Post-Operative Imaging after Anatomic and Reverse TSA

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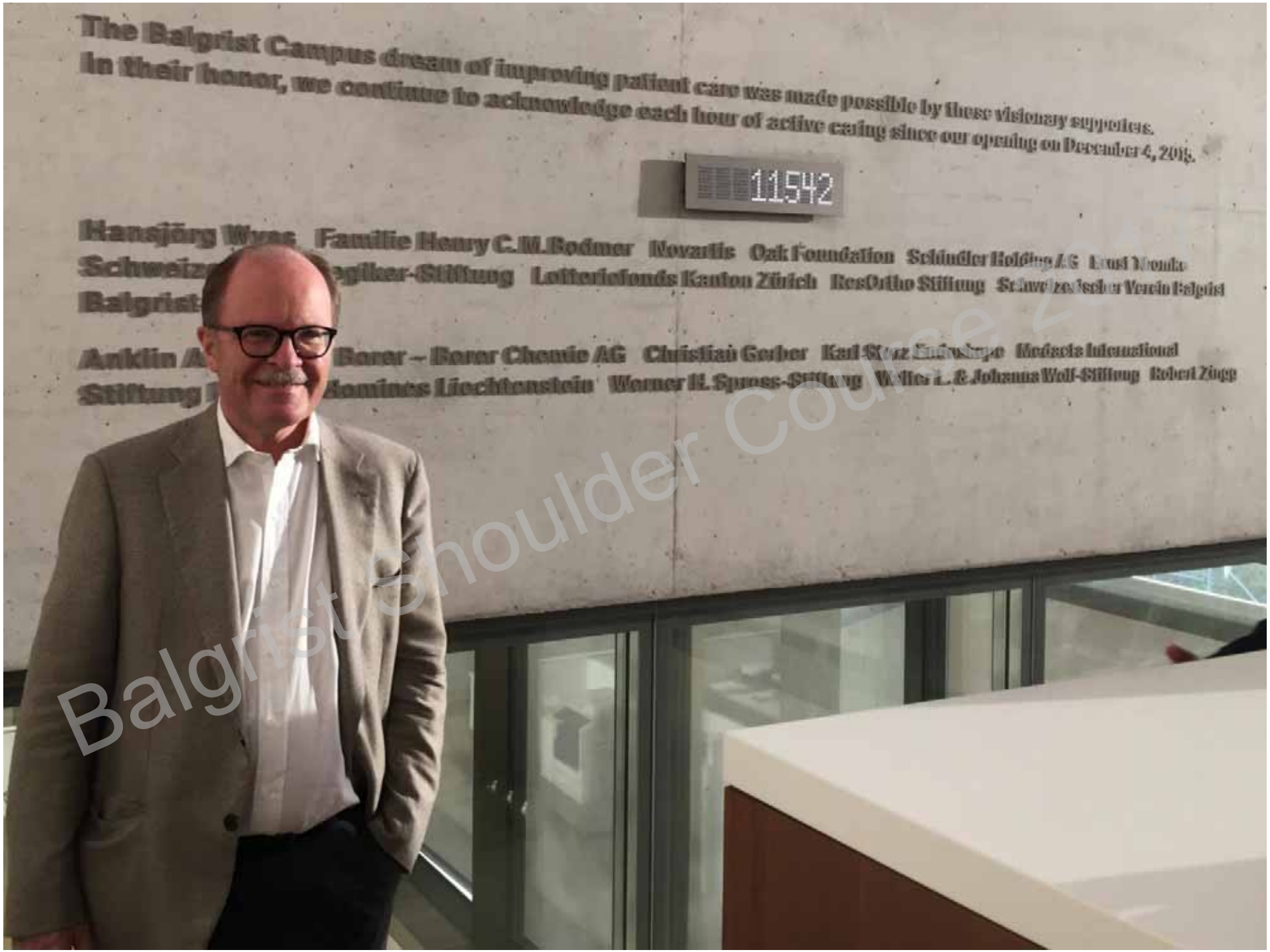
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Conflicts of Interest

- DePuy- Synthes Royalties
- DJO –Consulting and Royalties
- Wright – Tornier - Royalties
- Custom Orthopaedic Solutions - Equity
- Lippincott – Royalties

- None relevant to this presentation

Post Operative Imaging
What do we want to know?

- Implant position in 3D space
- Change in implant position over time
- Implant wear and loosening
- Relationship between implants
- Implant- tissue interfaces
- Functional kinematic motion of component

Why to we want to know these?

- Accuracy of the surgery
- Relationship of anatomy, implant placed and component function to implant failure: Mechanism of failure
- Reconstructive options for failed implants
- Predicting failure: implant, surgical and patient factors

How do we study these relationships?

- 2D imaging: x-ray and CT
  - Limited by variations in planes of image acquisition and inability to understand 3D relationships:
  - Inaccurate tools that miss subtle but important findings that result in can large differences over time that can be seen on x-ray.
- Static and Dynamic RSA maker based and structure model fitting methods
  - Needs specialized image acquisition hardware and software: Not readily available for clinical use

How can we measure these relationships?

- CT and MR imaging
  - Metal artifact
  - Radiation dose (CT)
  - Requires post imaging software and 3D reconstruction and image registration over intervals of time
  - Imaging equipment is clinically available but the software and technology is not readily available for clinical use

No Perfect Solution or Imaging Method

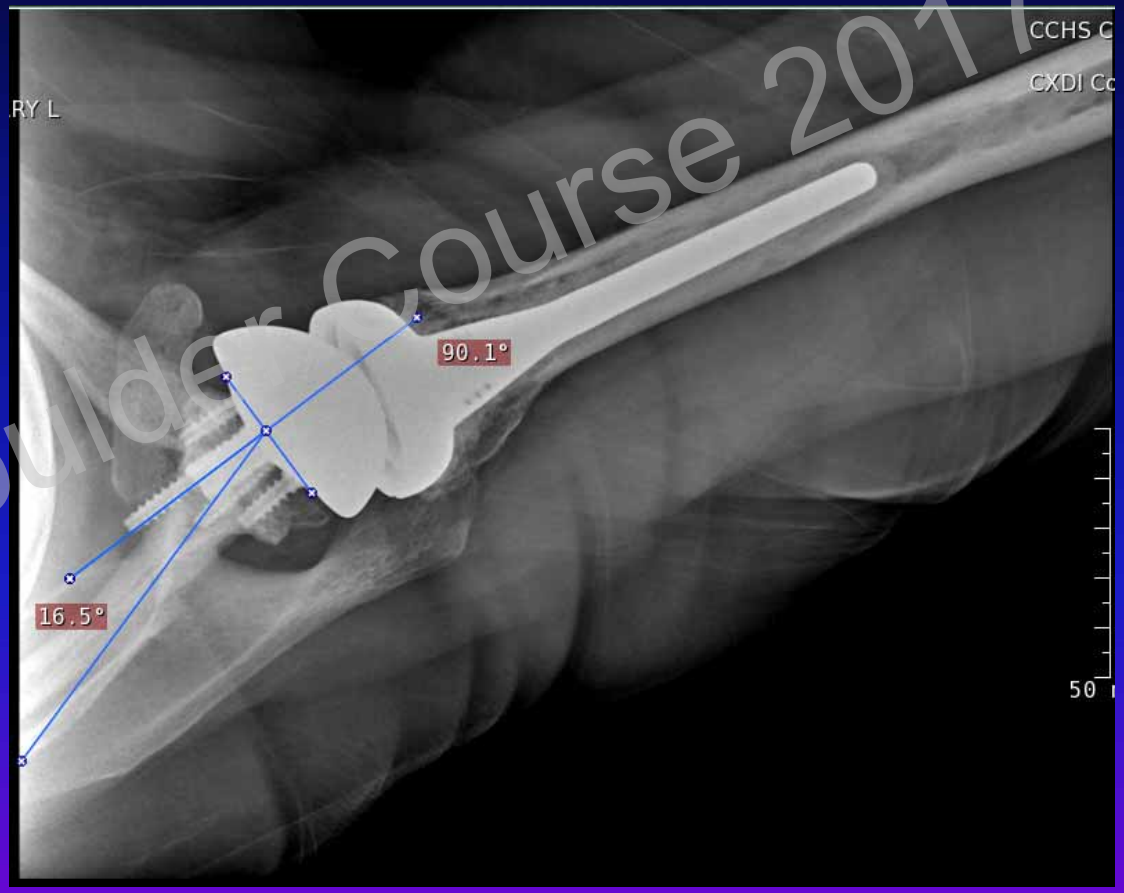
- Need to tailor the methods for the questions being asked AND
- The population to be studied
  - Diversity of pathology and implants
  - Sample size
  - Frequency and length of time for follow up
  - Access to the technology

Reverse TSA

- The glenoid is metal and can be more accurately measured by radiographic analysis
- Many have published methods to measure implant position and notching
- Some methods have inter-rater reliability evaluation: Defining reproducibility of the measurement
- Very few have correlated the measurements in 2D radiographs with 3D measurements: Defining accuracy of the measurement

Post-operative Version

- Measurement is based on the angle between the normal of the baseplate through the central peg and the line drawn from trigonum using the plane of the scapula through the central peg
- Requires an axillary view with a large portion of the scapula positioned perfectly. Fluoroscopically positioned



Reference for Inclination Measurement

- Maurer et al. demonstrated that angle β had the highest inter-rater reliability of all the angles shown

Figure 1 Definition of angles on conventional radiographs. The glenoid fossa line (*AB*) is defined as a line connecting the uppermost point (*A*) and the lowermost point (*B*) of the glenoid. Angle α is the angle between the spine of the scapula (*a*) and glenoid fossa line (*AB*). Angle β is the angle between the floor of the supraspinatus fossa (*b*) and the glenoid fossa line (*AB*). Angle γ is the angle between the lateral margin of the scapula (*c*) and the glenoid fossa line (*AB*). The distance from the medial border of the radiograph and the center of the glenoid fossa line (*AB*) is m_1. The angle between the scapular spine (*a*) and the medial border of the radiograph is φ.

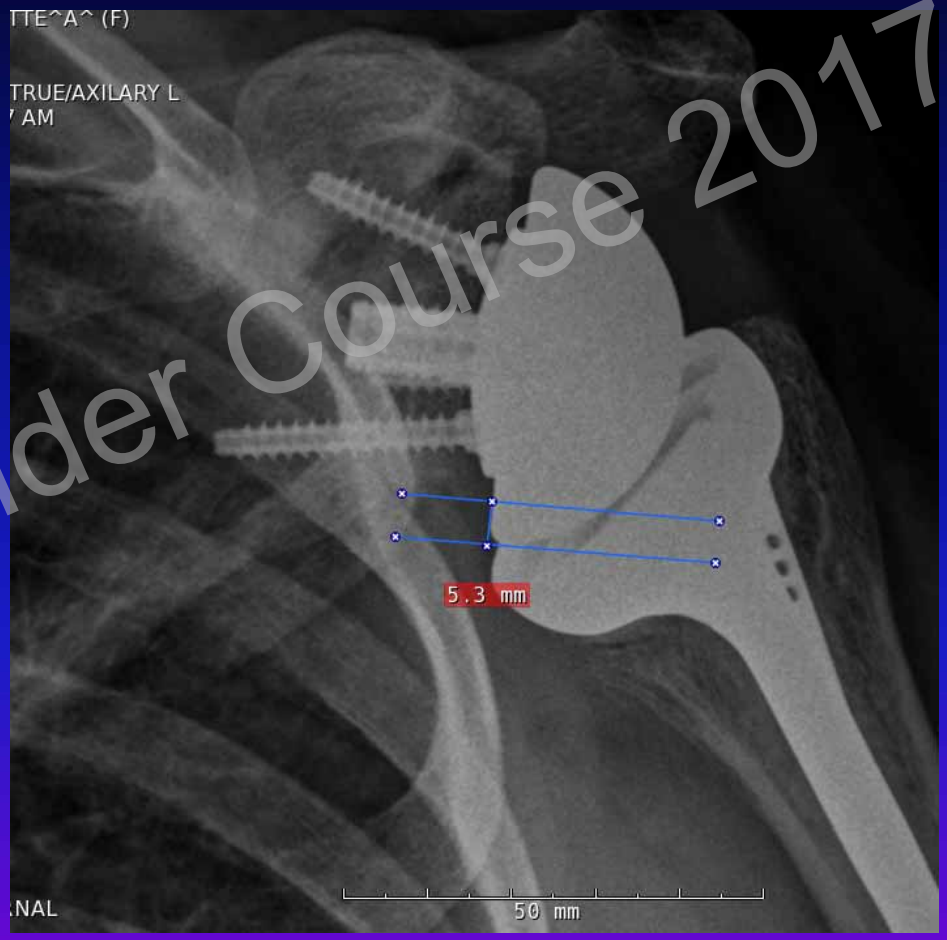
Maurer. JSES. 2012.

Post-op Inclination

- Vertical line is defined from apex-apex of the base of the glenosphere
- Horizontal line is defined from the top of scapula moving through the supraspinatus fossa

Inferior Overhang

- Reference: generate a line that lies along the scapular neck
- Create a parallel line that intersects with bottom-most point of glenosphere, measure distance between two lines
- Requires an AP view in the plane of the scapula

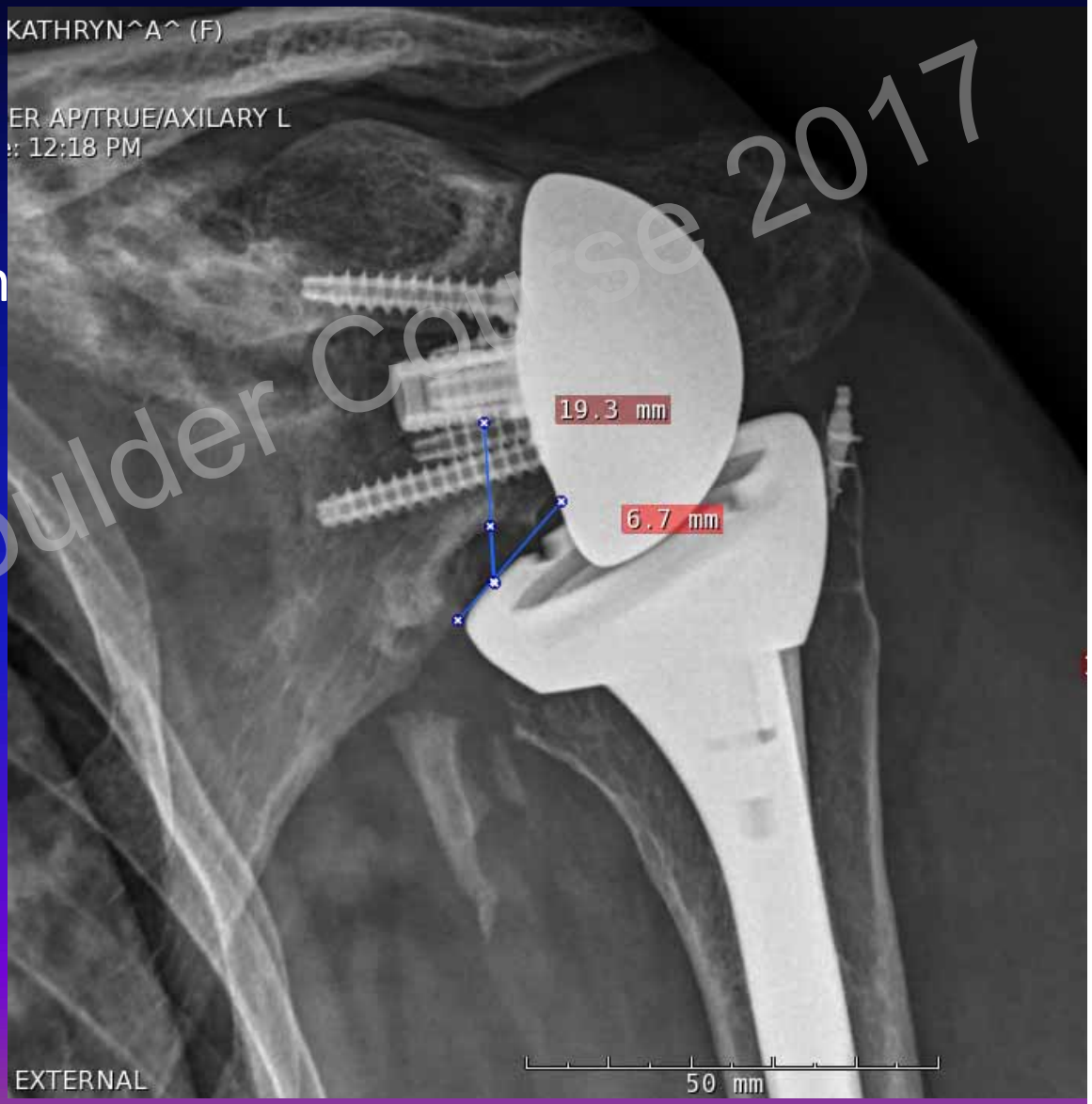


Lateralization of the center of rotation

- Requires perfect AP view perpendicular to the back side of the implant

Scapular Notching

- Kowalski ratio method
  - Length from neck to notching/Length from neck to inferior border of central peg
  - Type 1: ratio <2/3
  - Type 2: ratio > 2/3
  - Subtype A: Involves baseplate
  - Subtype B: Does not involve baseplate



