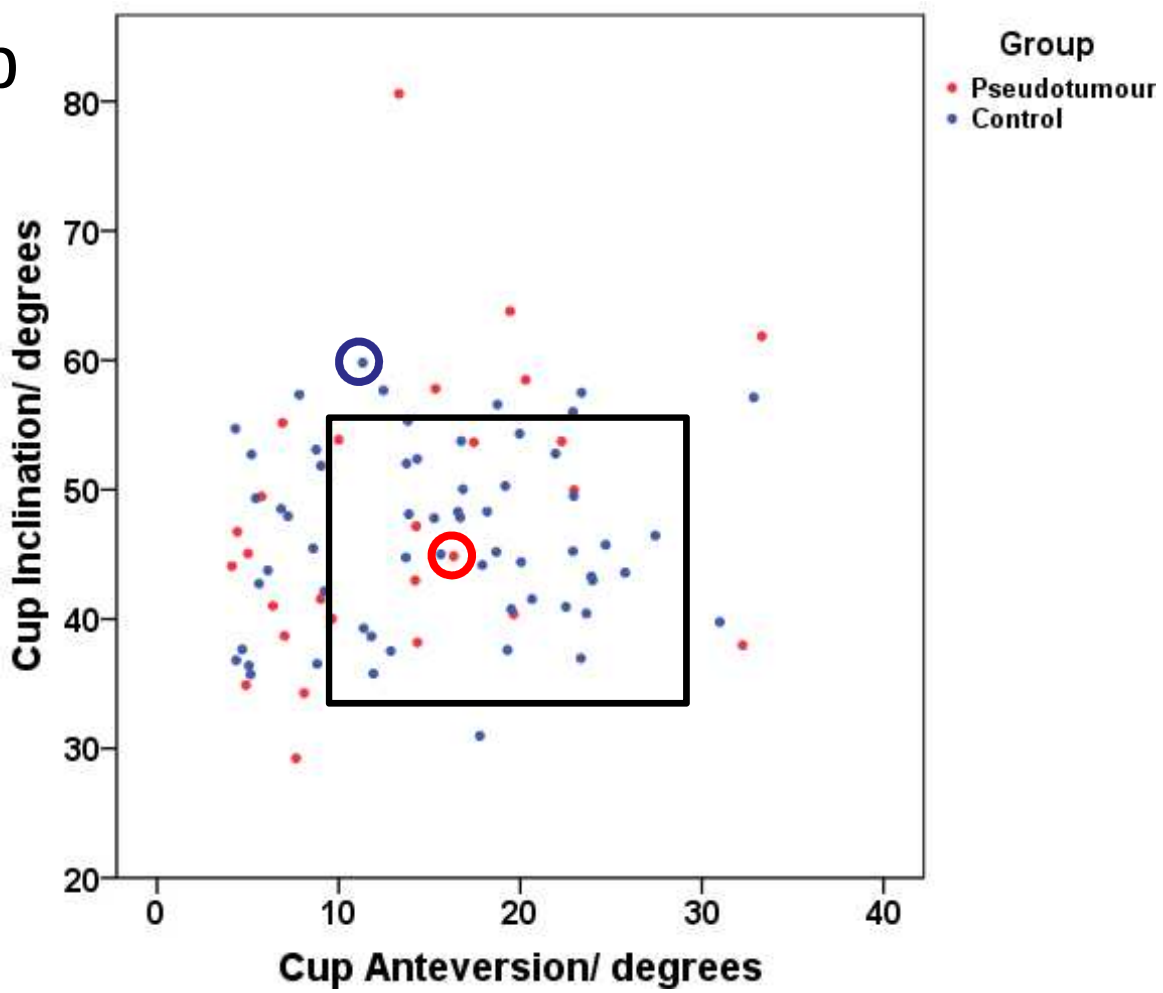


CUP ORIENTATION - PT

- Wide scatter of cup orientations
- Identified an optimum zone that reduced risk by a factor of 4
- Outside zone:

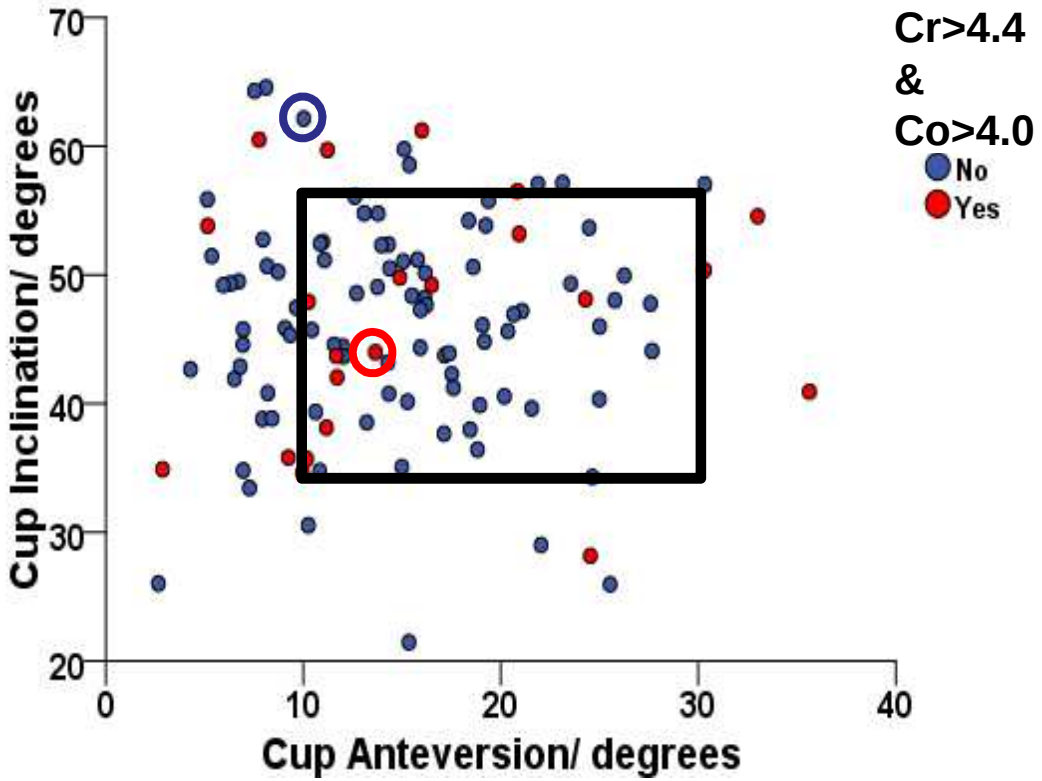
  not all have PT
- Inside zone:

  could have PT



CUP ORIENTATION - IONS

- Metal ions are surrogate markers of wear
- Similar observations:
  - Outsize zone can have low wear
  - Inside zone can have high wear



Metal Wear: Edge-Loading

- Risk of biological reaction is lower for an acetabular orientation of 40°(±10) inclination and 20°(±10) anteversion

However,

- Pseudotumours have been reported in patients with well positioned components

Grammatopoulos *et al.* (2011) JBJS, 93-B, SUPP_II, 223.

WEAR = DYNAMIC PROCESS

ELSEVIER

Journal of Biomechanics 34 (2001) 873–881

JOURNAL OF BIOMECHANICS

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Duration and frequency of every day activities in total hip patients

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[d] *Department of Orthopedic Surgery, General Hospital Barmbek, Hamburg, Germany*

Accepted 22 February 2001

- Sitting: 44%
- Standing: 24%
- Walking:10%
- Stair climbing: 0.5%

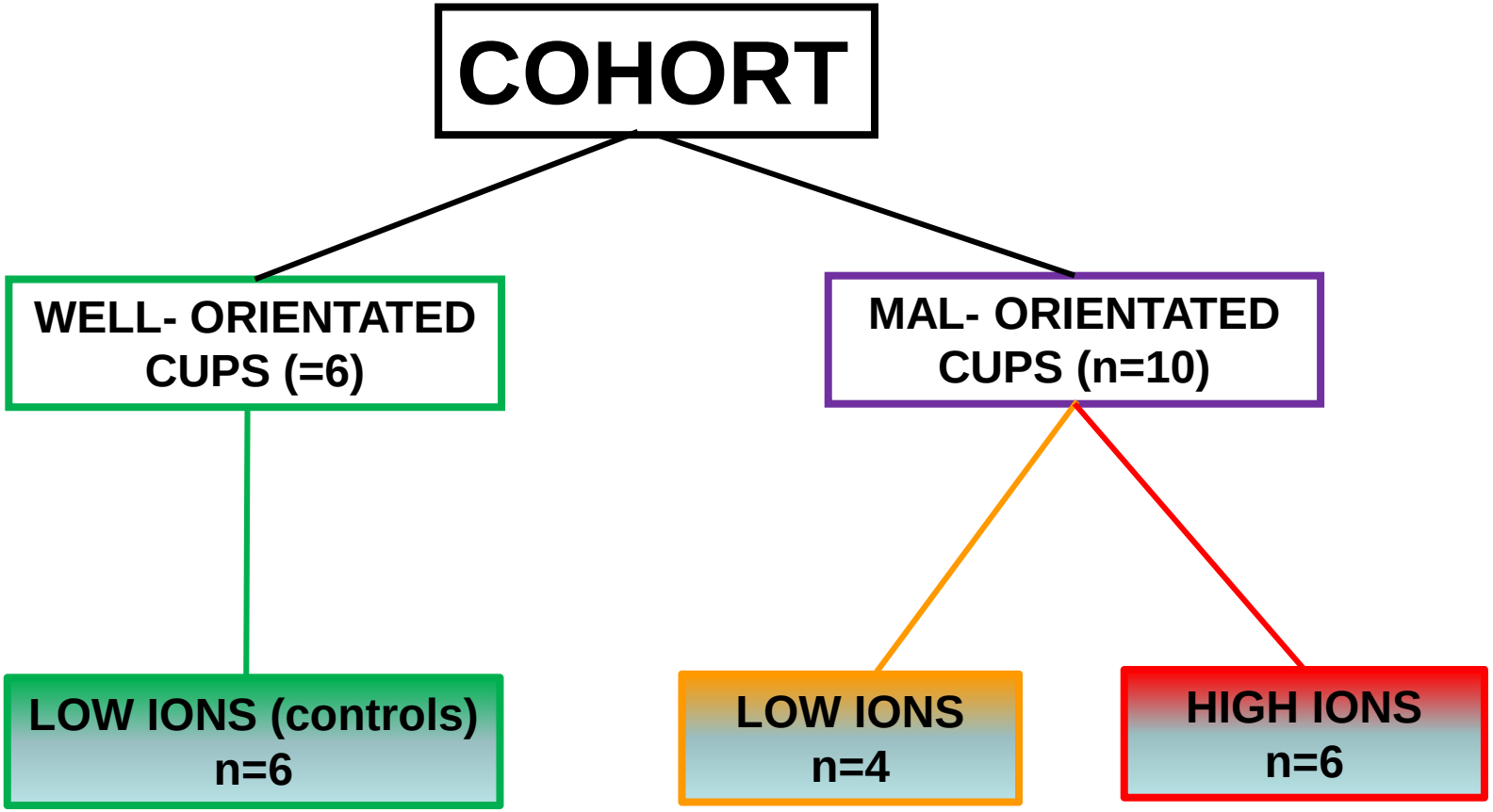
- **Sit to stand (STS) is a frequently occurring action (approximately 50 times per day)**

- **Important transition as hip goes from resting to load bearing state**

Research Question

- **Do individual activity patterns during activities of daily living insulate some patients from the risk of edge-loading?**

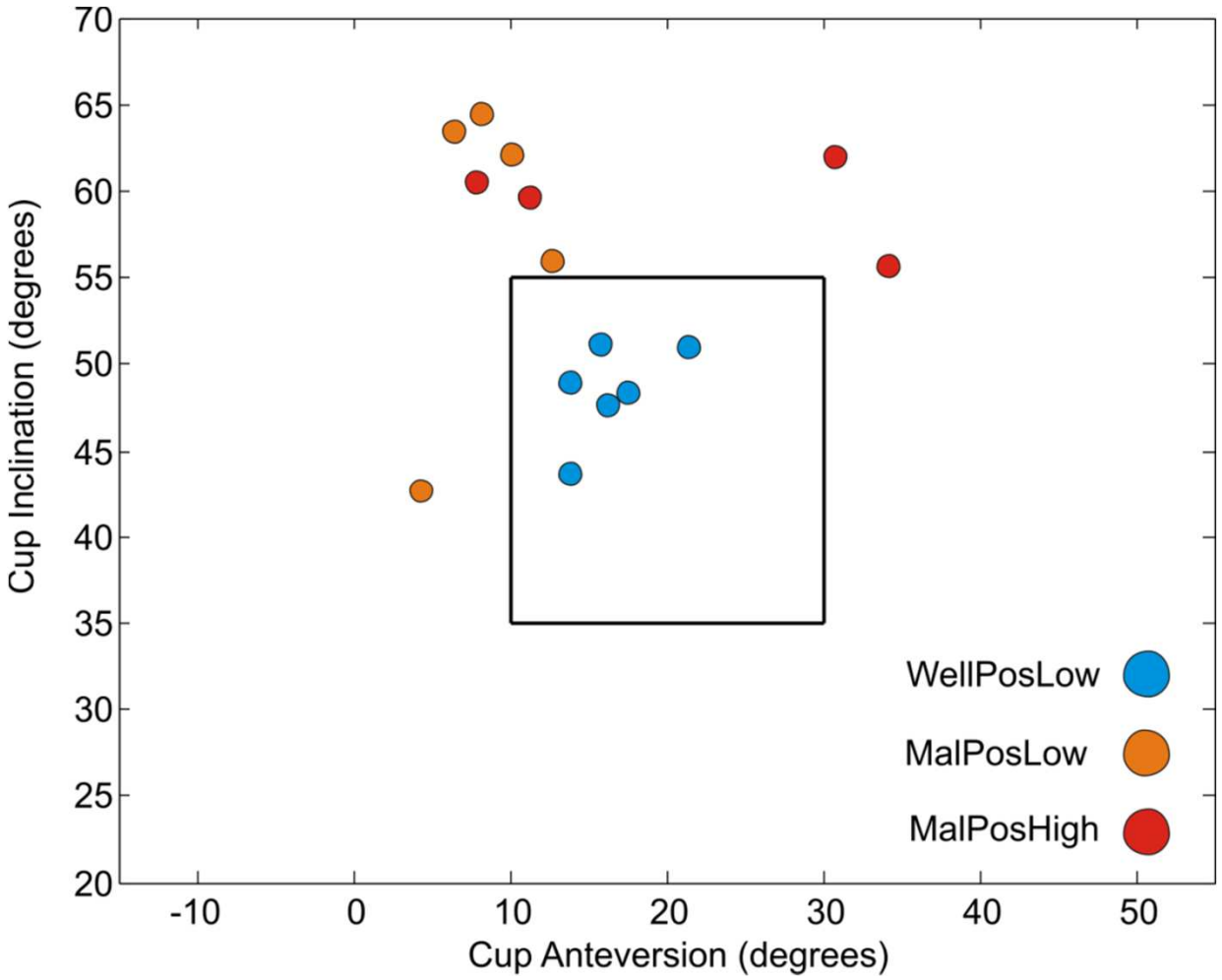
COHORT SELECTION



DEMOGRAPHICS

	Well –Positioned Cups	Mal-Positioned Cups	
	Low Ions (n=6)	Low Ions (n=5)	High Ions (n=4)
Gender (M/F)	4/2	3/2	1/3
Age Years	57	43	46
Weight (kg)	73	73	66
Size (mm)	52	49	47
Chromium (µg/l)	1.5	1.7	6.7
Cobalt (µg/l)	1.5	1.8	6.9

COHORT'S CUP ORIENTATIONS



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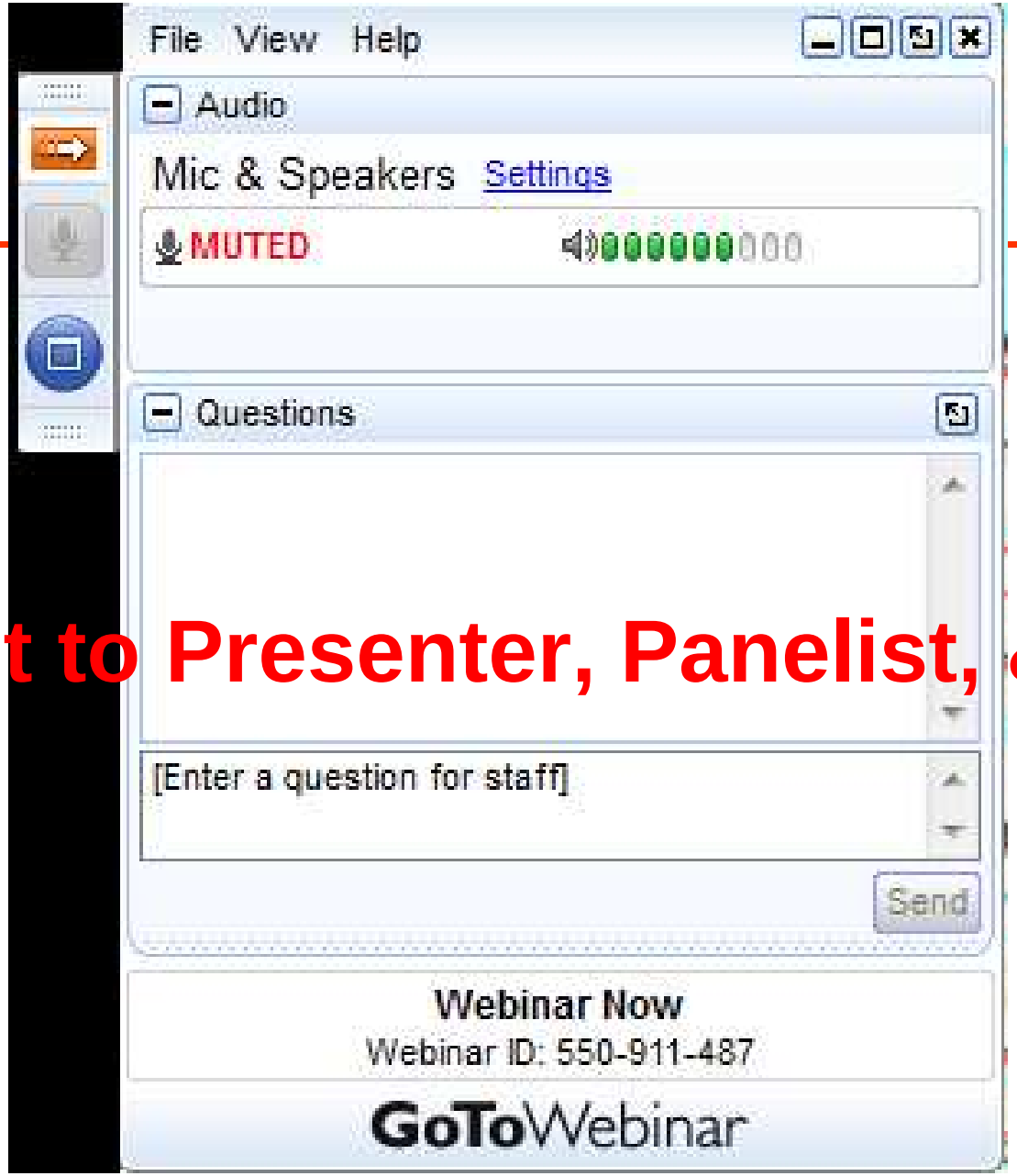