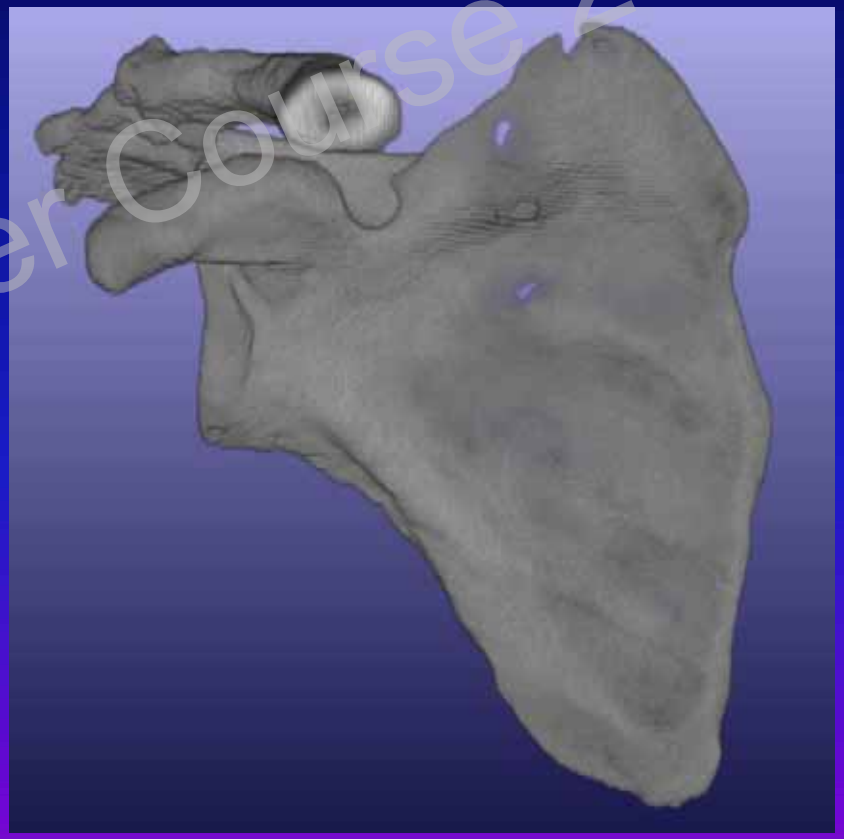
Advanced Kinematic 3D Imaging Combined with Patient Specific Active ROM: 30 patients studied

- Combining 3D Pre and Post operative 3D CT imaging with
- Post operative 3D active ROM of a patient
- Placing the implants in the pre operative CT and adding the patient specific post-operative range of motion
- Correlation of location of impingement found on the pre – operative CT scan with the Notching found on the post- operative CT Scan
- Defining where and how impingement occurs and
- What implant position would have avoided

Objective #1: Predicting Impingement

Pre-op Humerus

Pre-op Scapula



Objective #1: Predicting Impingement

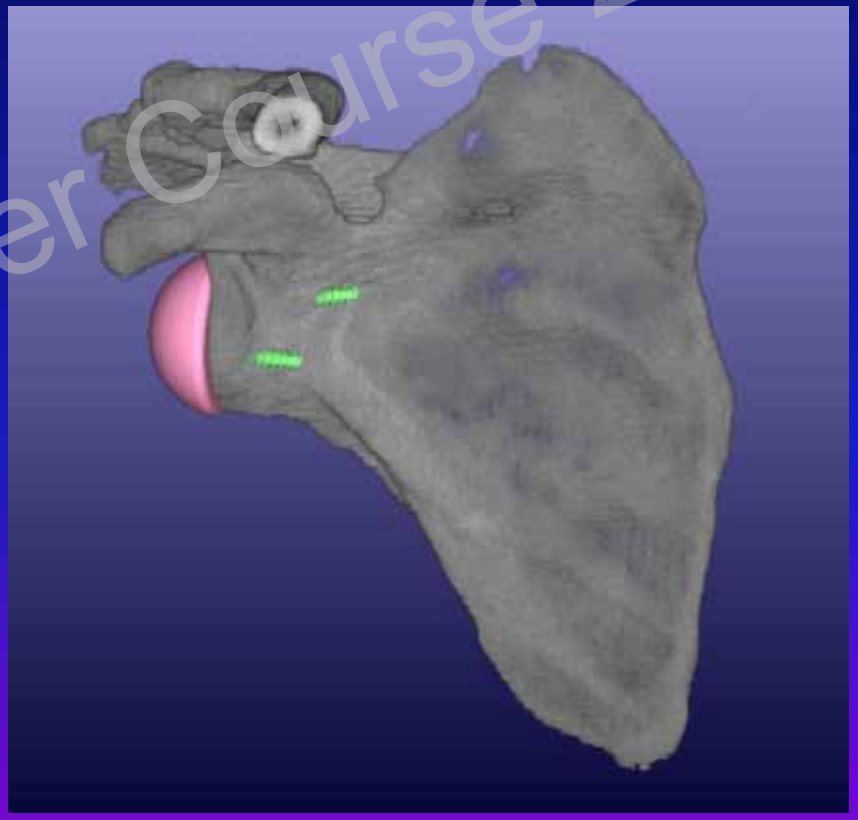
Post-op Humerus

Post-op Scapula

Objective #1: Predicting Impingement

Implant in Pre-op Humerus

Implant in Pre-op Scapula



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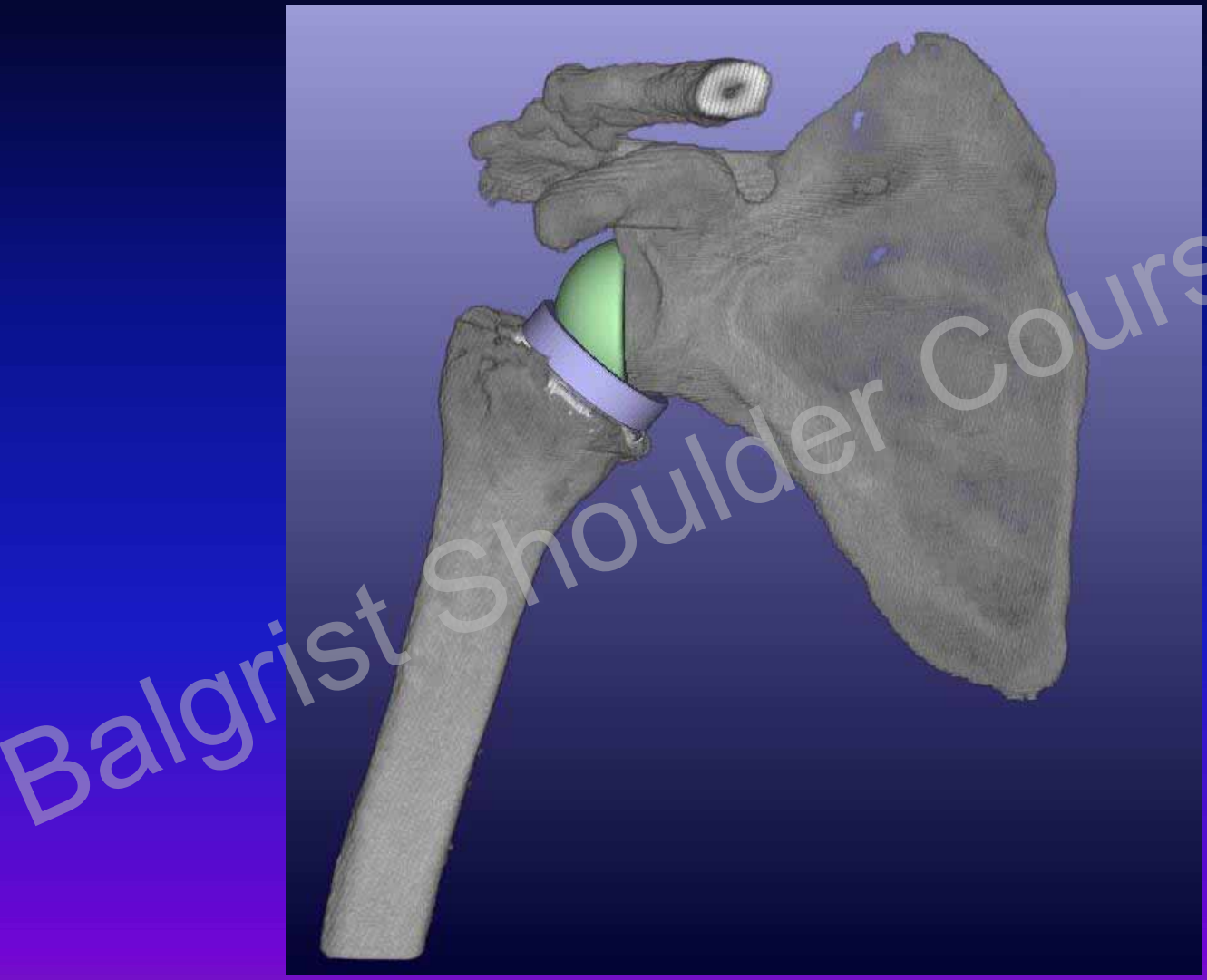

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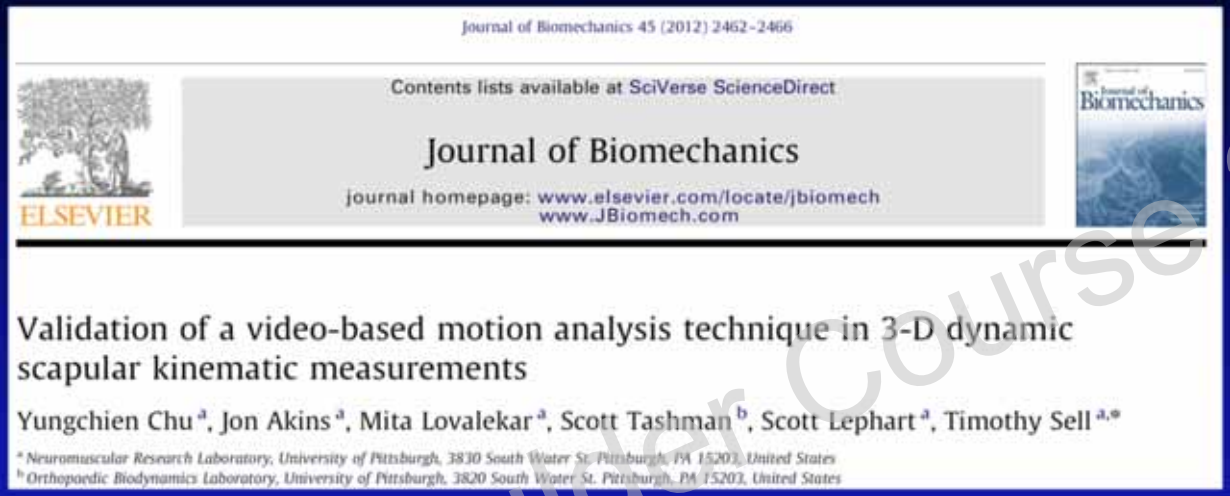

Journal of Biomechanics 45 (2012) 2462–2466

Contents lists available at SciVerse ScienceDirect

Journal of Biomechanics

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Validation of a video-based motion analysis technique in 3-D dynamic scapular kinematic measurements

Yungchien Chu [a], Jon Akins [a], Mita Lovalekar [a], Scott Tashman [b], Scott Lephart [a], Timothy Sell [a,*]

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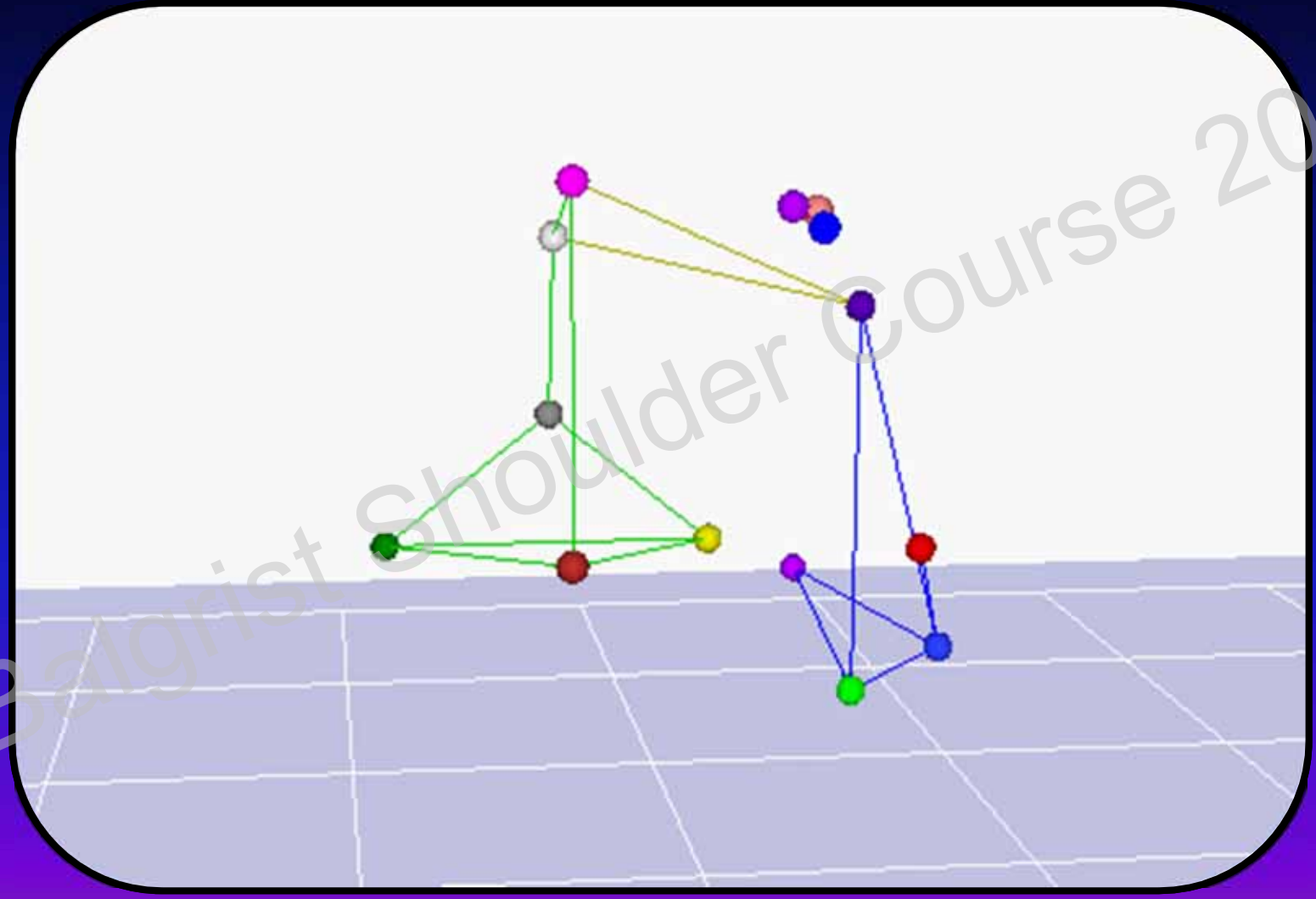
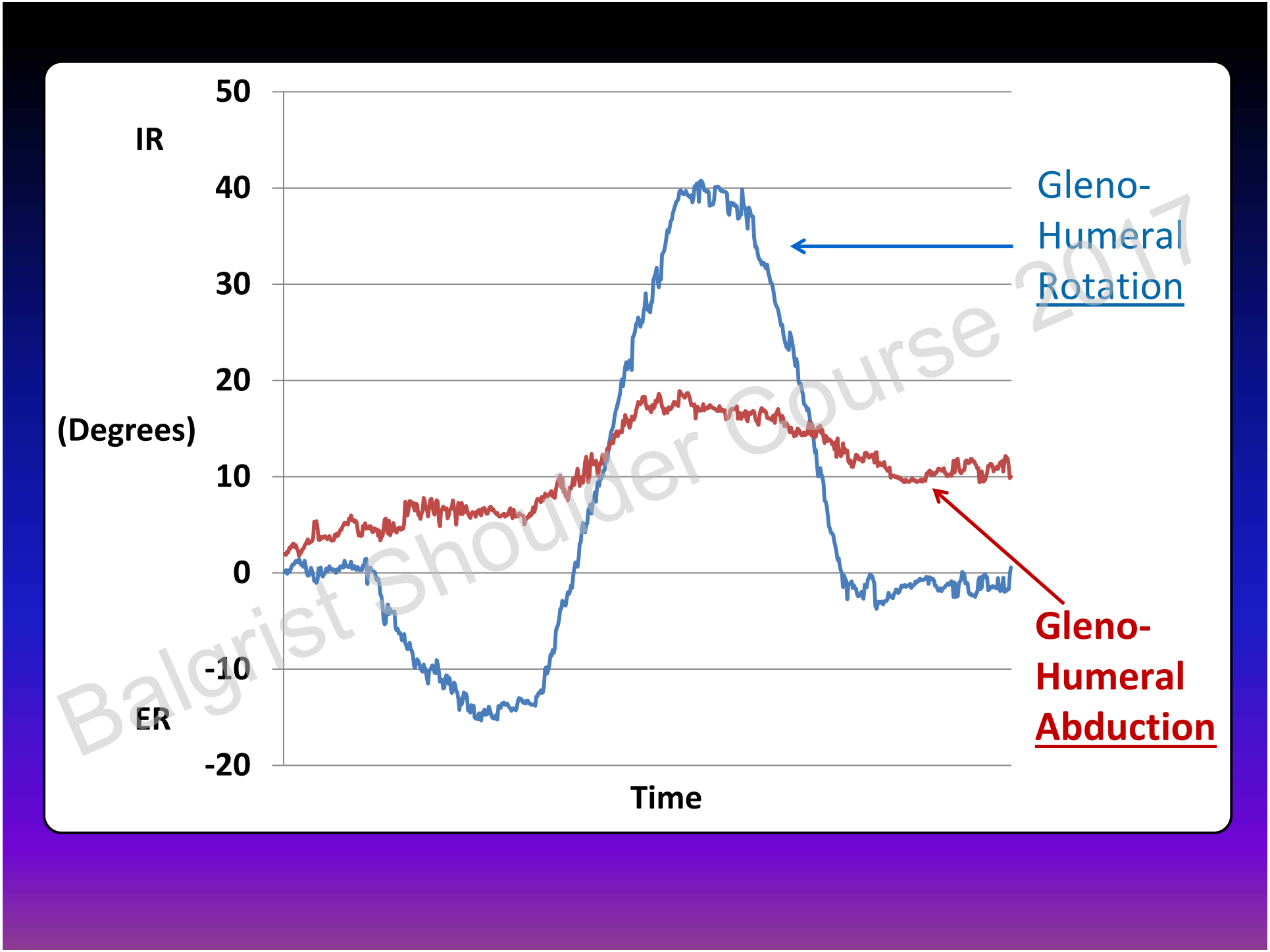
- Video-based Motion Analysis (VMA)
- Capture patient shoulder kinematics
  - *Glenohumeral* and Scapulothoracic motion