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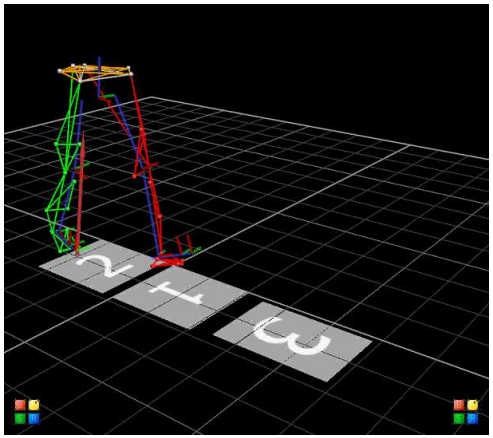
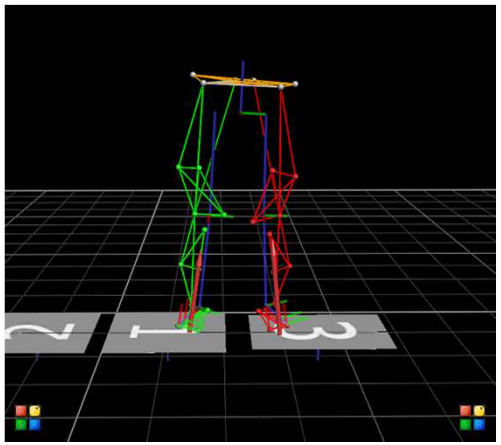
PROTOCOL

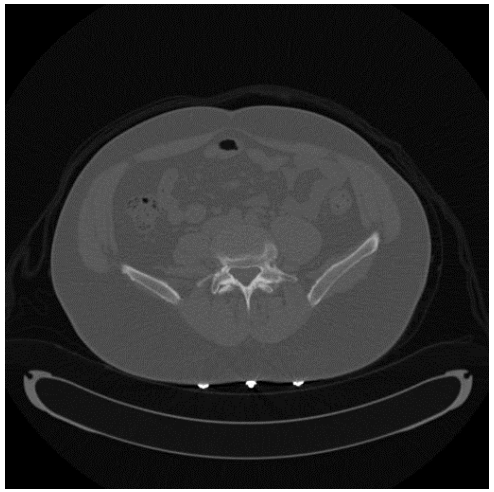
Motion Analysis





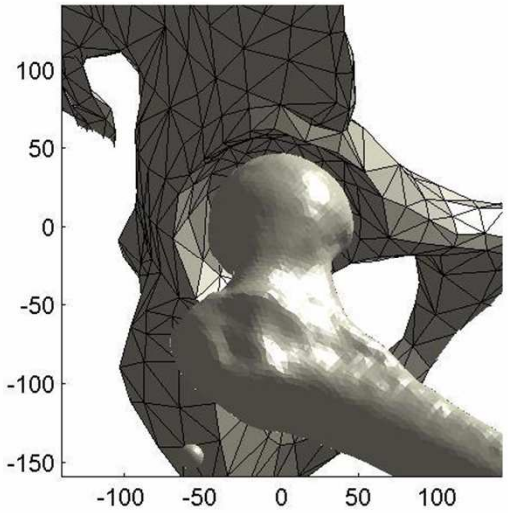
Lower extremity kinematics during functional activities

CT Scan



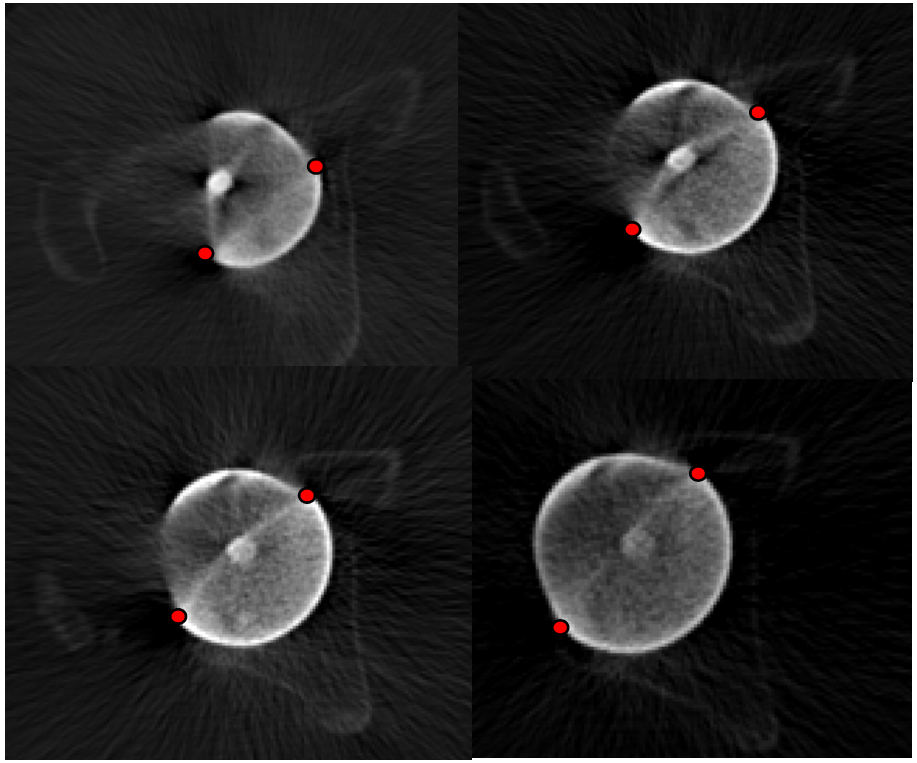
Relative positions of acetabular and femoral components

GAIT-LAB & CT DATA INCORPORATION



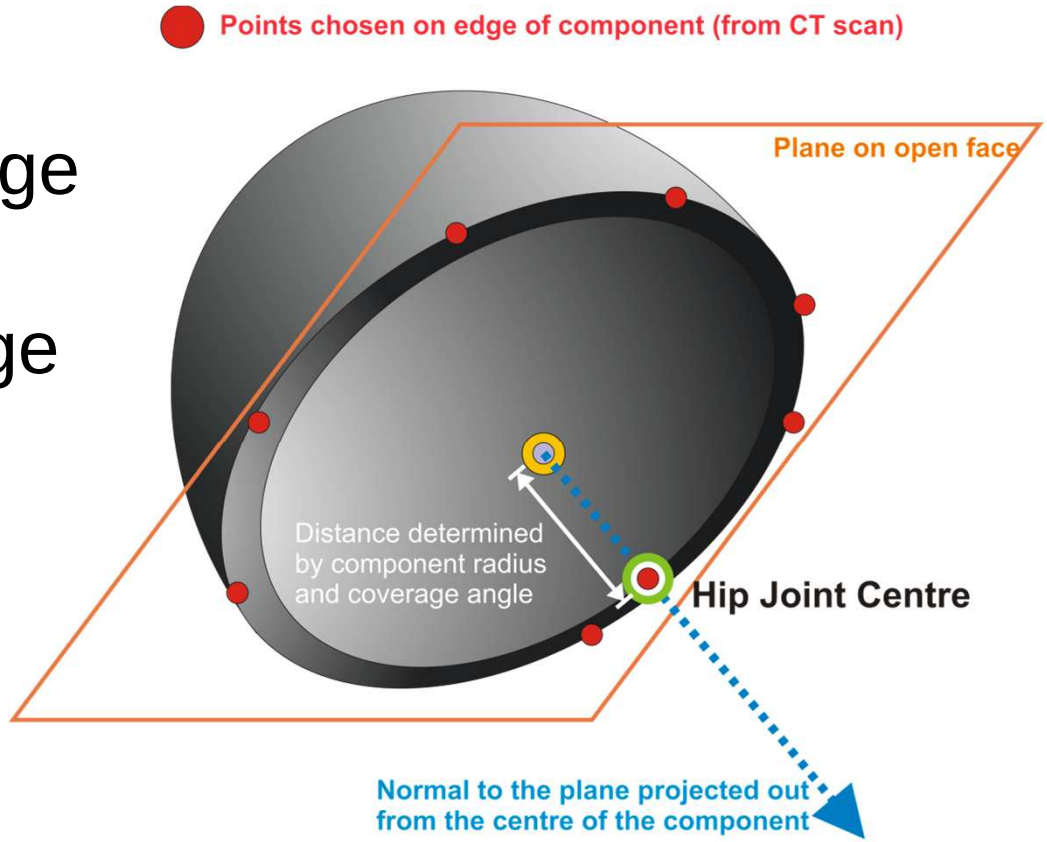
Hip Joint Centre Calculation

- Points at cup edge in CT slices chosen
- Plane defined through these points
- Circles fitted through combinations of points to find the average centre