Objective #1: Predicting Impingement




50
IR
40
30
20
(Degrees)
10
0
-10
ER
-20
Time
Gleno-
Humeral
Rotation
Gleno-
Humeral
Abduction
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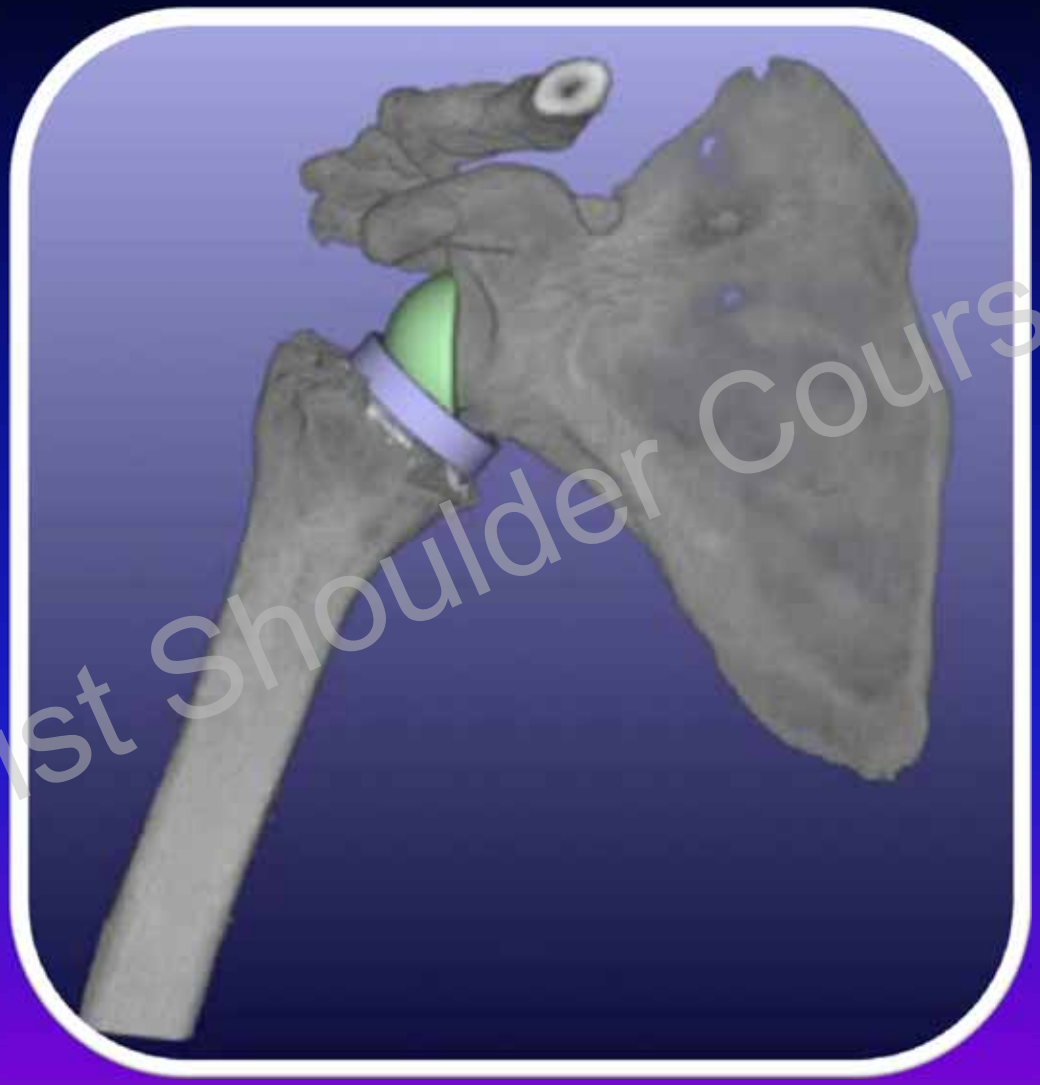
Objective #1: Predicting Impingement



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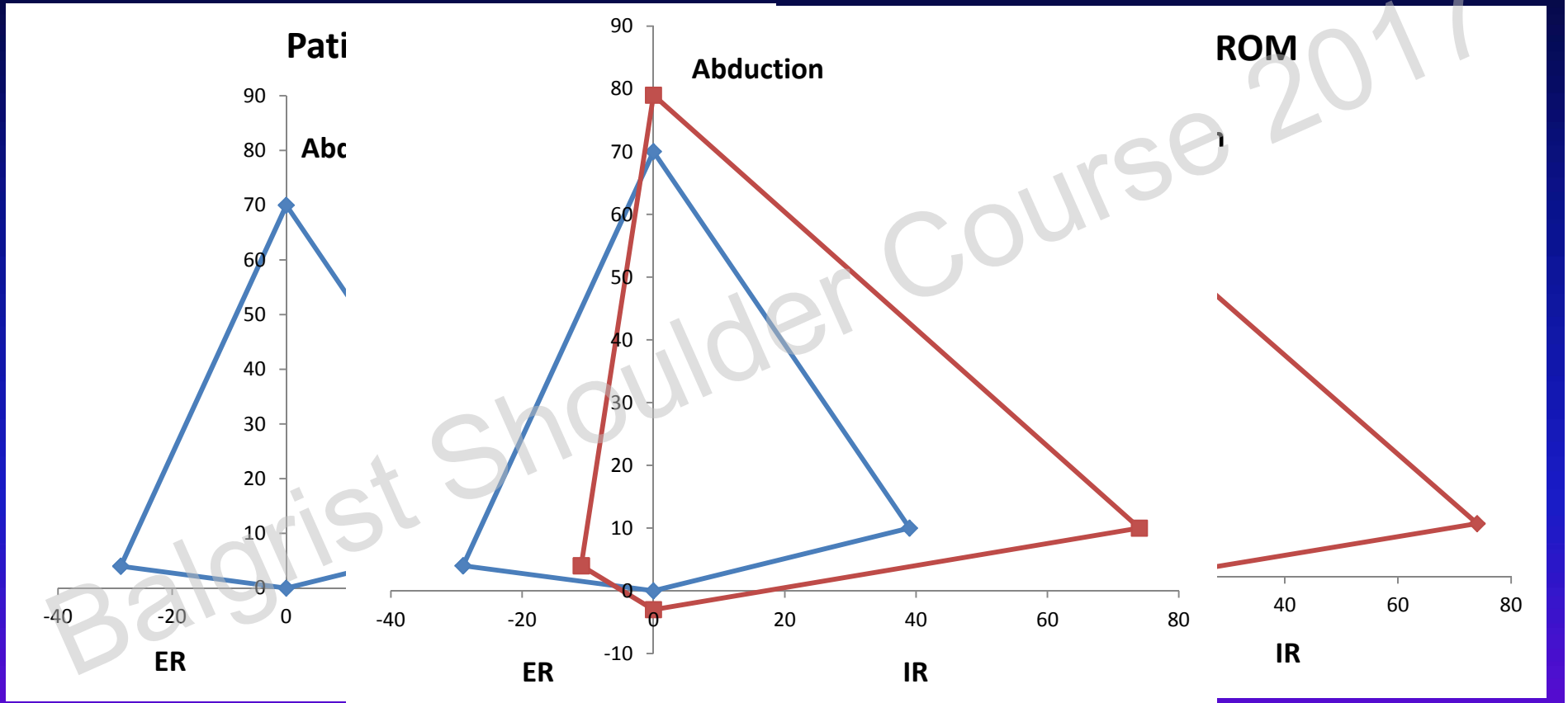

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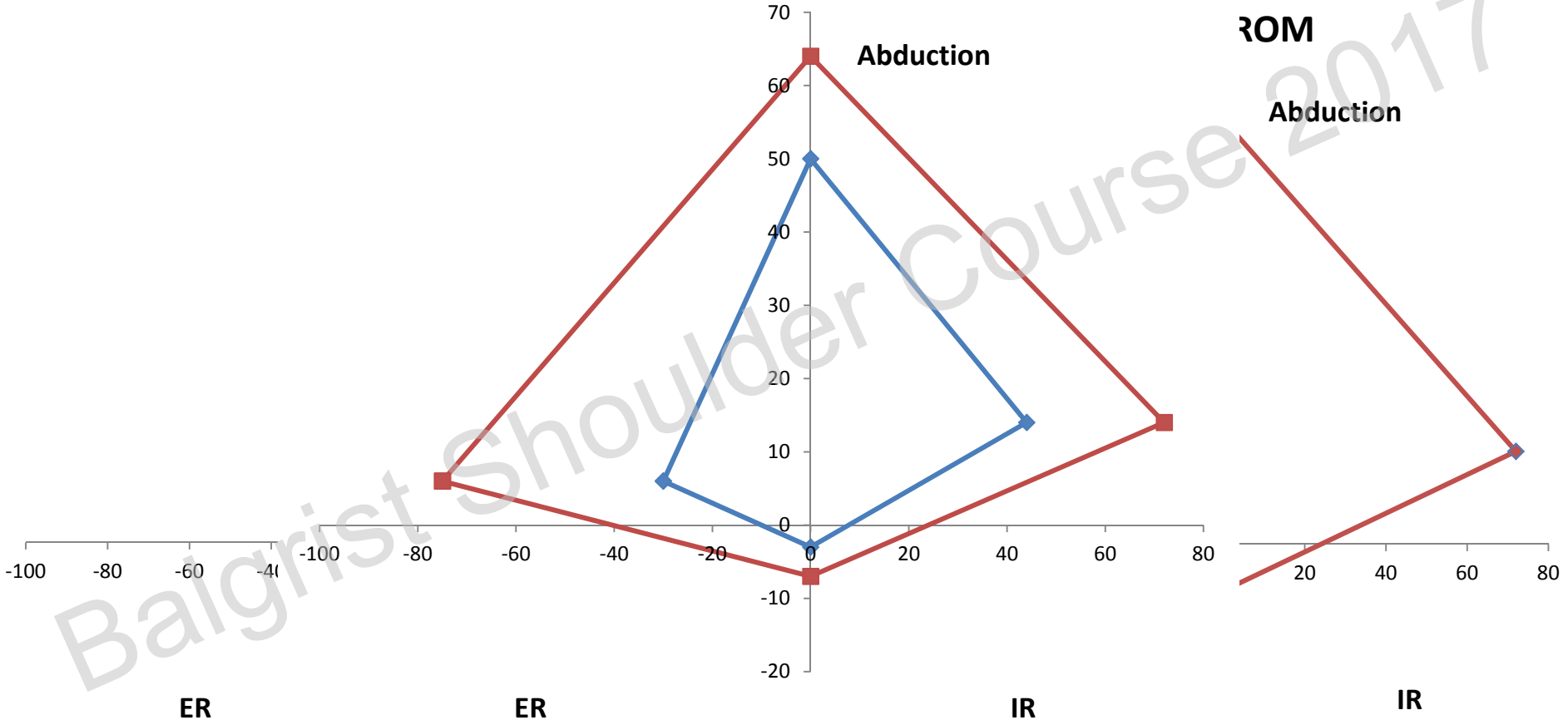
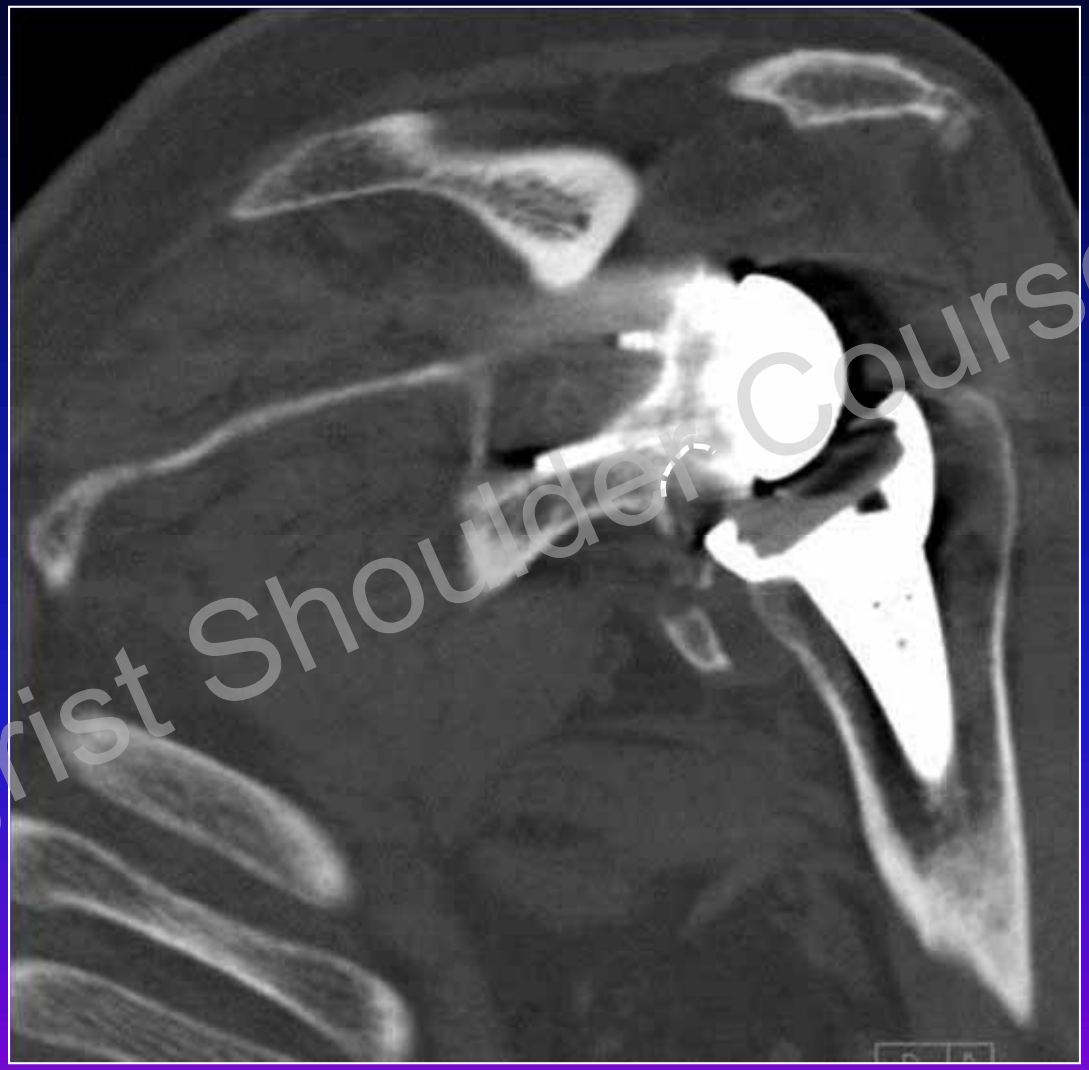


Objective #1: Predicting Impingement



Objective #2: Patient and Prosthetic Factors

Scapular Neck Length

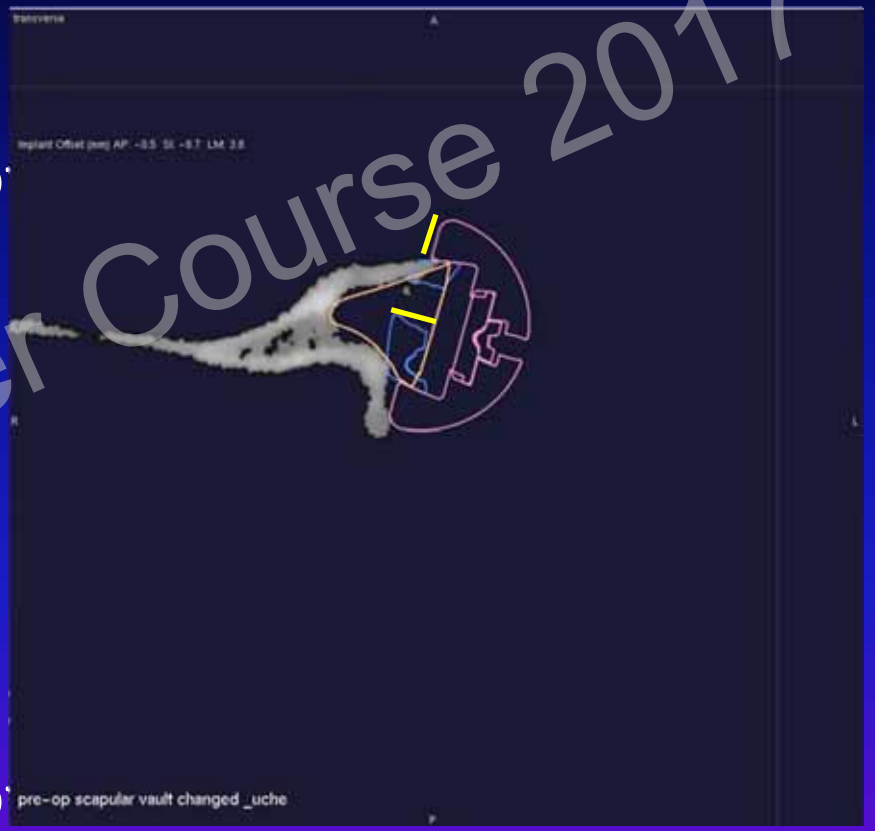
Premorbid joint

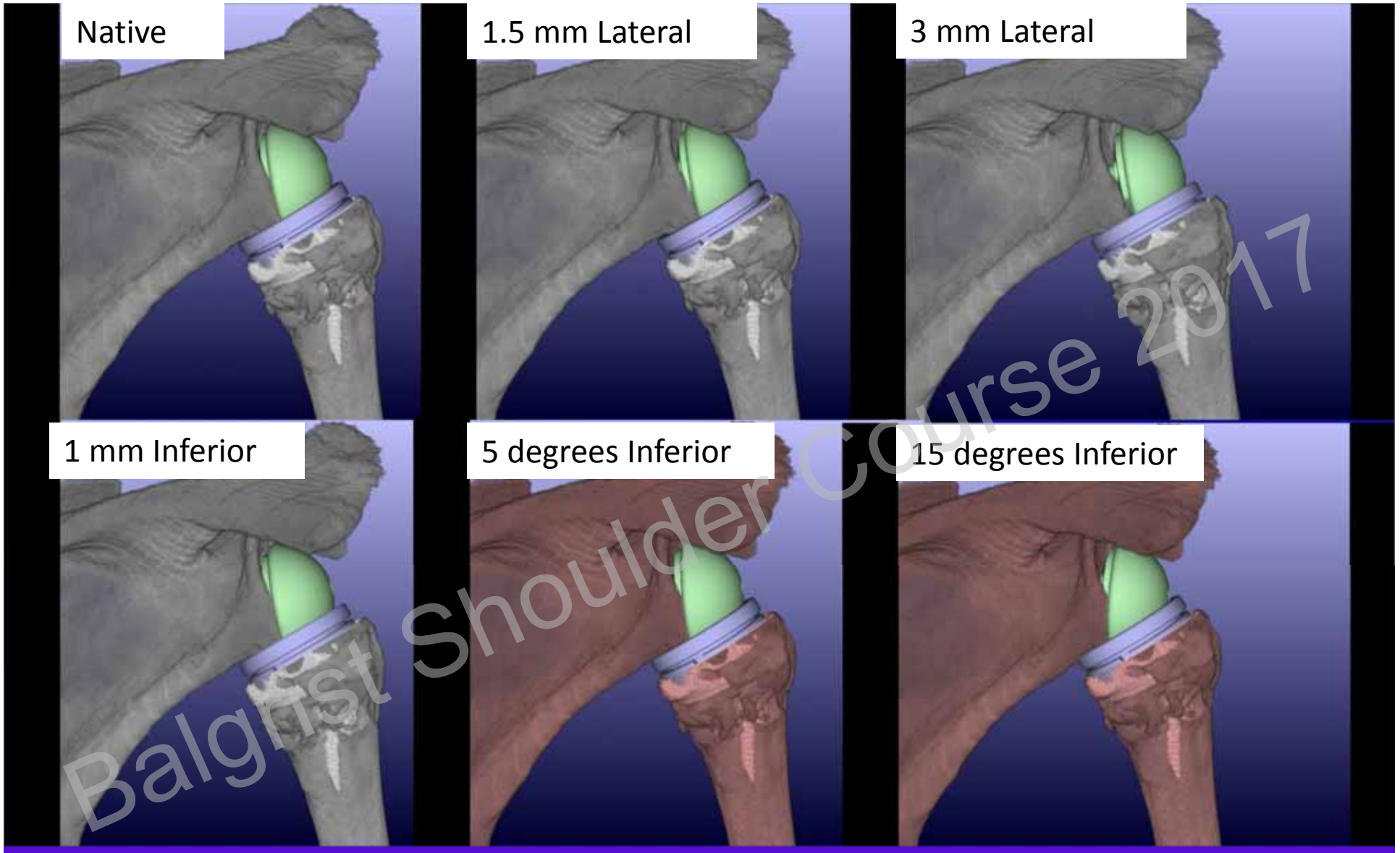
Use of three-dimensional computed tomography for the analysis of the glenoid anatomy

Young W. Kwon, MD, PhD, Kimerly A. Powell, PhD, Jae Kwang Yum, MD, John J. Brems, MD, and Joseph P. Iannotti, MD, PhD, *Cleveland, OH*

Objective #2: Patient and Prosthetic Factors

- Implant Inferiorization:
  - Glenosphere clearance o
    the scapular neck
- Implant Lateralization:
  - Implant COR relative to
    premorbid jointline (as
    determined by vault)
- Implant Posteriorization
  - Glenosphere clearance o
    the posterior glenoid rim





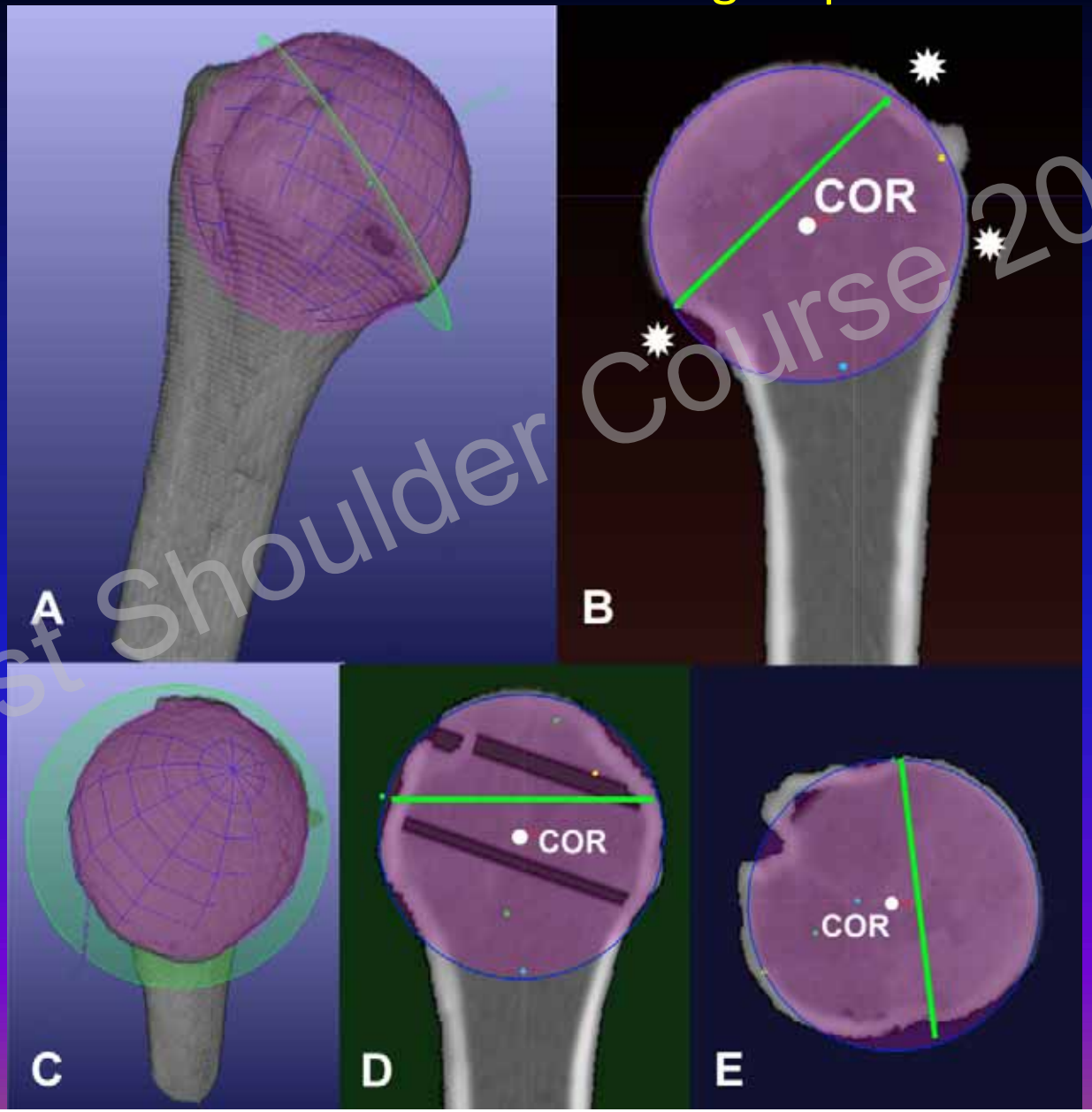
How is impingement affected if the ROM remains the same and the implant were placed in a different position for that patient?

What is an Anatomic Reconstruction of the Humeral Head and How do you Define it?
Role of Radiographs

Clinical Consequences of Malposition or Overstuffing

- Stiffness
- Subscapularis tears
- Glenoid loosening
- Instability
- We don’t know the limit of deviation to avoid these problems
- But we now know how to measure the correct humeral head size and its location

The Normal Humeral Head can be approximated by a sphere defined by three lateral landmarks in the sagital plane



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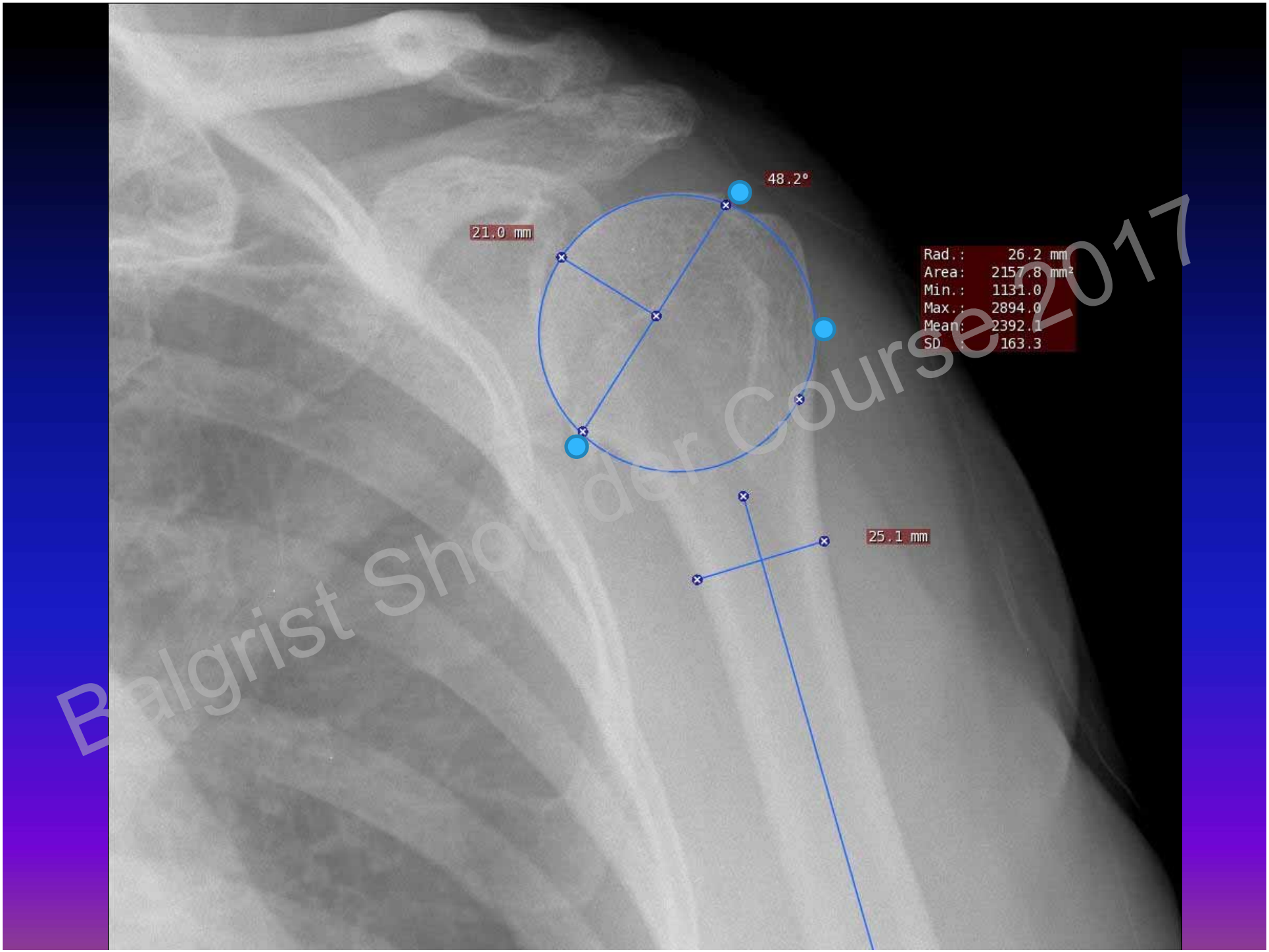
JSES 2013