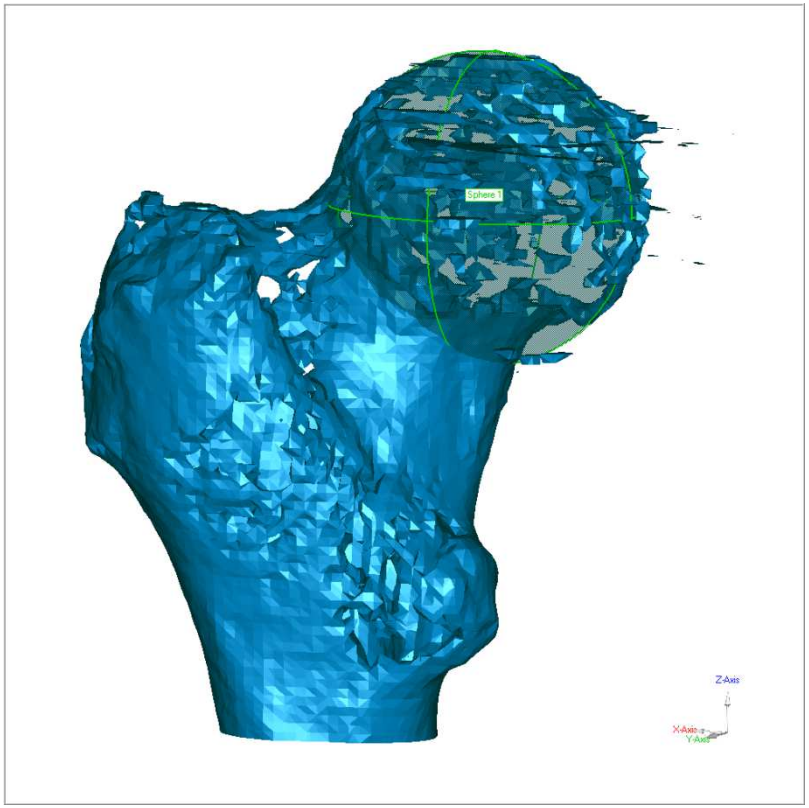


Hip Joint Centre Calculation

- HJC was found by projection from average centre relative to cup diameter and coverage angle

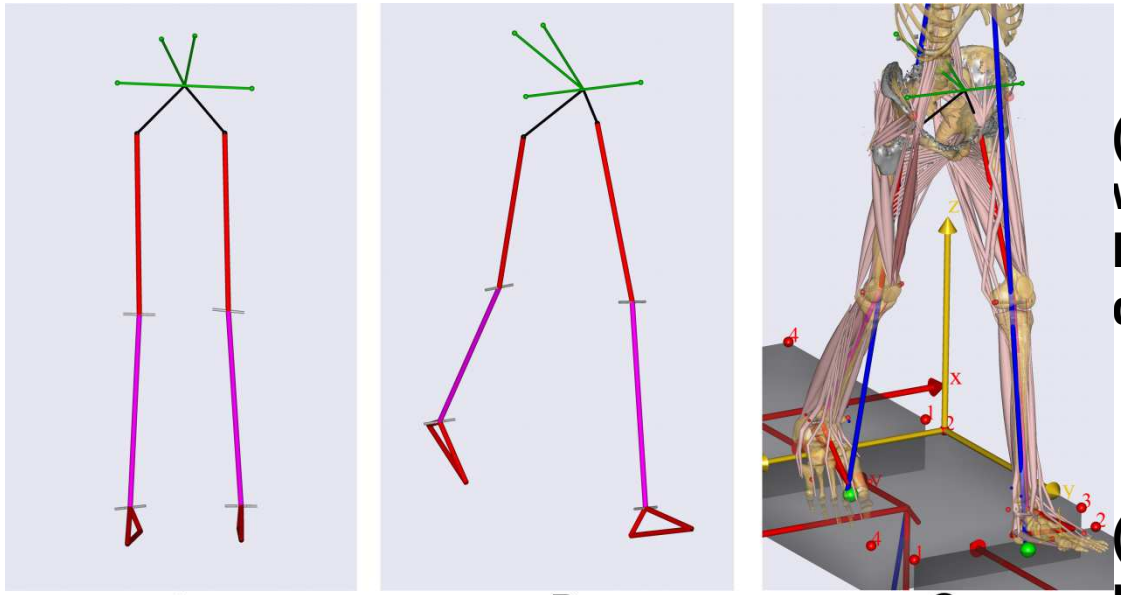


HJC: Unimplanted Side



- Unimplanted hip was segmented in Mimics (v.14,Materialise, Belgium)
- HJC was centre of sphere fitted to femoral head (Geomagic Studio 11)

MUSCULOSKELETAL MODEL

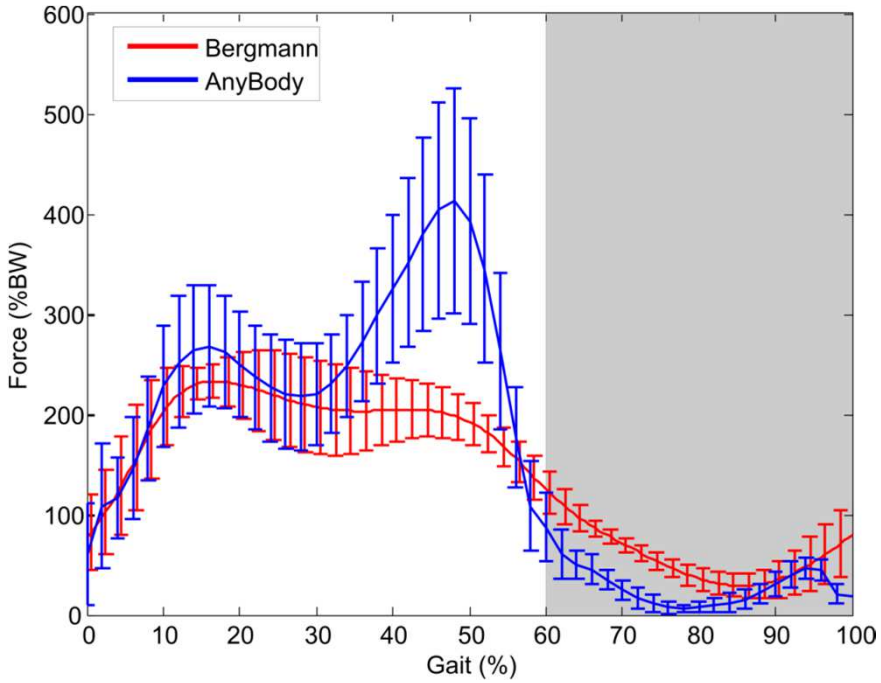


(A) a stick-figure model was derived based on the markers from the standing reference trial and the HJCs from the CT scan

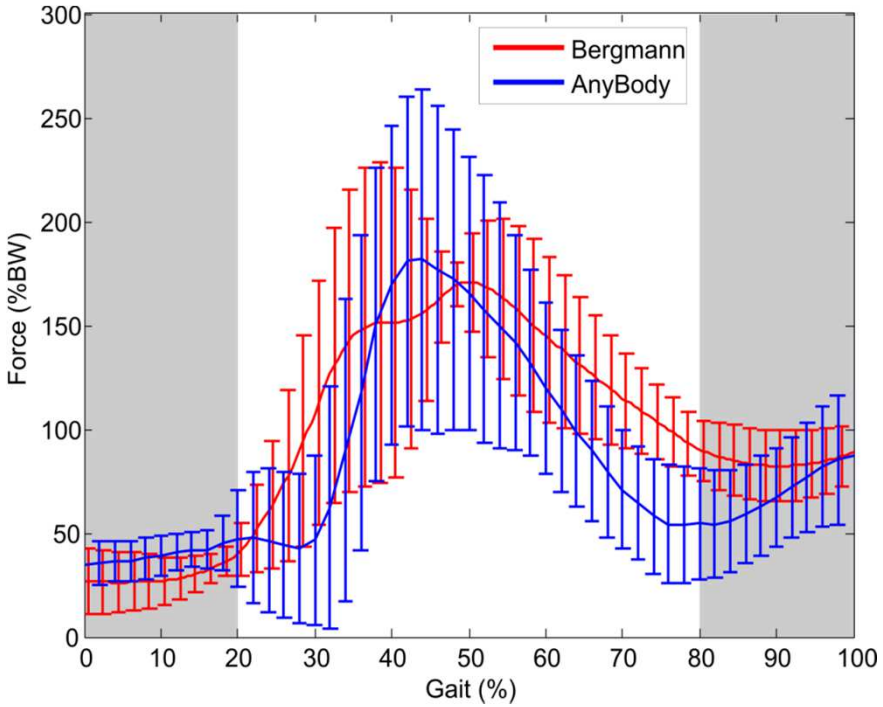
(B) Next, the stick-figure model was used to estimate the kinematics of the patient for dynamic trials

(C) Lastly, the TLEM musculoskelatal model was nonlinearly morphed to match the stick-figure and inverse dynamic analysis performed using the estimated joint kinematics in (B) and the measured ground reaction forces.