48.2°
21.0 mm
Rad.: 26.2 mm
Area: 2157.8 mm²
Min.: 1131.0
Max.: 2894.0
Mean: 2392.1
SD : 163.3
25.1 mm
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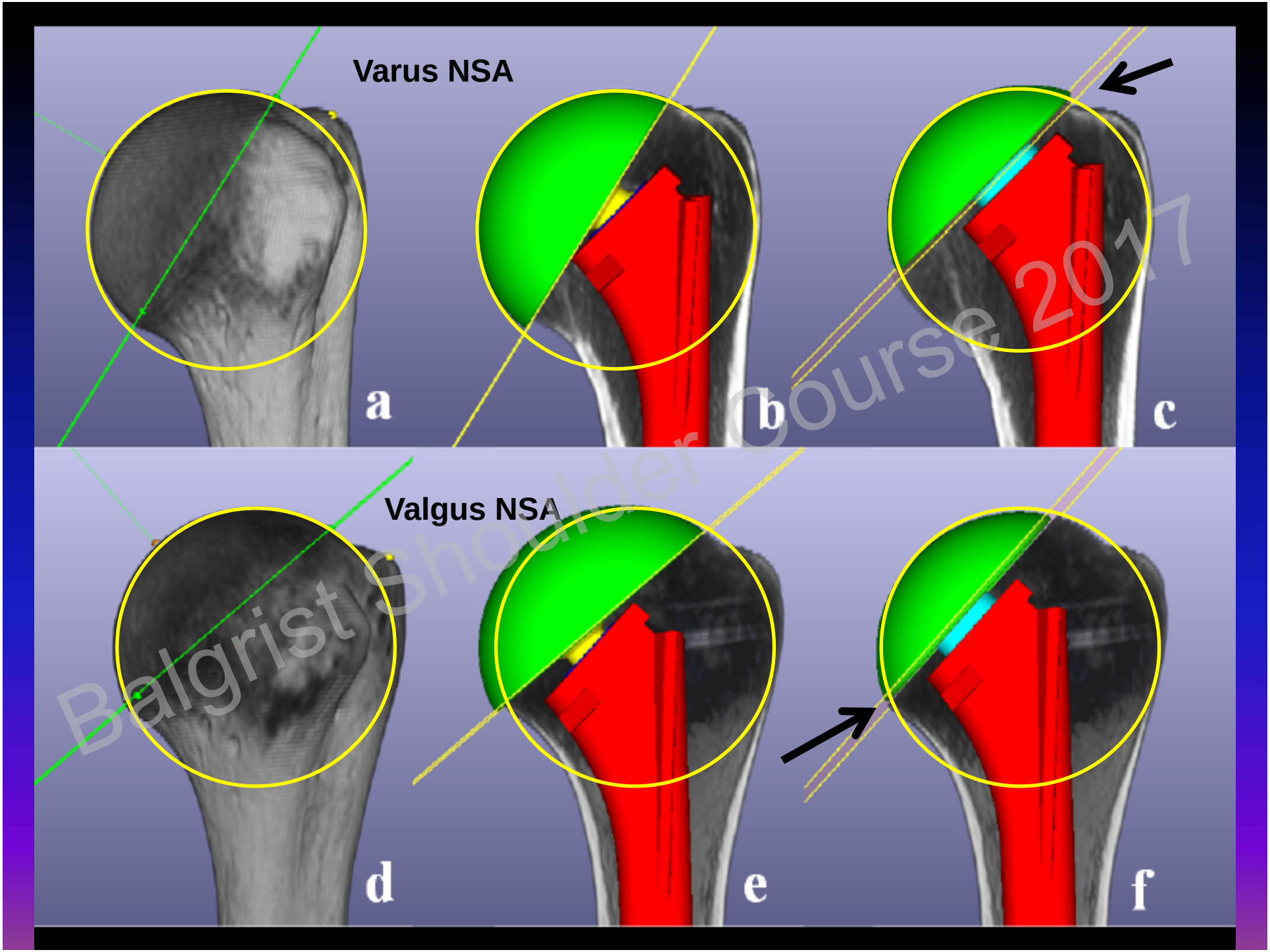
Varus NSA
a
b
c
Valgus NSA
d
e
f
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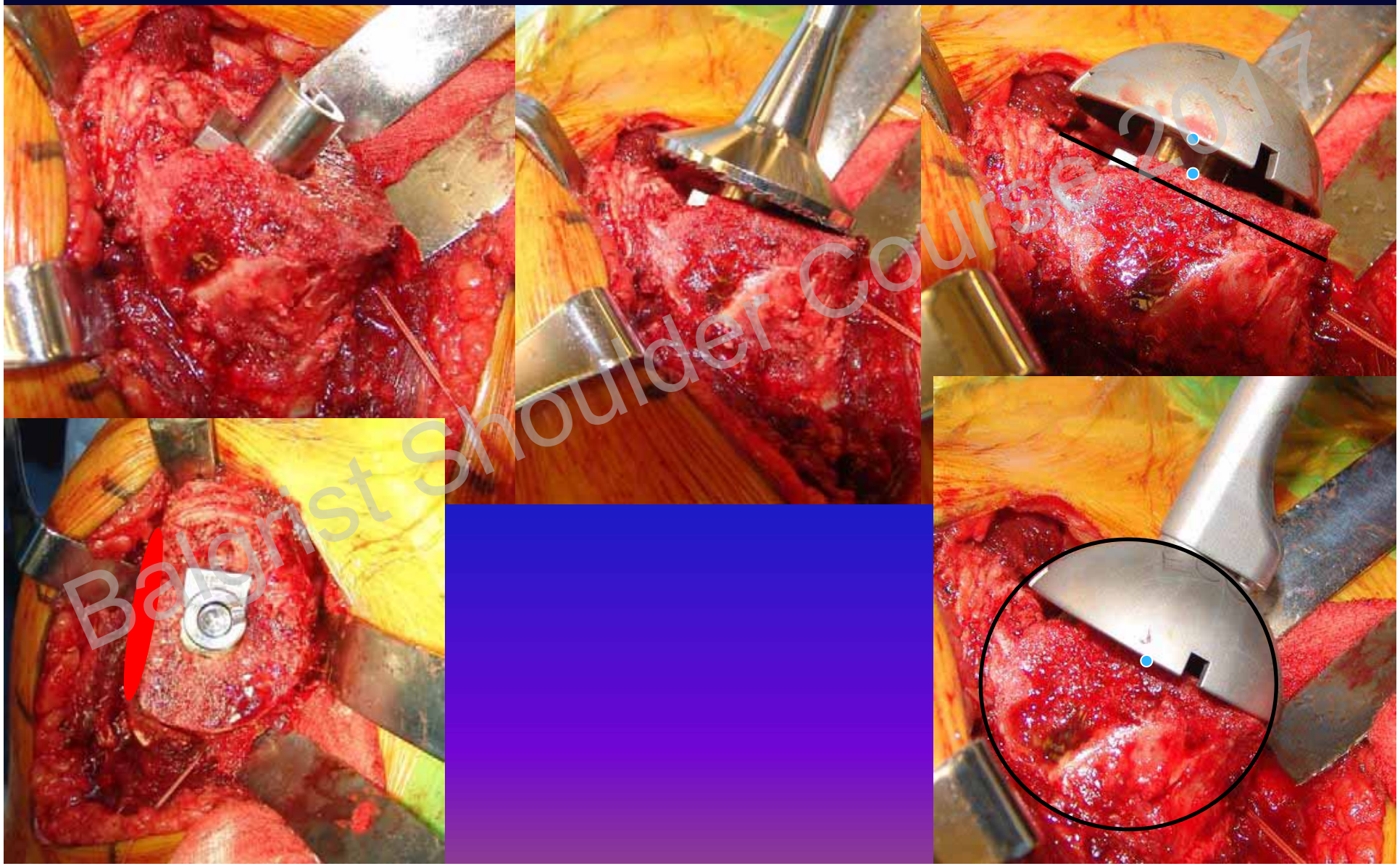
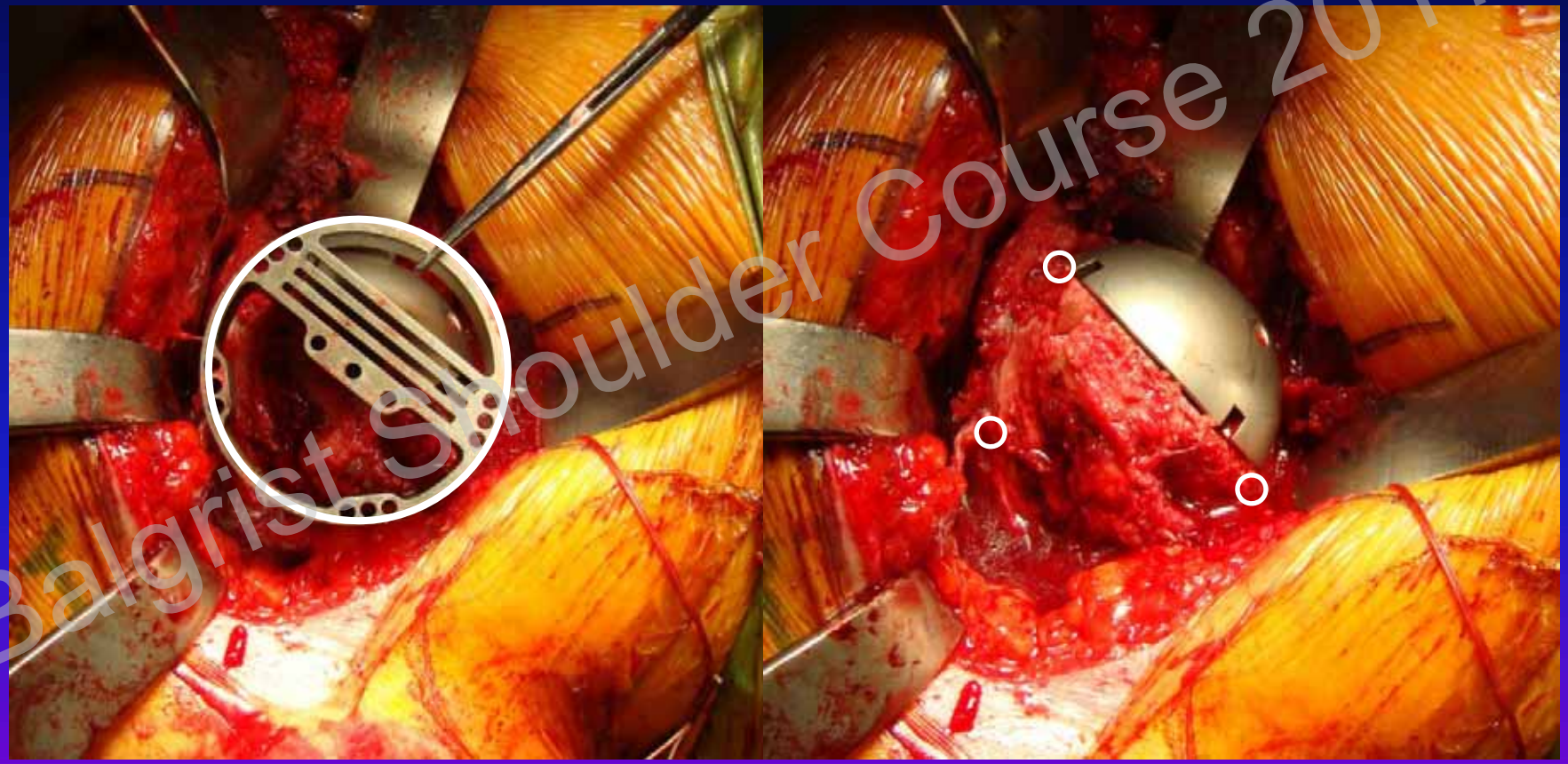
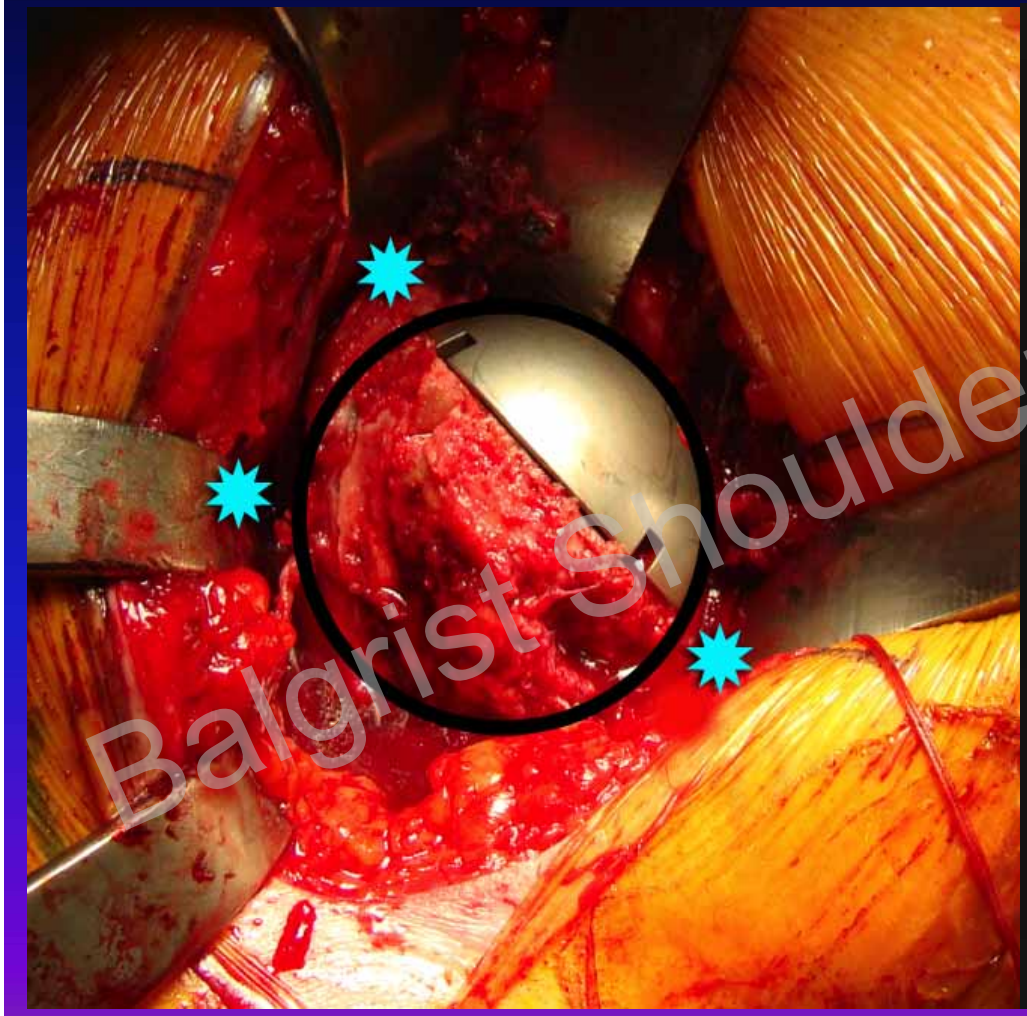
Valgus Neck – Shaft Angle



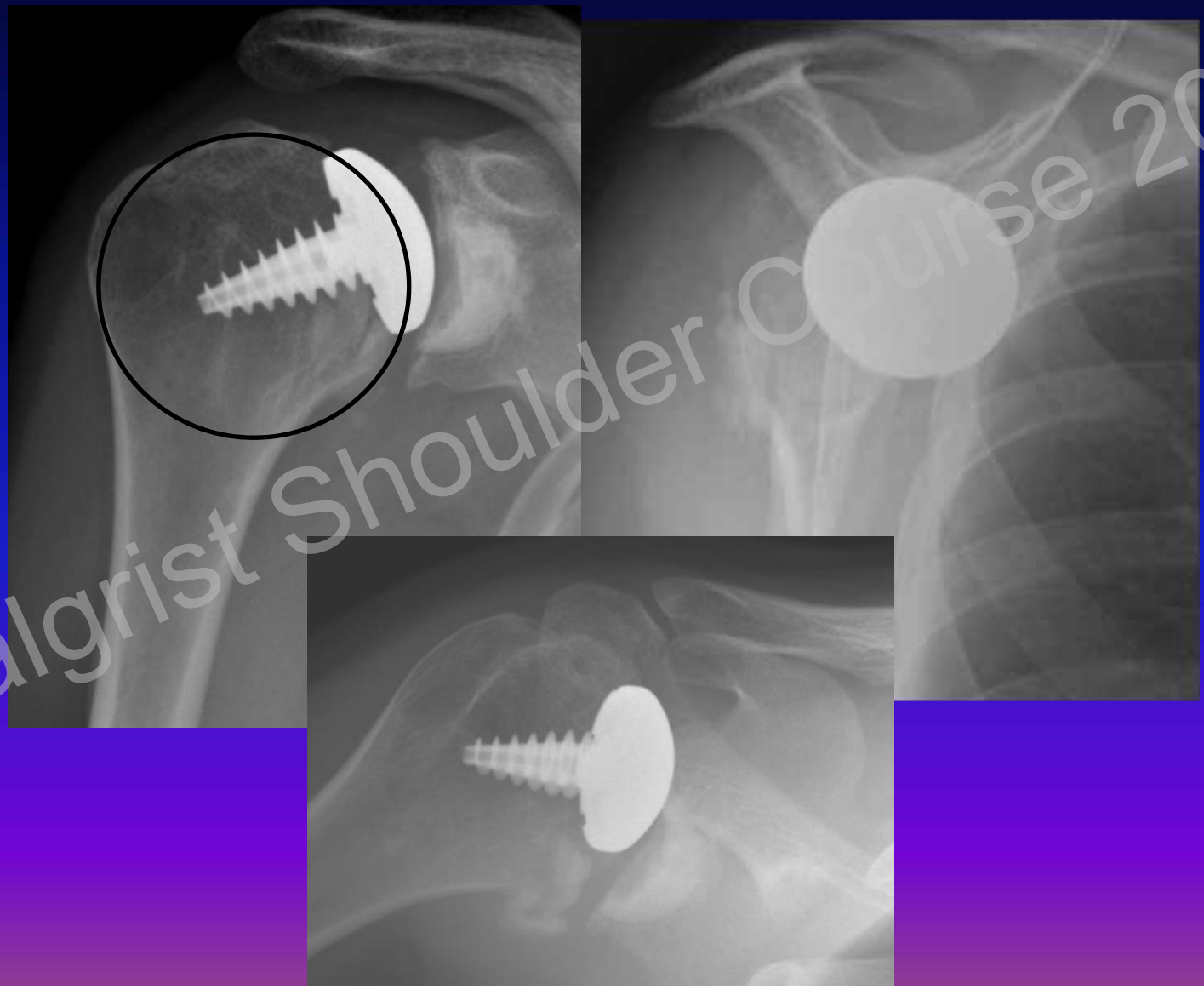
Intra-operative assessment of humeral head size and location



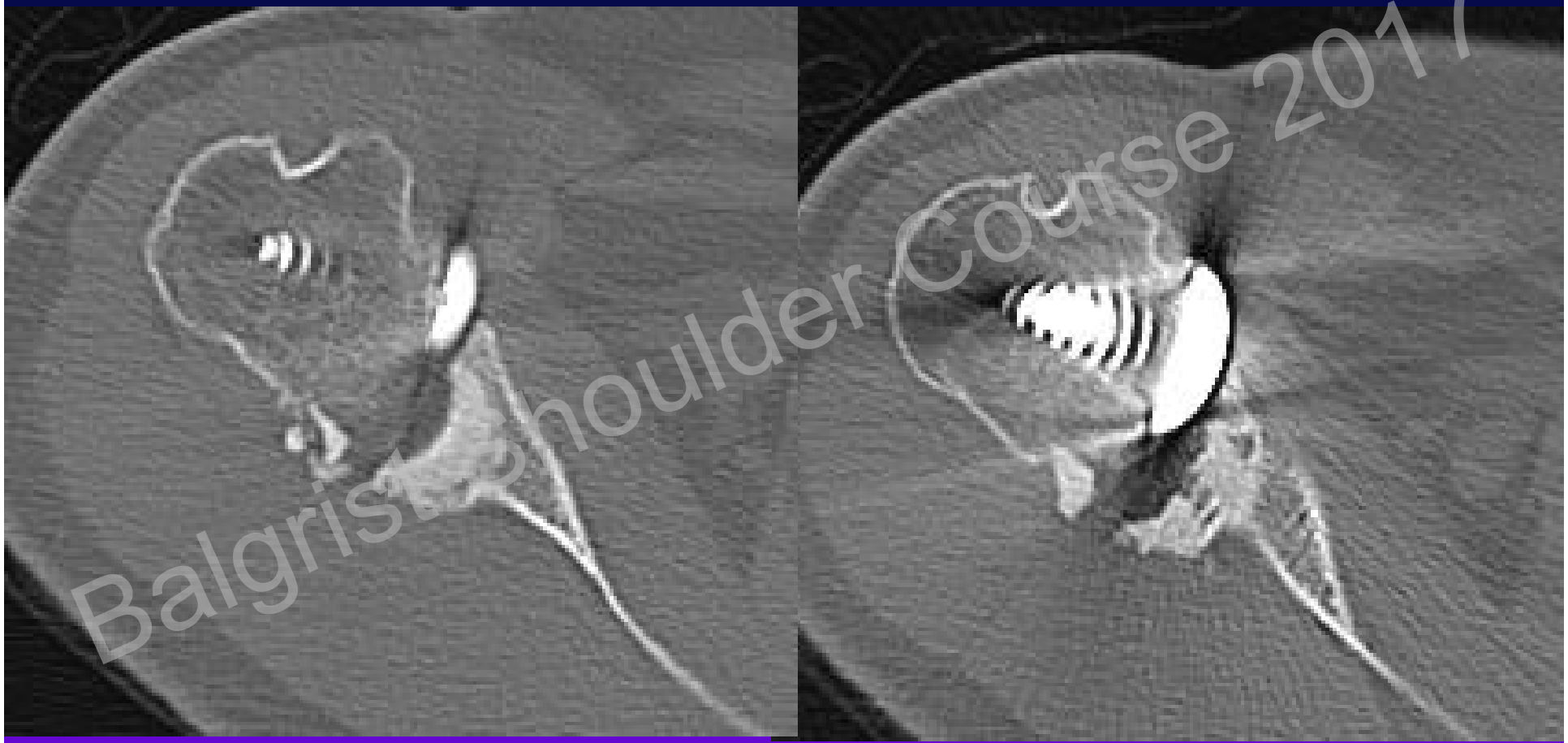
Intraoperative templating 2D post operative assessment