Predicted Forces vs. Bergmann

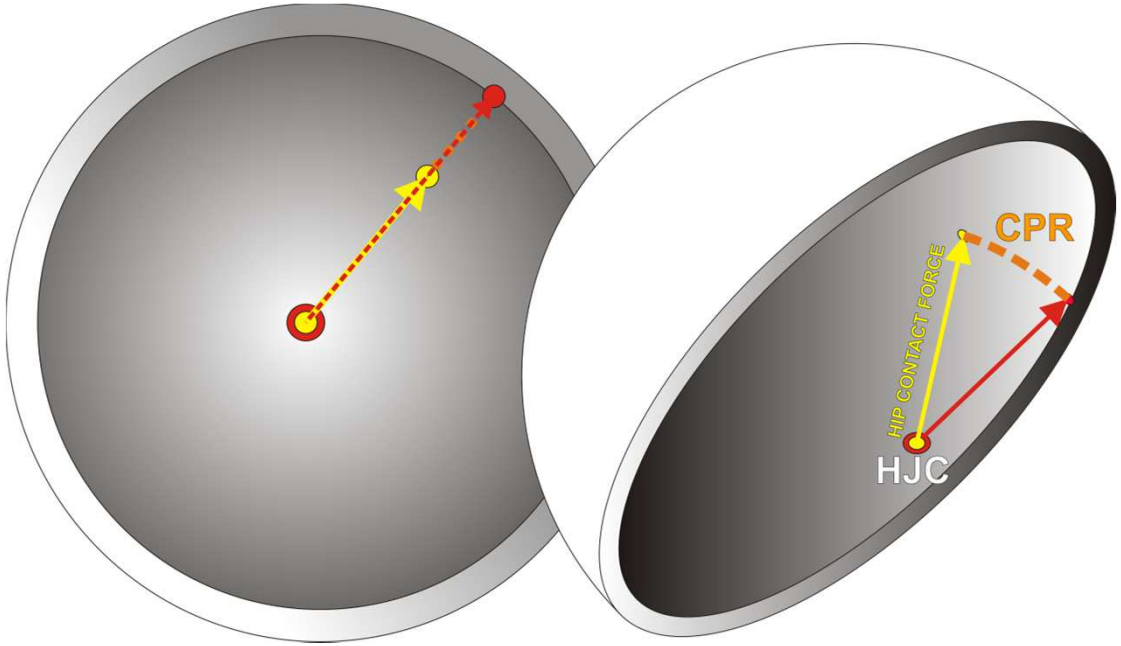


P = 0.945



P < 0.05
Highest 10% P = 0.338

CALCULATIONS: CPR



- Intersection of HCF with acetabular component was calculated
- Calculated the CPR distance (mm) of the Hip Contact Force from the edge

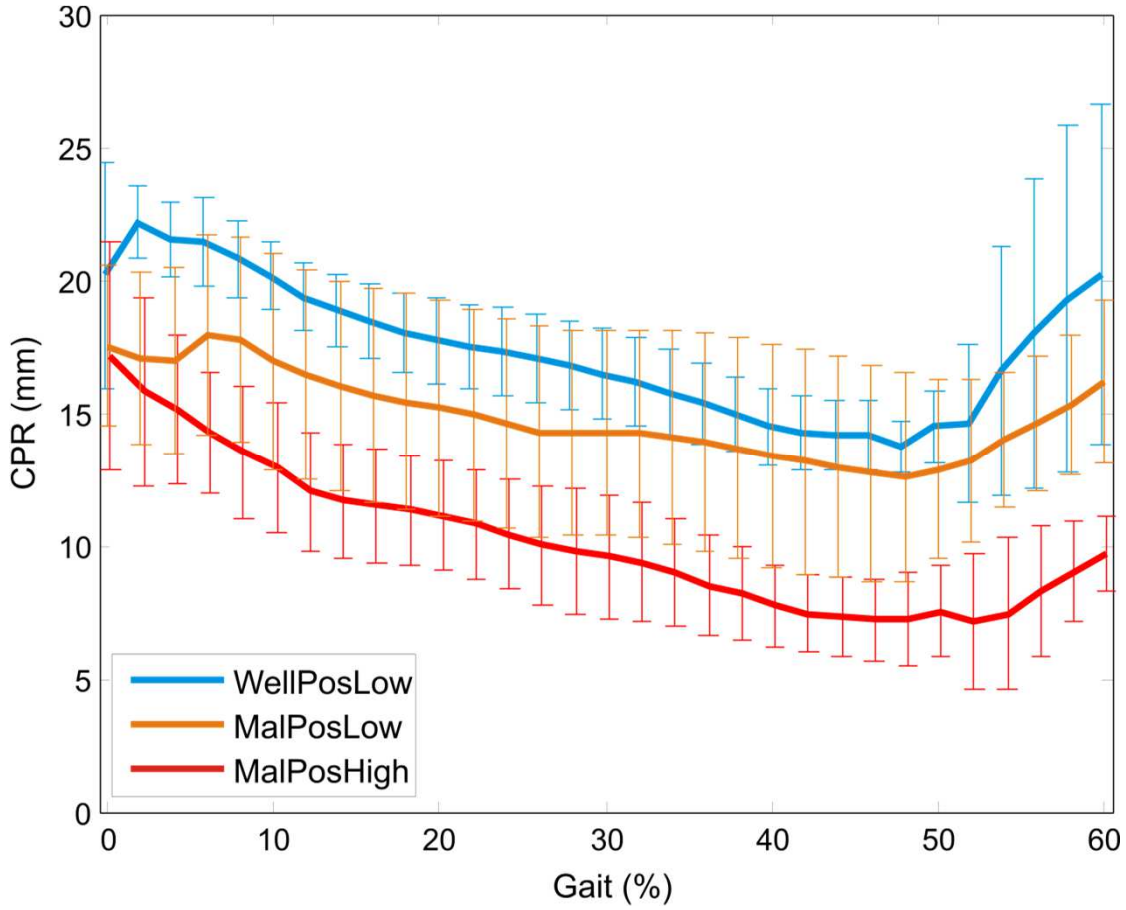
CPR & Metal Ions

- Blood metal ion concentrations after hip resurfacing arthroplasty: a comparative study of articular surface replacement and birmingham hip resurfacing arthroplasties. Langton *et al.* JBJS, British Volume, 2009. 91-B(10):1287-1295

- Contact patch to rim distance predicts metal ion levels in hip resurfacing. Yoon *et al.* Clin. Orthop. Relat. Res. 2013;471(5):1615-21

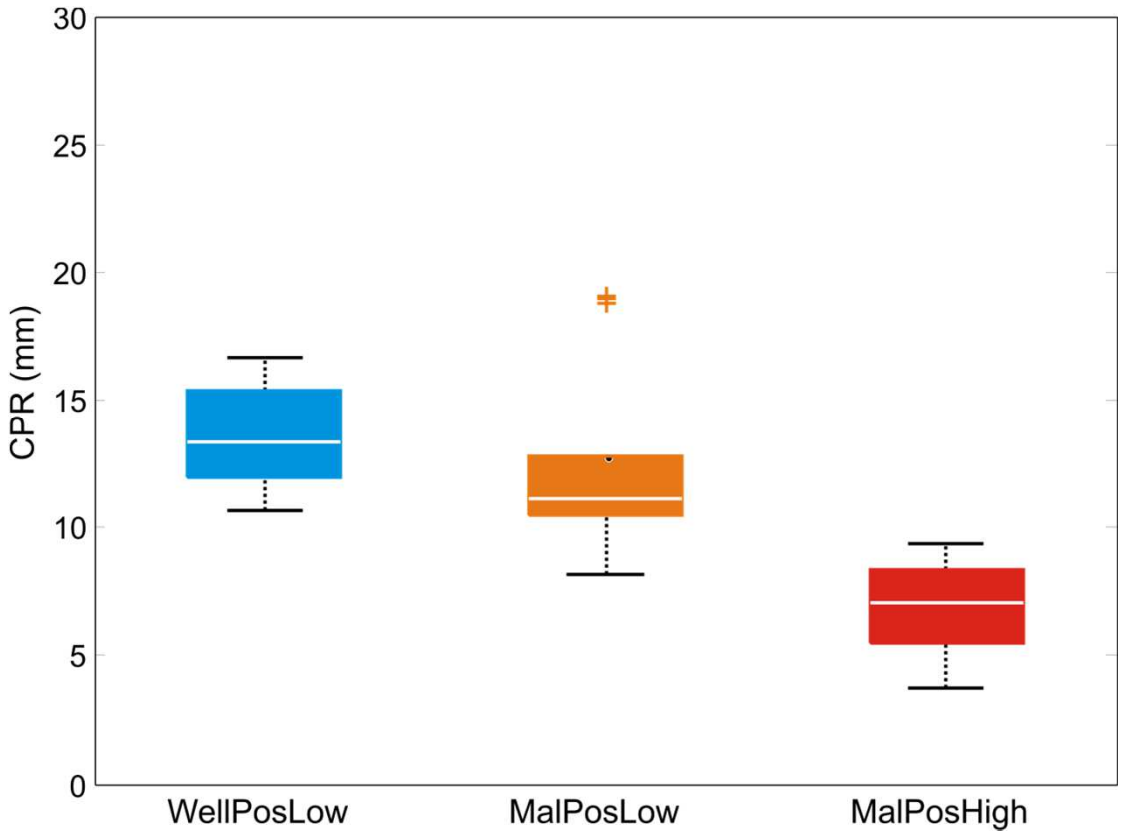
- Contact patch to rim distance can be used to predict component wear and blood metal ion levels in metal-on-metal hip resurfacing. Matthies *et al.* Bone & Joint Journal Orthopaedic Proceedings Supplement, 2013:95-B(SUPP 13):11

RESULTS
Mean CPR per group (Gait)



The subjects in the **MalPosHigh** group had hip contact forces that were closest to the edge of the acetabular component during the stance phase of gait

GAIT
Lowest 10% CPR Distance

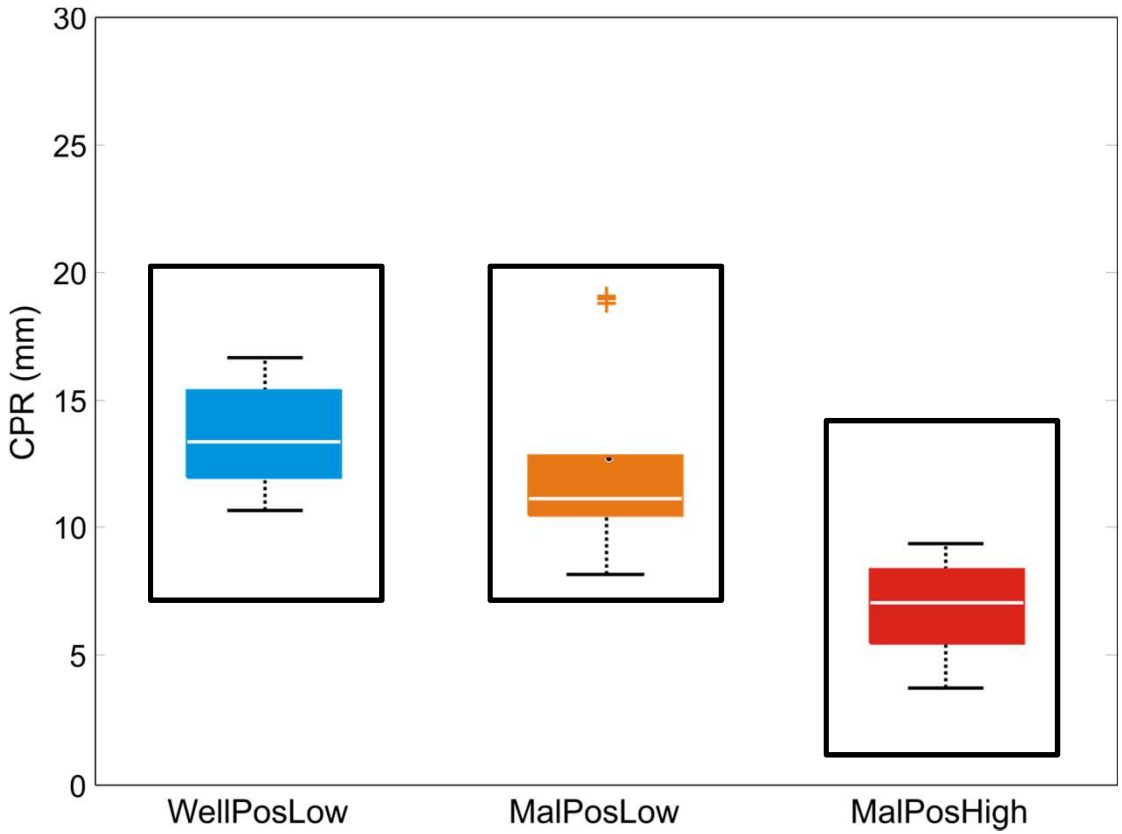


Well positioned Low:
13.1 (SD: 1.7)
range: 10.5 – 15.4

Mal-positioned Low:
12.6 (SD: 4.2)
range: 8.2 – 18.9

Mal-positioned High:
8.9 (SD:7.2)
range: 3.6 – 15.9

GAIT
Lowest 10% CPR Distance



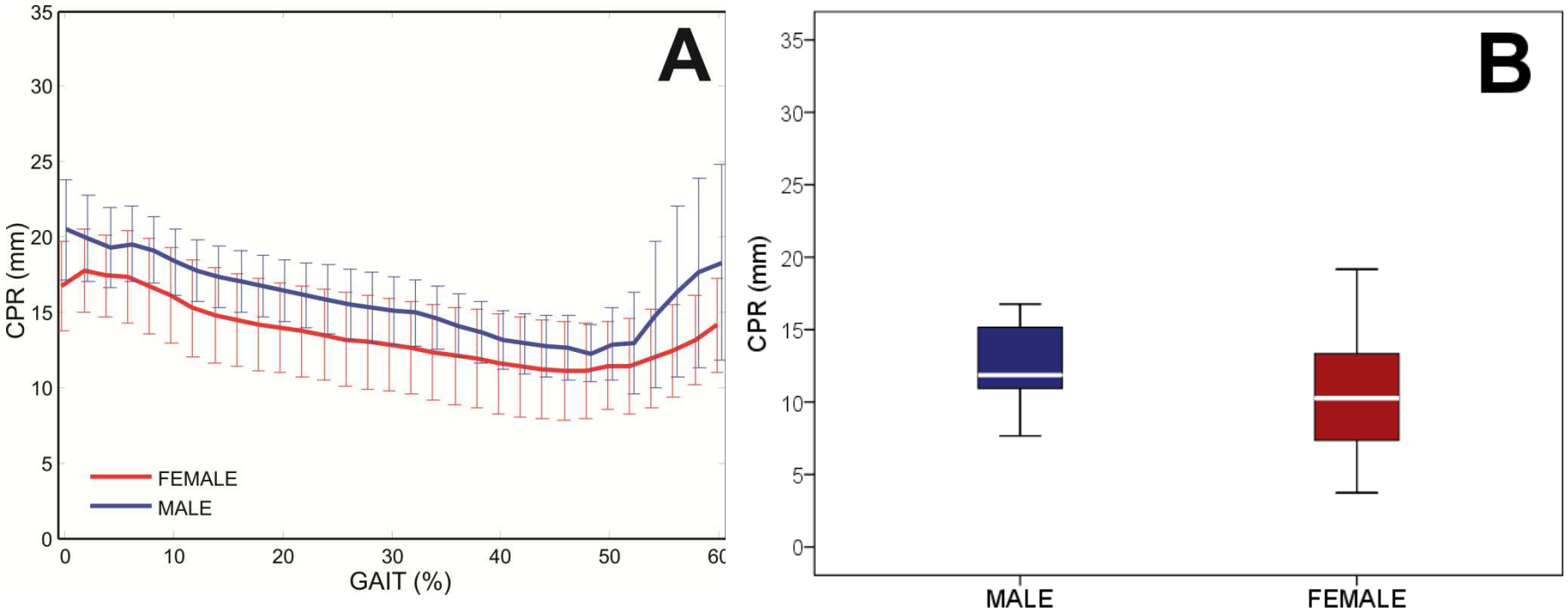
Mann–Whitney U test

WPL vs. MPH p < 0.001

WPL vs. MPL p = 0.003

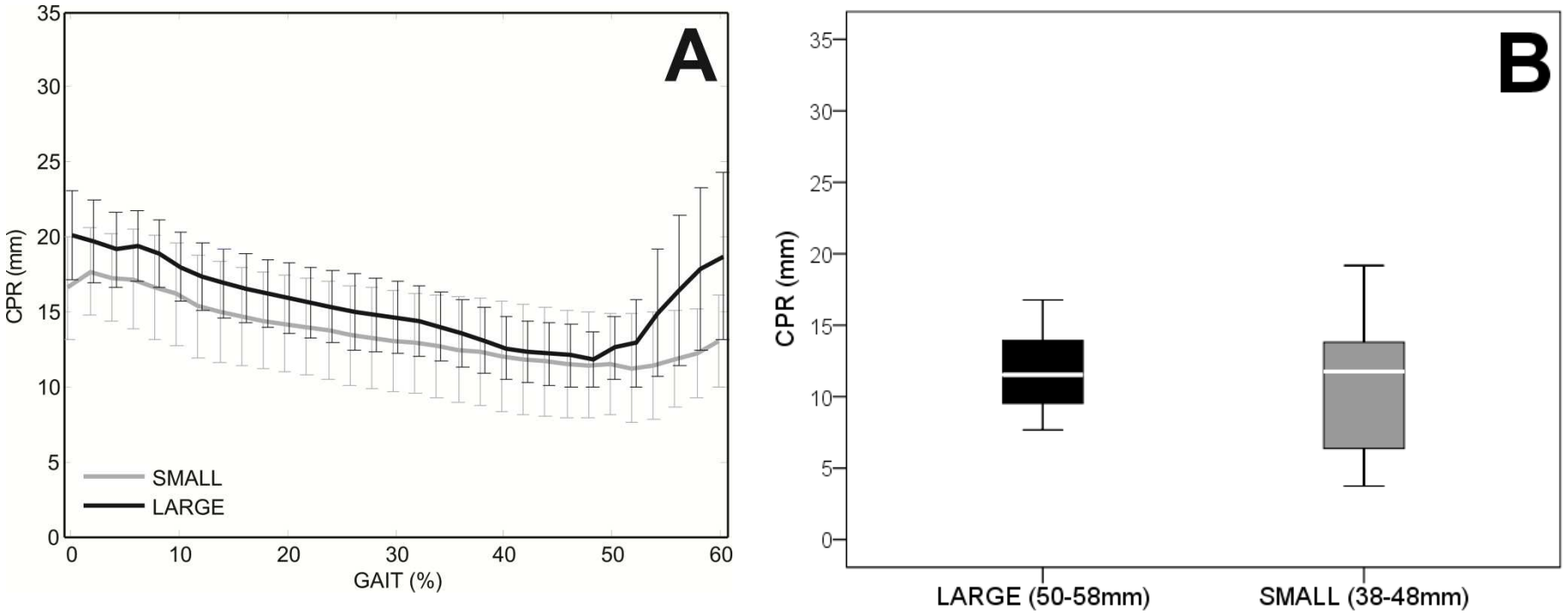
MPL vs. MPH p < 0.001

Gait: Male v Female



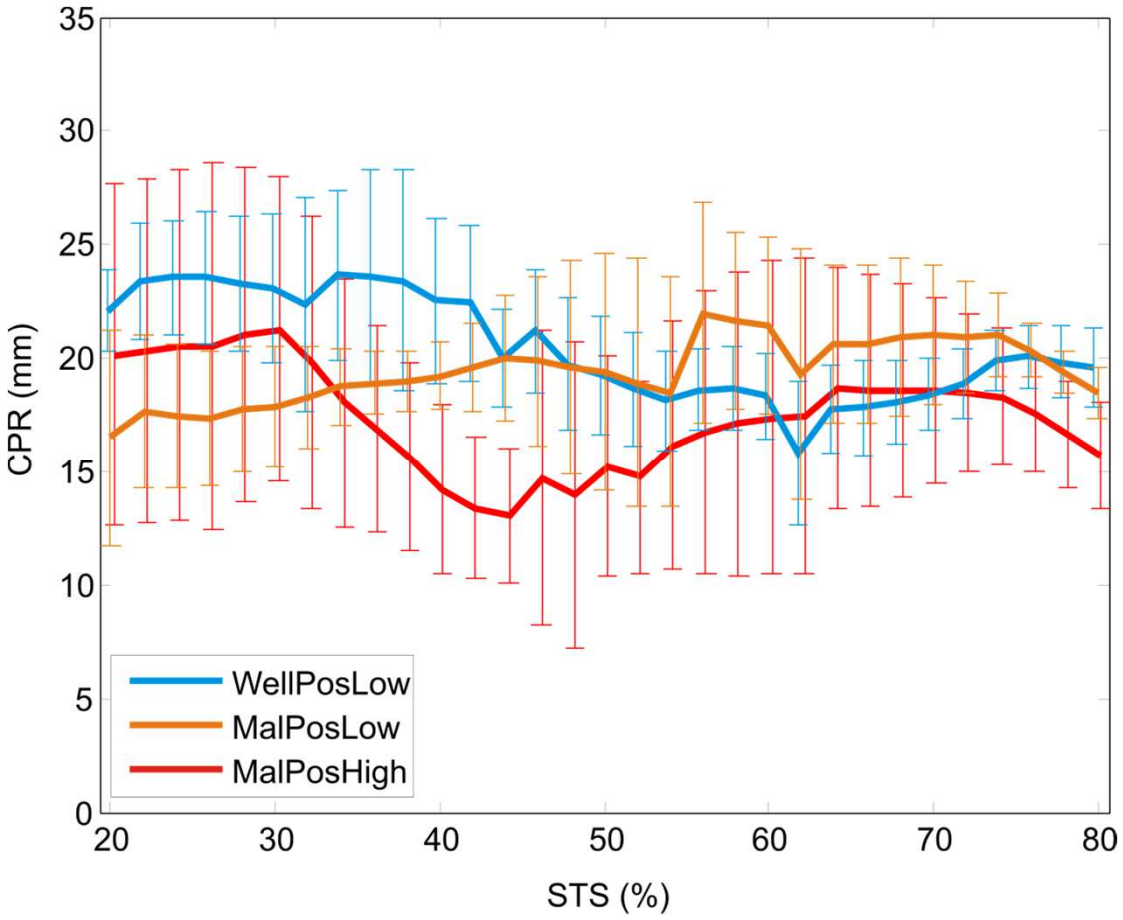
When the lowest 10% of CPR values for gait were grouped according to gender, there was no statistically significant difference (p=0.067)