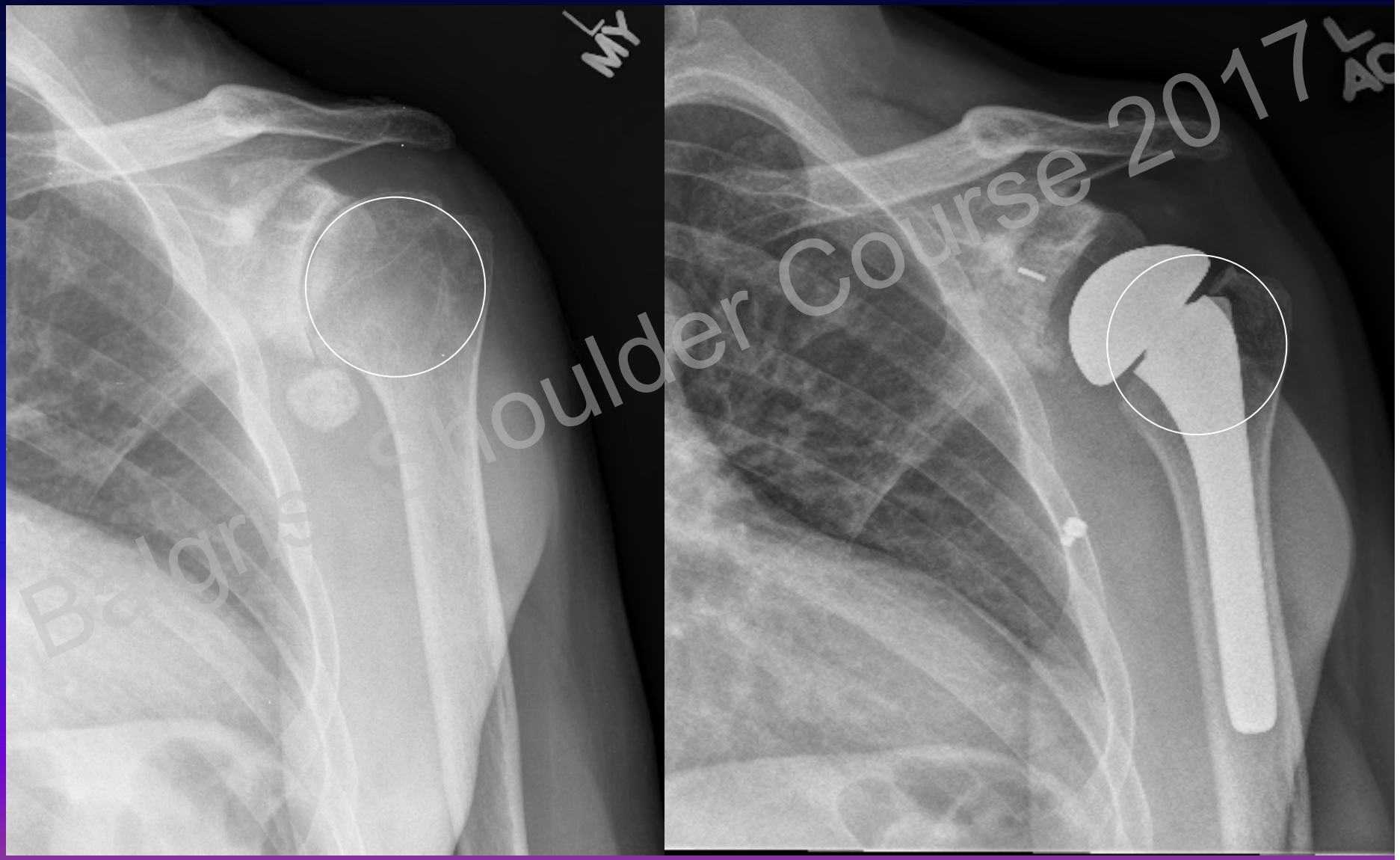
Gross Failure: Humeral Head Over-sizing, Glenoid Malposition and Dislocation



Humeral Head Oversizing, Glenoid Malposition and Dislocation



Standard OA Shoulder:
What Went Wrong?



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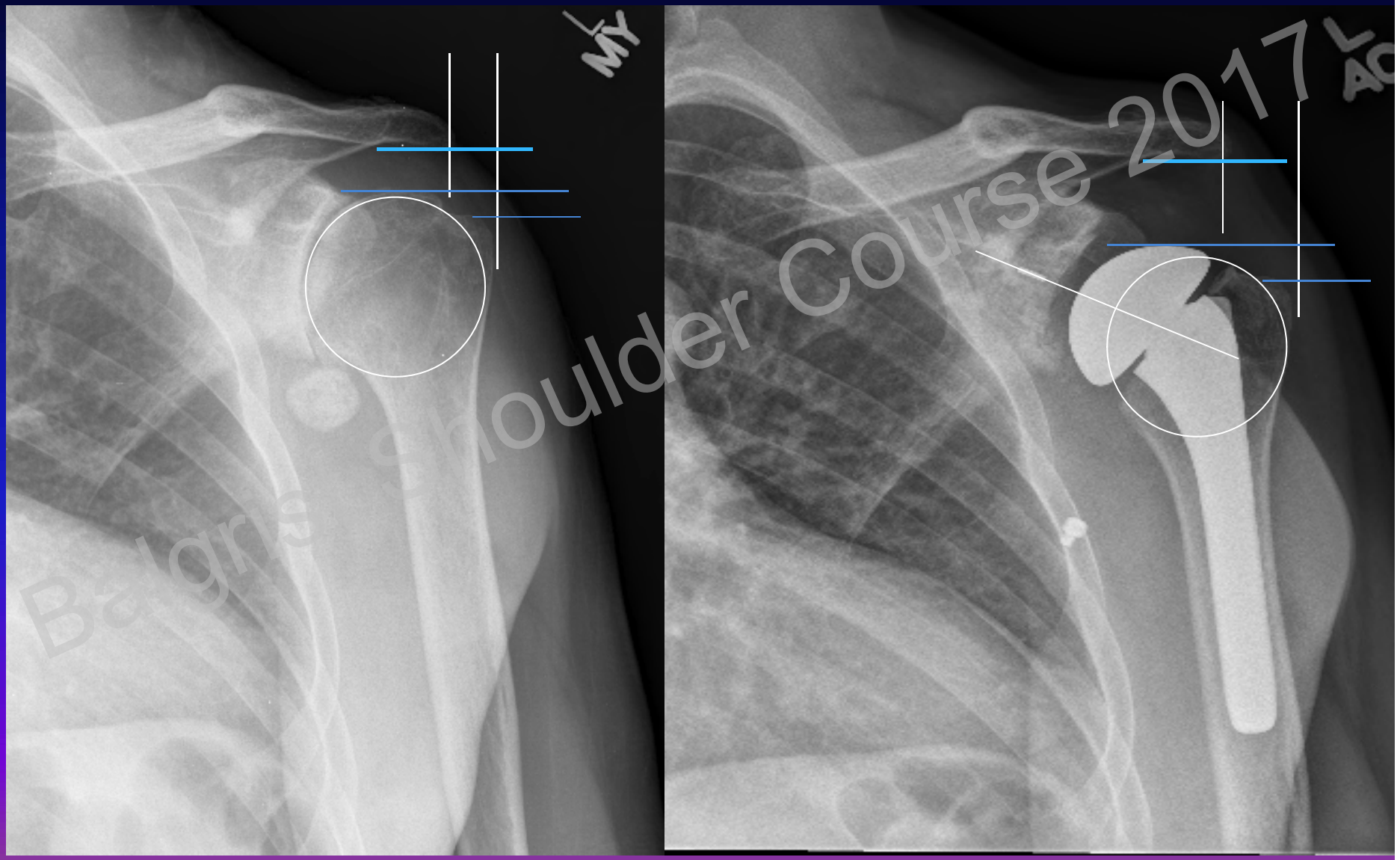
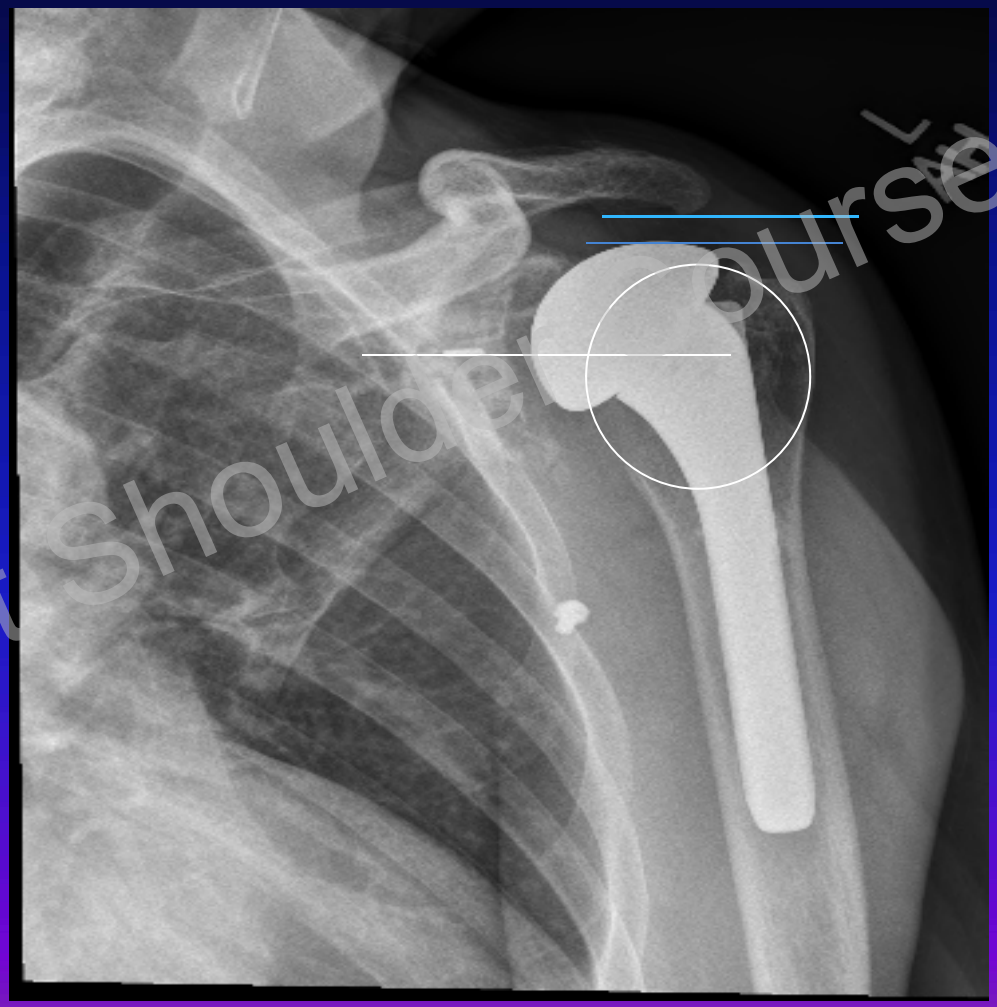
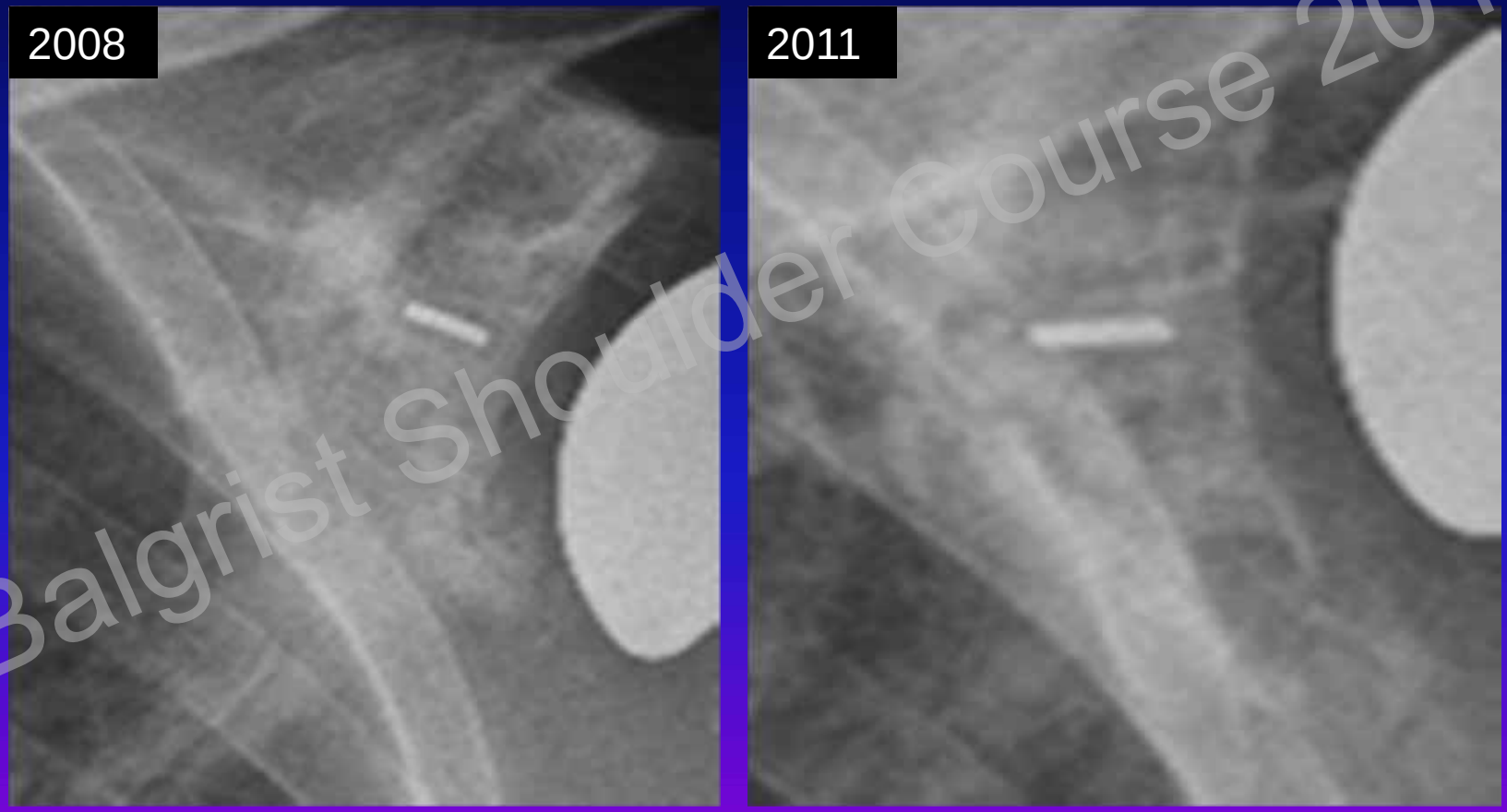


Three Years Later

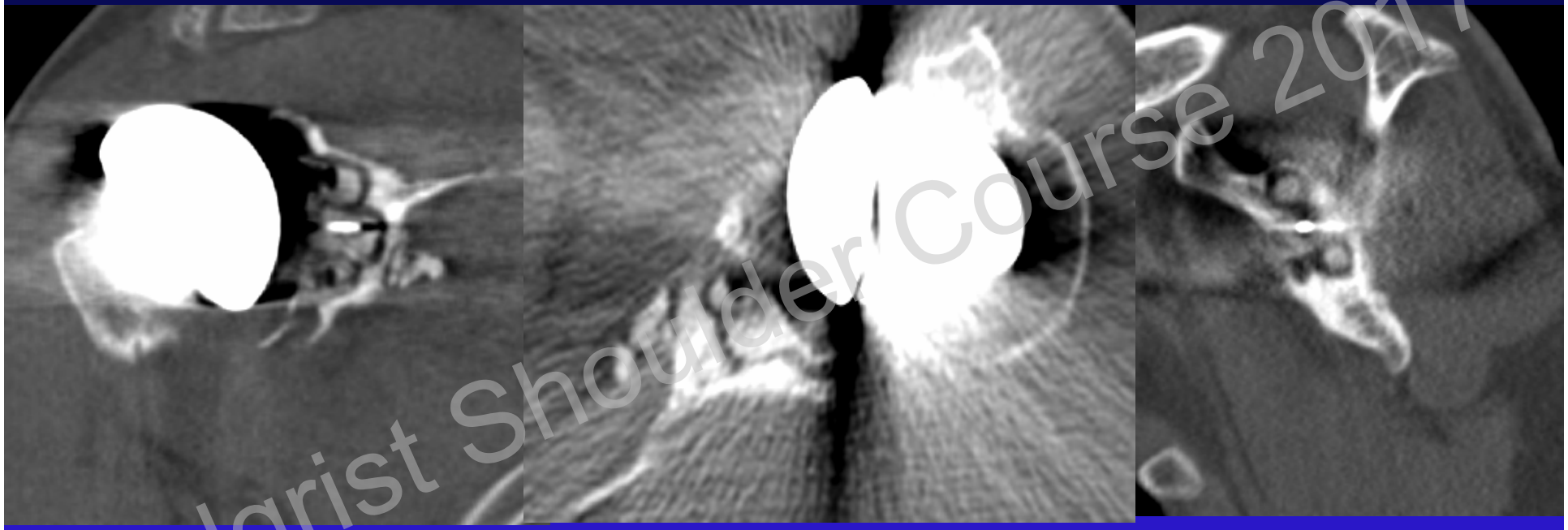
Did it get better with physical therapy?