GAIT: ‘Large’ v ‘Small’



When the lowest 10% of CPR values for gait were grouped according to component size, there was also no statistically significant difference (p=0.44)

RESULTS
Mean CPR per group (STS)



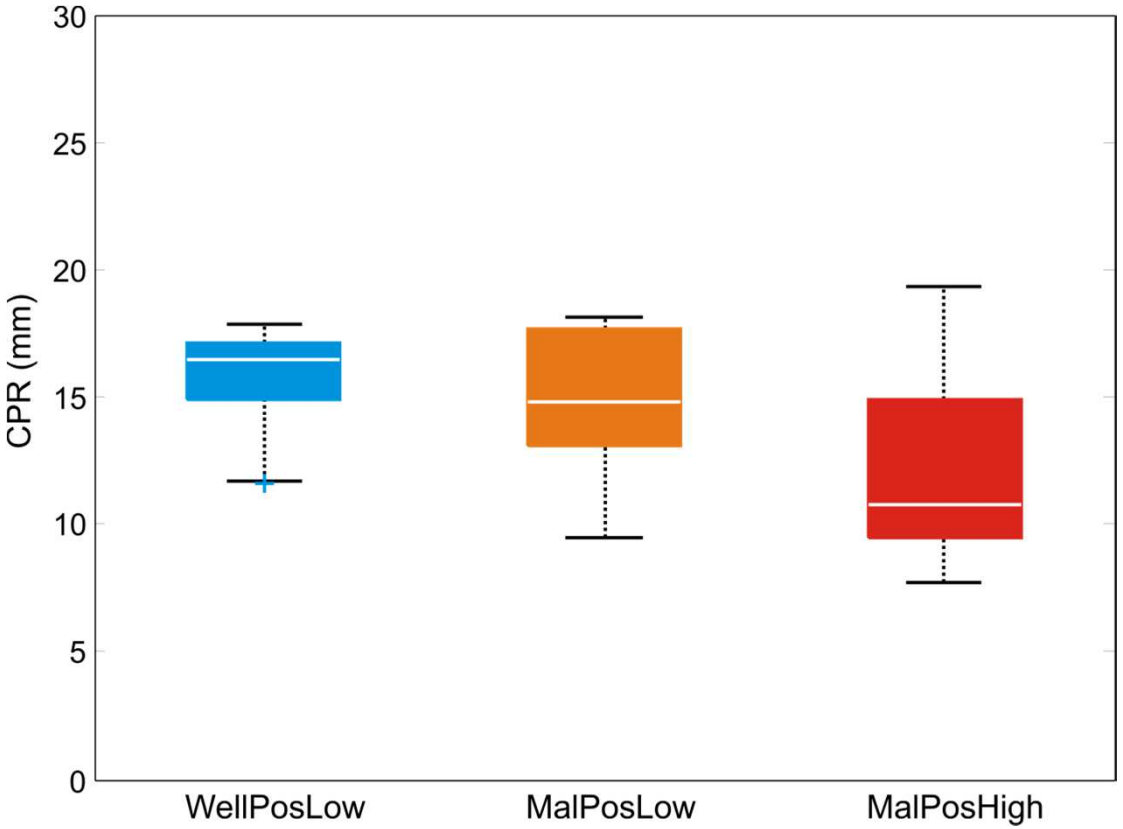
During the loading phase of STS, the mean values of CPR were:

20.5mm (SD 2.3mm, range 15.8–23.6mm) for **WellPosLow**,

19.4mm (SD 1.4mm, range 16.5–22.0mm) for **MalPosLow**

17.4 for **MalPosHigh** (SD 2.3mm, range 13.1–21.3mm)

STS
Lowest 10% CPR (per patient)



Well positioned Low:
16.9 (SD: 3.7)
range: 11.9 – 23.7

Mal-positioned Low:
16.2 (SD: 2.4)
range: 12.3 – 18.9

Mal-positioned High:
10.1 (SD: 2.6)
range: 8.1 – 15.4

STS
Lowest 10% CPR

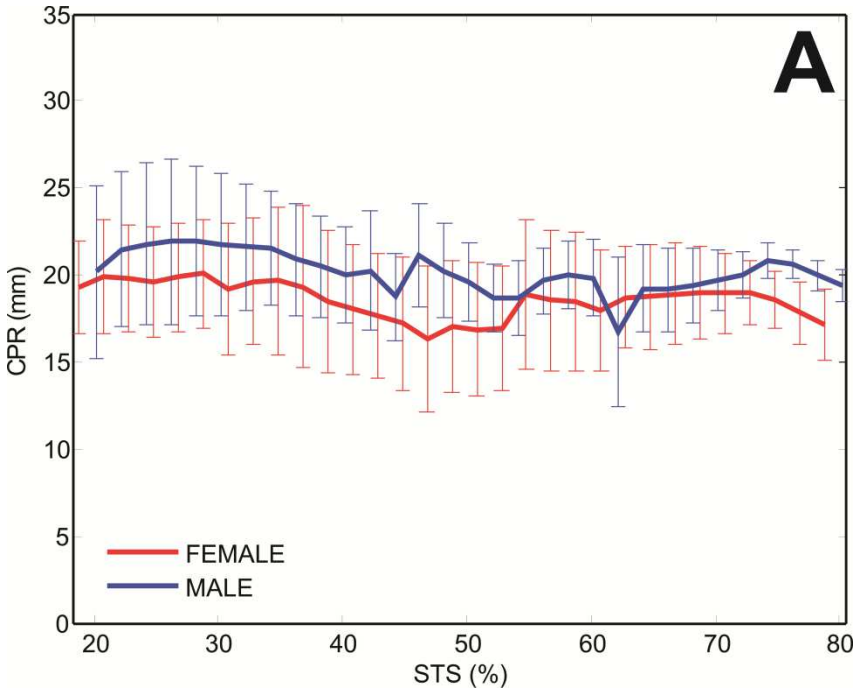
Mann–Whitney U test

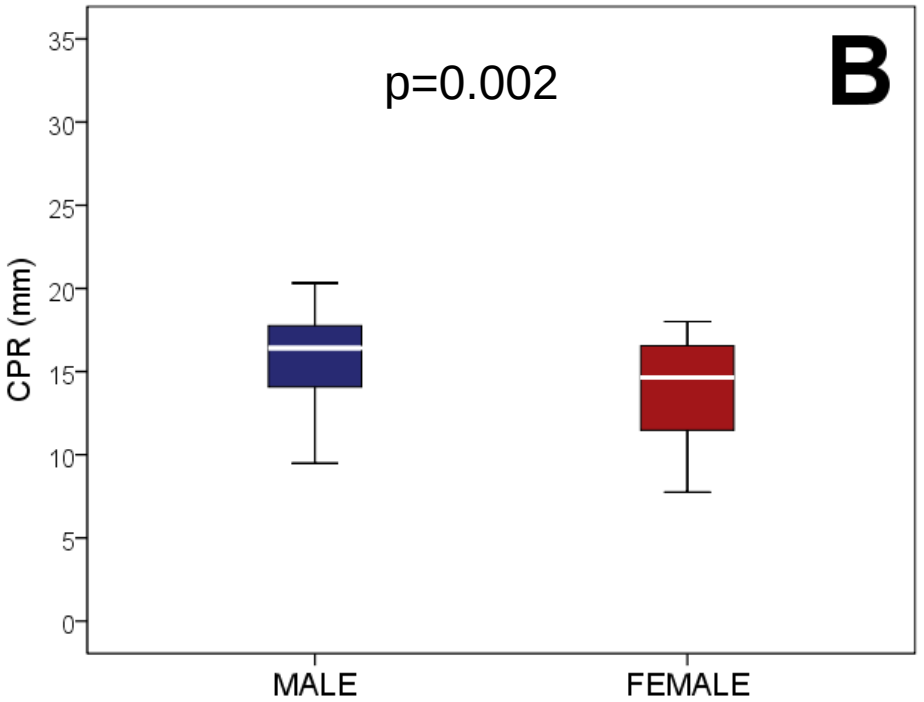
WPL vs. MPH p < 0.001

WPL vs. MPL p = 0.309

MPL vs. MPH p < 0.001

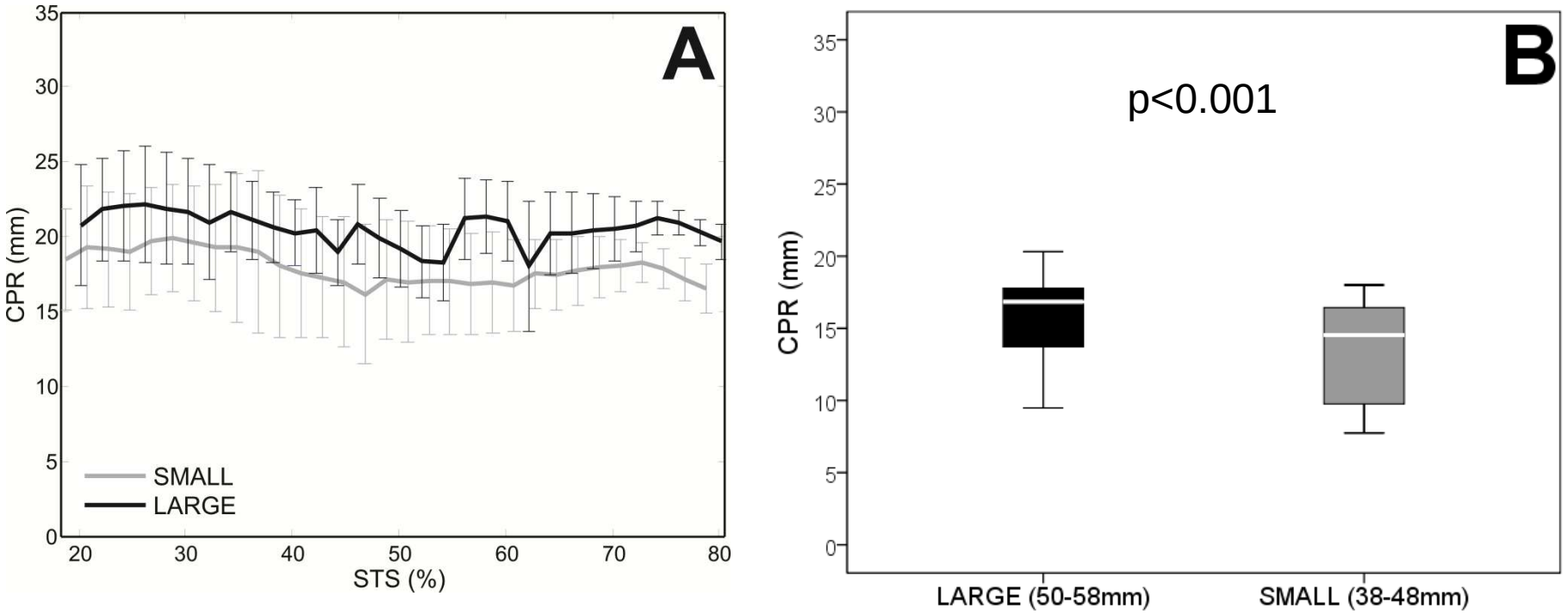
STS: Male v Female





When the lowest 10% of CPR values were grouped by gender, there was a statistically significant difference between males and females (p=0.002)

STS: ‘Large’ v ‘Small’



When the values were grouped by component size, there was also a statistically significant difference between large and small components ($p<0.001$)

DISCUSSION I

- In this study, subjects in the MalPosLow group had motion patterns that insulated their acetabular component from elevated wear rates caused by edge loading
  - This could also explain why some patients with well-positioned cups demonstrate high serum metal ion levels

- Results in this study agree with others who found a significant inverse correlation between CPR (static standing) and serum metal ion levels

DISCUSSION II

- Gender and component size had an affect on edge-loading risk for sit-to-stand but not gait
  - Gender and component size play a role in edge-loading risk of MoMHRA
  - Further work is required to fully identify their affect

DISCUSSION III

- First study assessing edge-loading risk in resurfaced hips dynamically

- Risk of edge loading is an issue for other hard bearing combinations such as ceramic-on-ceramic
  - ‘stripe-wear’ and ‘squeaking’

DISCUSSION II

- Such differences were present in both activities tested (Gait and STS)
  - STS exhibited greater differences
  - ? More important action as hip enters a load-bearing state following a period of rest?

DISCUSSION IV

- **LIMITATIONS:**
  - Small patient number
  - No Well-Positioned High Ion group
  - Mal-positioned with high ions group had only four subjects, three of whom were females
  - MalPosHigh also had the smallest components

CONCLUSION

- In addition to component position, an individual's motion patterns play an important role in wear mechanisms
- Some patients with mal-orientated cups will avoid edge loading with the way they perform daily activities
- The motion patterns that exert this influence over component wear are a result of anatomy and subject-specific kinematics

THANK YOU

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  - DePuy
  - NIHR BRU

Paper Reference

Mellon SJ, Grammatopoulos G, Andersen MS, Pegg EC, Pandit HG, Murray DW, Gill HS Individual motion patterns during gait and sit-to-stand contribute to edge-loading risk in metal-on-metal hip resurfacing Proc Inst Mech Eng H. 2013 Apr. doi: 10.1177/0954411913483639

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Questions?

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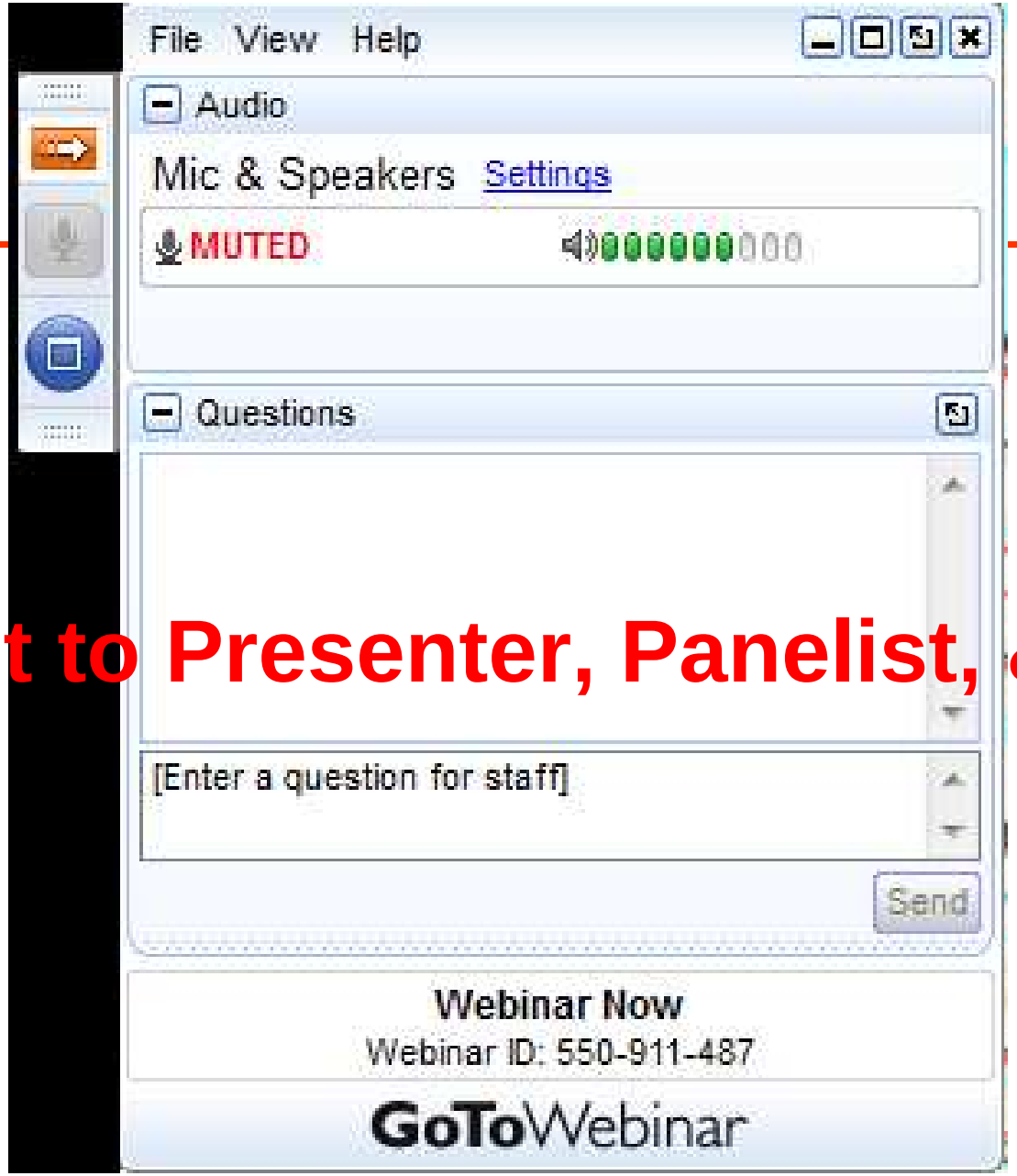

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