Glenoid Loosening

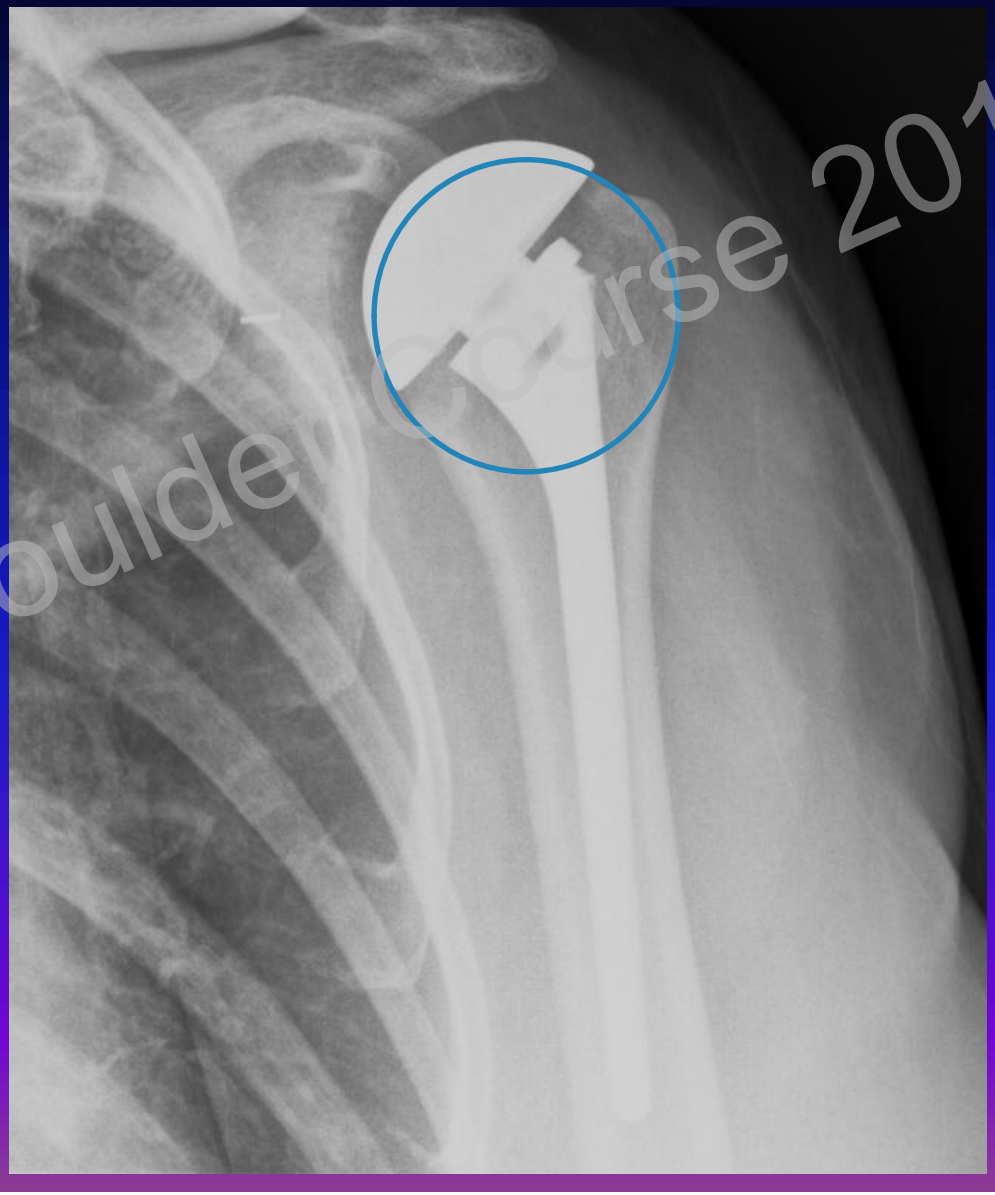


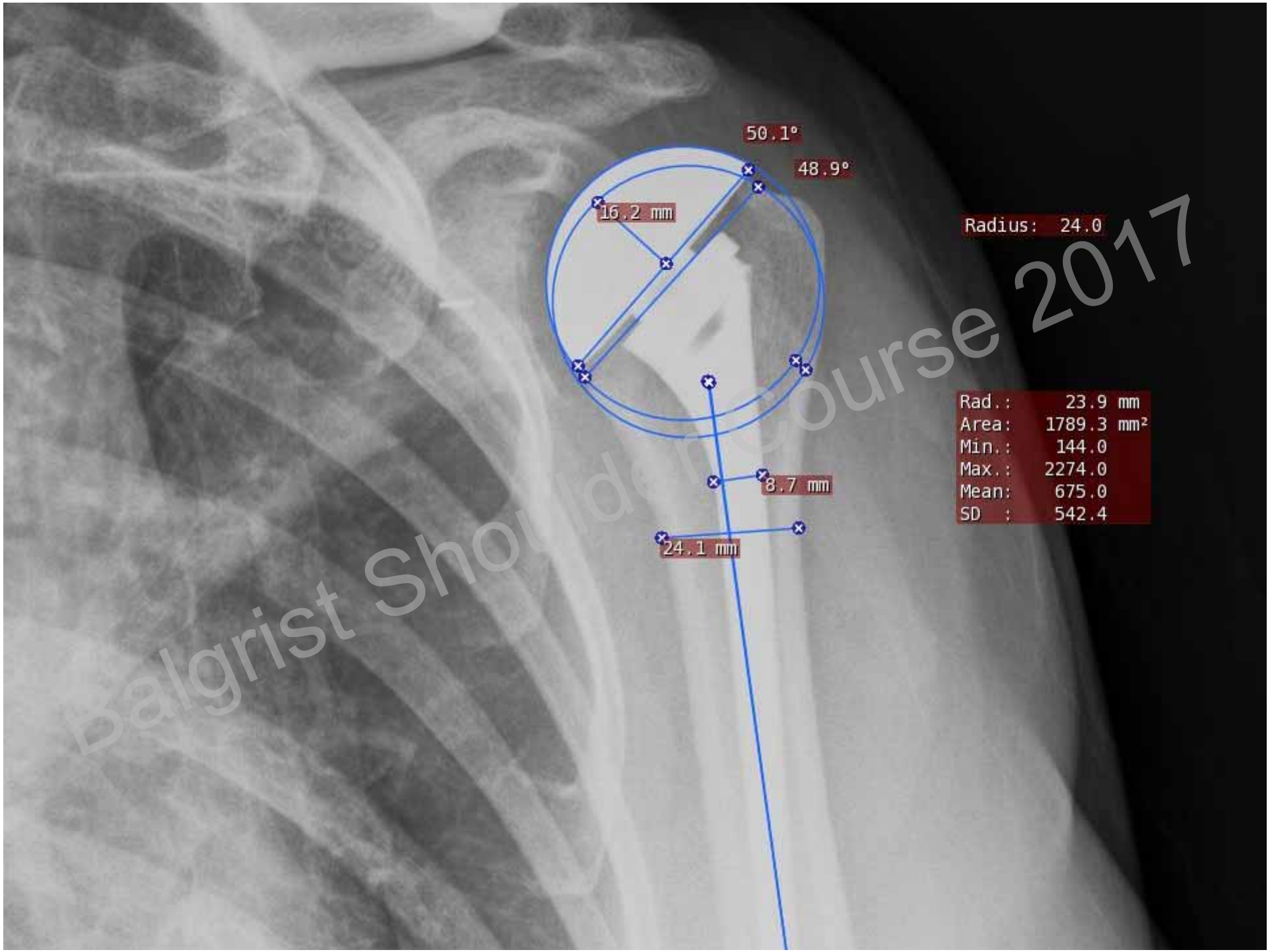
CT Three Years Post Op



Evaluation Patient Series

- Assessing Post operative humeral head size and position
- 125 cases
- 5 surgeons
- Stemmed and
- Resurfacing




50.1°
48.9°
16.2 mm
Radius: 24.0
Rad.: 23.9 mm
Area: 1789.3 mm²
Min.: 144.0
Max.: 2274.0
Mean: 675.0
SD : 542.4
8.7 mm
24.1 mm
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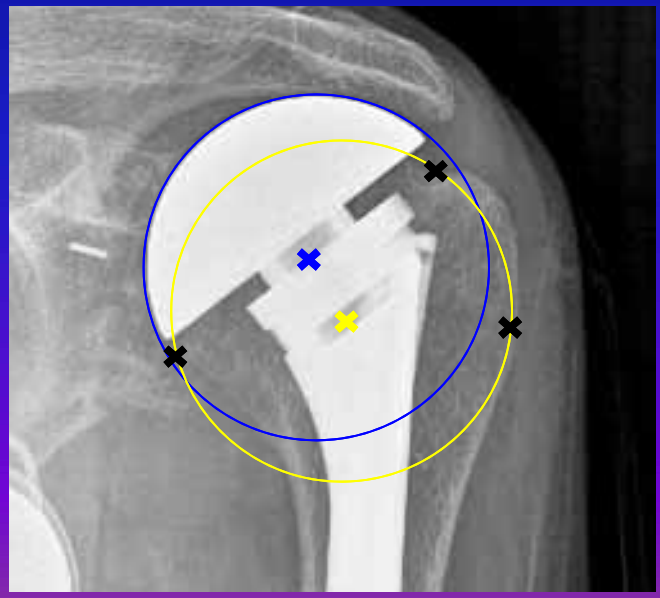
Methods

- Outcome measure: distance between CORs (deviation)
- > 3mm deviation = outlier
- For outliers, main factors causing the deviation was assessed
  - Humeral neck cut or humeral head reaming
  - Prosthetic head size (ROC and height)



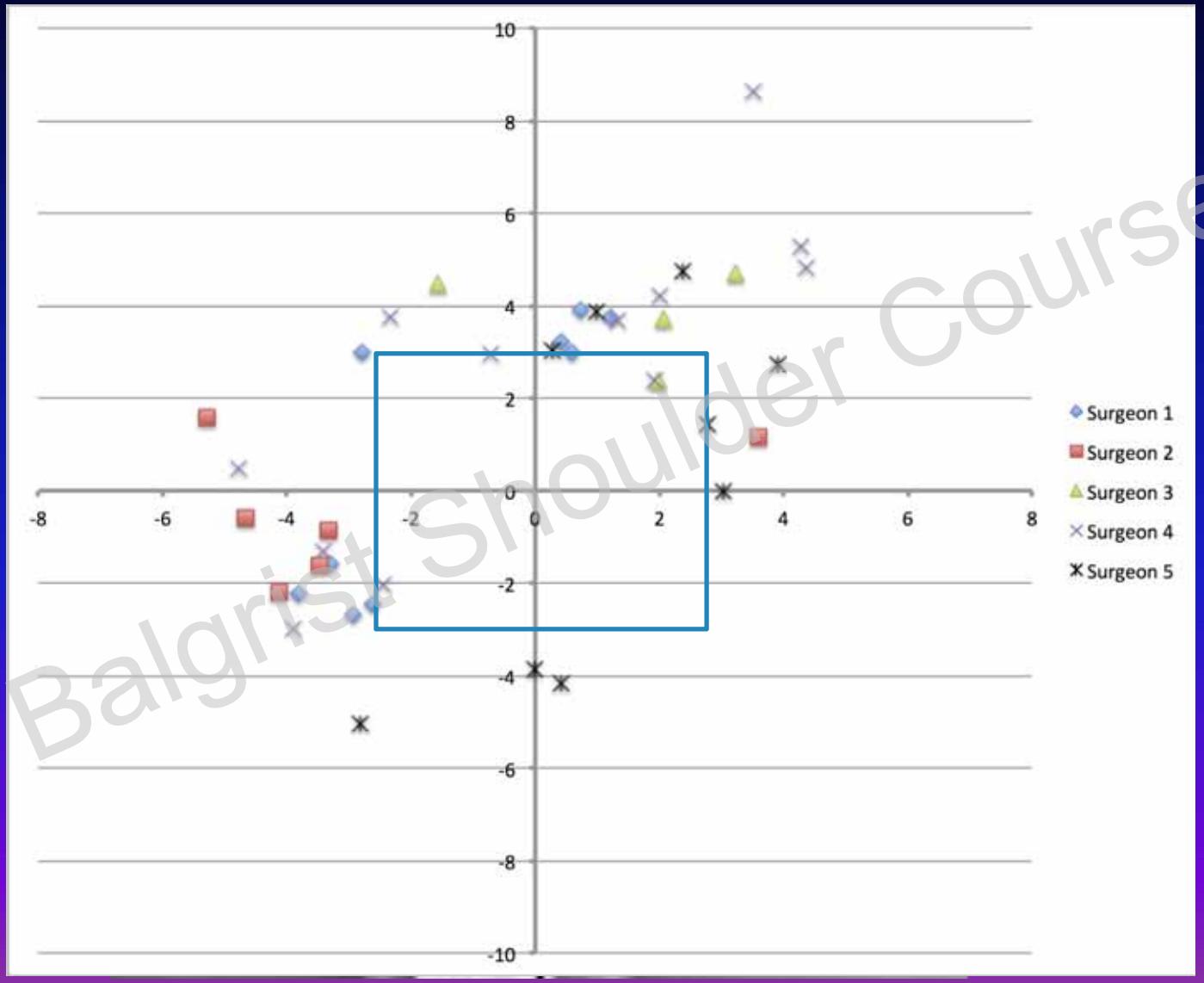
Methods

Results

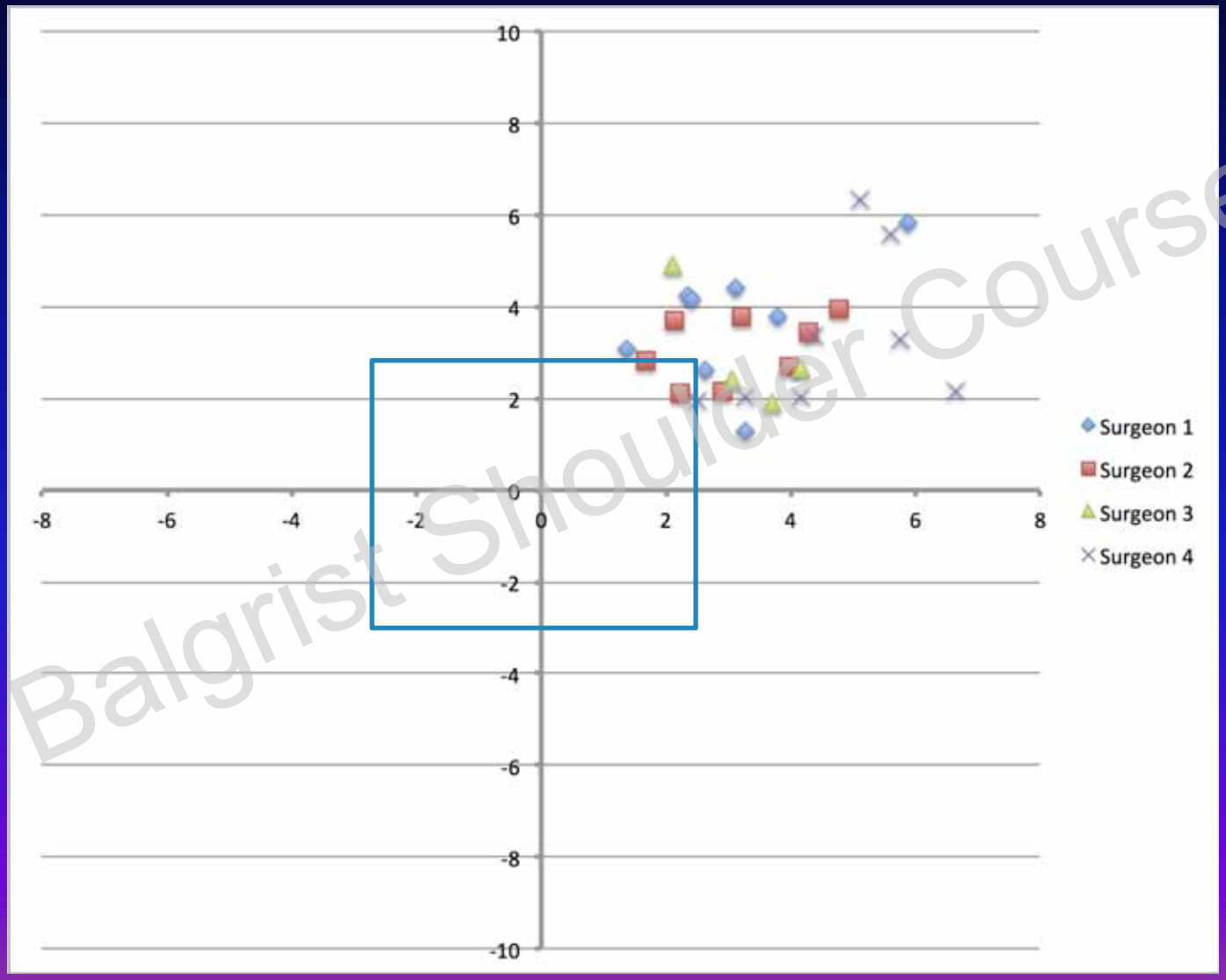
31.2% outliers

65.1% outliers

Stemmed Prosthetic Outliers

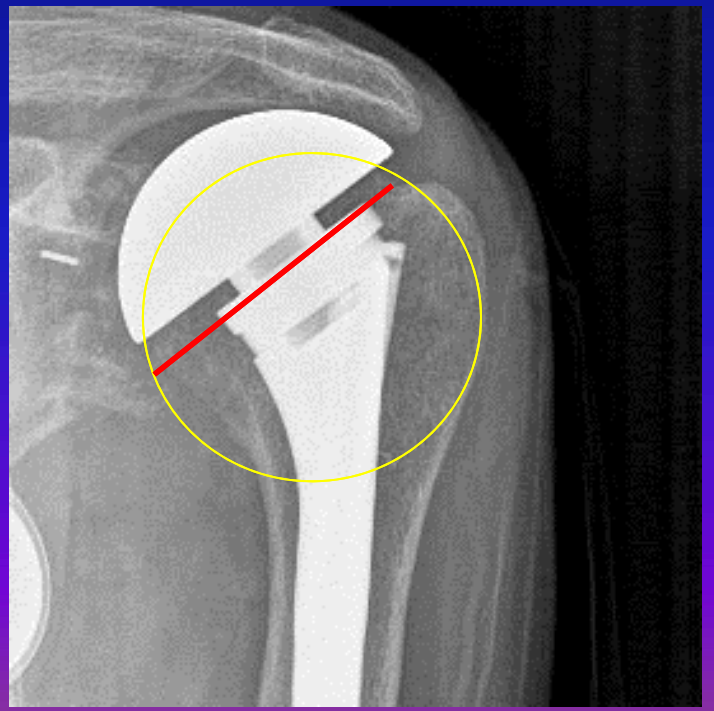


Resurfacing Outliers



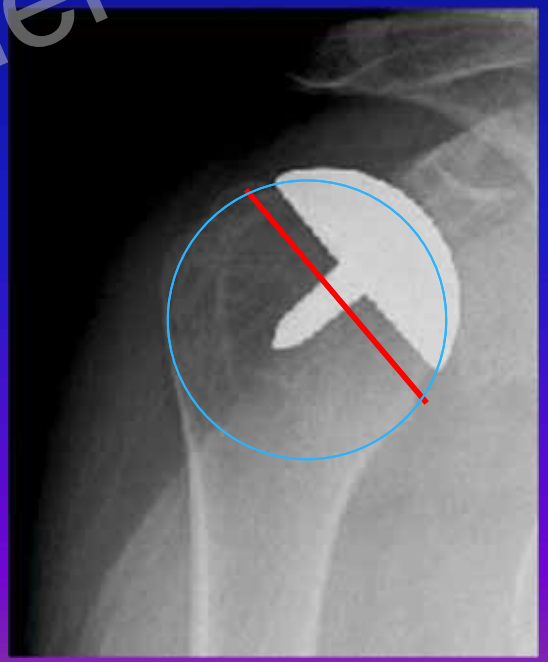
Overall Results

- Main cause for deviation in stemmed cases:
  - Improper humeral head selection: 56.4%
  - Improper humeral neck cut: 20.5%
  - Combination of both: 23.1%



Overall Results

- Main cause for deviation in resurfacing cases:
  - Inadequate humeral head reaming: 100%
  - Improper resurfacing size selection: 9.3%

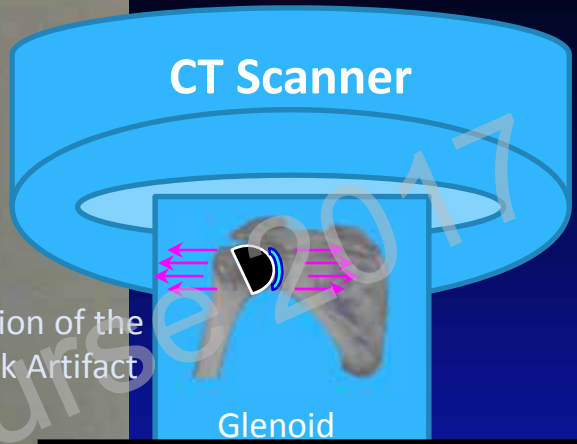


Assessment of the Glenoid Component
The Role of 3D CT Imaging

Techniques

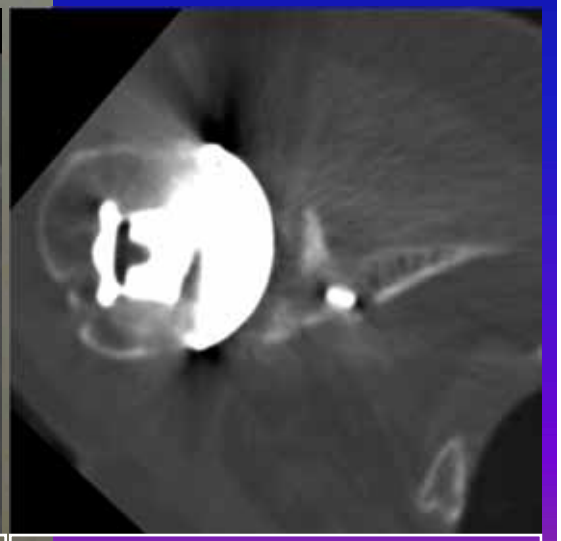
- Metal artifact reduction
  - Positional
  - Software
- 3D reconstruction
  - Scapula Coordinate System
- Image Registration
  - Bones and implants

Positional Reduction of the Metal Artifact



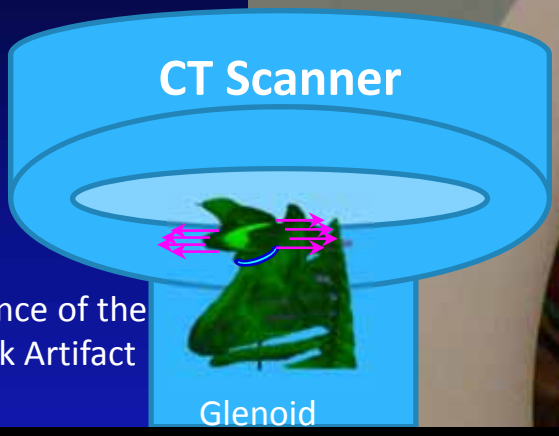
Conventional Position

Coronal (arm at the side)



Axial (arm at the side)

Positional Reduction of the Metal Artifact



Lateral decubitus Position

Coronal (arm overhead)

Axial (arm overhead)

Edwards and Emory

Software Reduction of Metal Artifact: Iterative Metal Artifact Reduction (IMAR)

- Technique developed by Siemens [1,2]
- Standard reconstruction performed (FBP) using all the raw data
- Metal identified (threshold density 2000 – 3000 HU)
- Forward projection of metal image to identify which projections traversed through the metal
- The raw data from the metal trace discarded using linear interpolation
- To recapture the edge data that is lost, high-frequencies from the original FBP images are filtered out and added back to the MAR image close to the metal
- The final image therefore results in removal of most of the corrupt data from projections that go through the metal while minimizing creation of new artifacts and loss of data near the metal

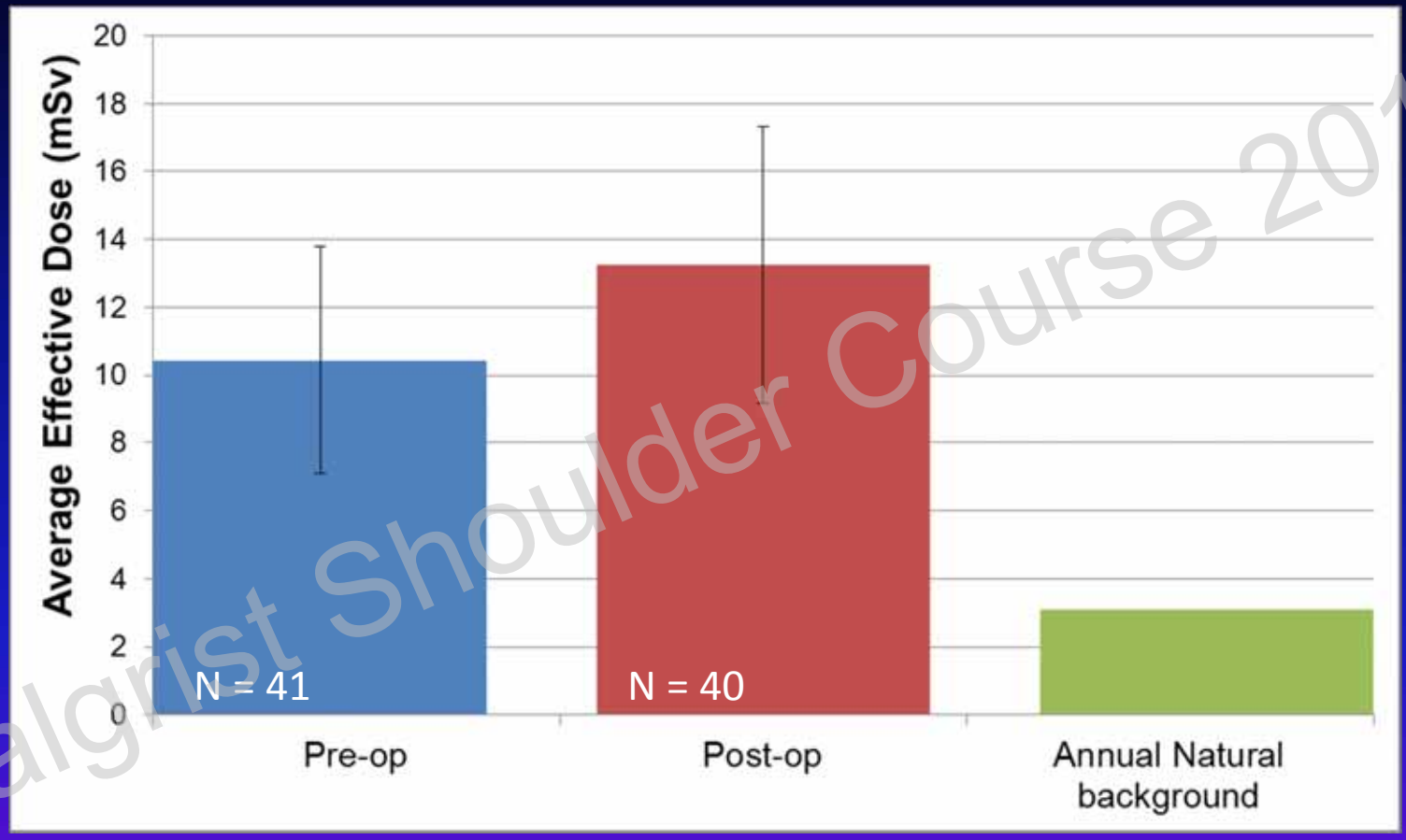
1 Meyer, E., et al., *Normalized metal artifact reduction (NMAR) in computed tomography.* Med Phys. **37**(10): p. 5482-93.
2 Meyer, E., et al., *Frequency split metal artifact reduction (FSMAR) in computed tomography.* Med Phys. **39**(4): p. 1904-16.

Radiation Exposure

- Ionizing radiation dose
  - Modern CT scanners have dose reduction protocols to reduce the radiation exposure to patients
  - The likelihood of radiation-induced malignancy is a function of the patient's age, with the lifetime risk of radiation-induced fatal cancer significantly reducing after the age of 60 years**
- Effective radiation dose
  - Radiation is naturally present in our environment
  - Average annual radiation exposure from natural sources is about 3.1 mSv
  - Current radiation exposure from CT scan is averaged 10.4 mSv with standard deviation 3.3 mSv

** Dendy and Brugmans, Br. J. Radiol, 2003

Radiation Dose



- 0.6 mm slice thickness
- Entire scapula in FOV

Metal Artifact Reduction: Position and Image Processing IMAR

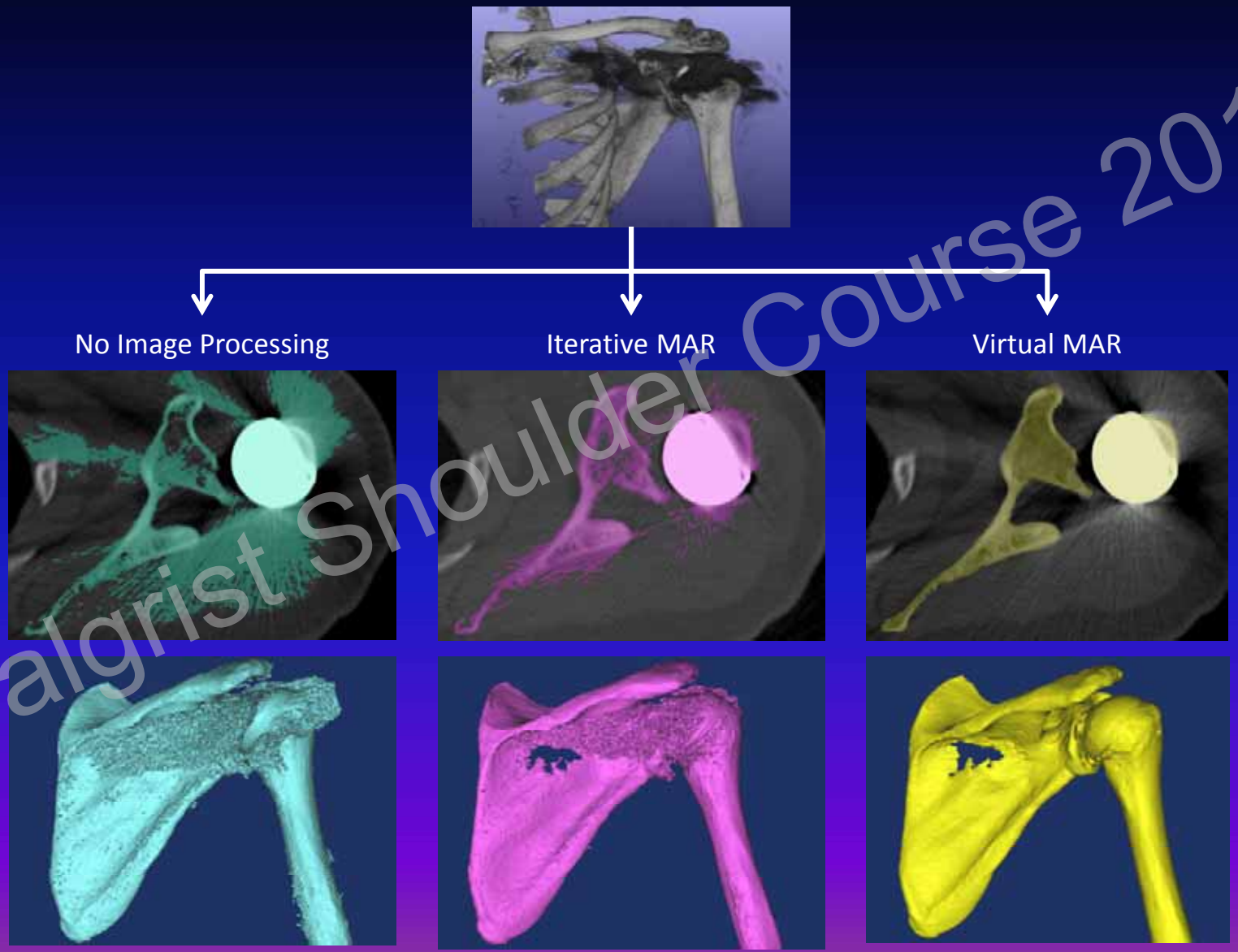
Original

IMAR

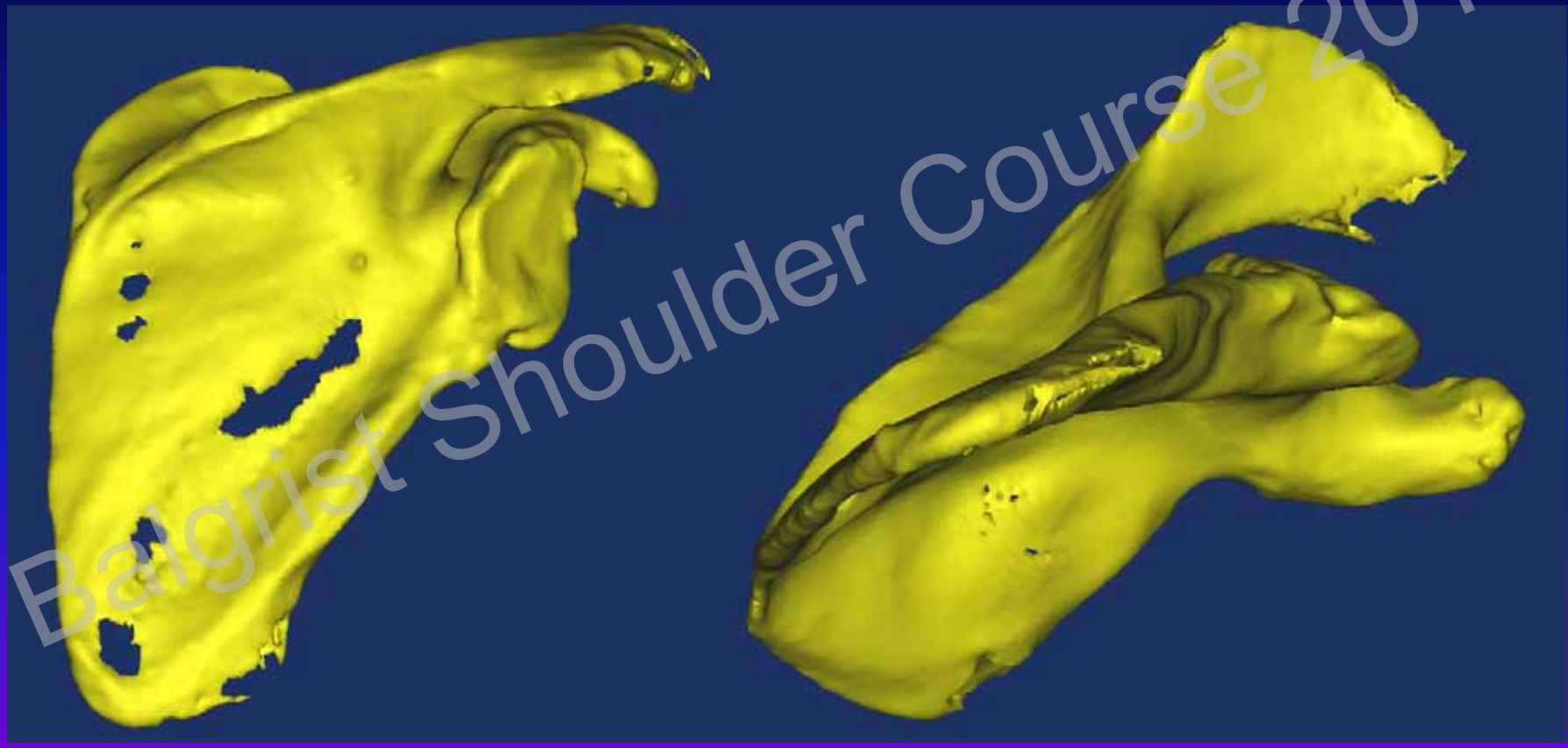
Standard Segmentation

iMAR Segmentation

Metal Artifact Reduction (MAR) 3D CT Imaging



CT1: 7/10/2012

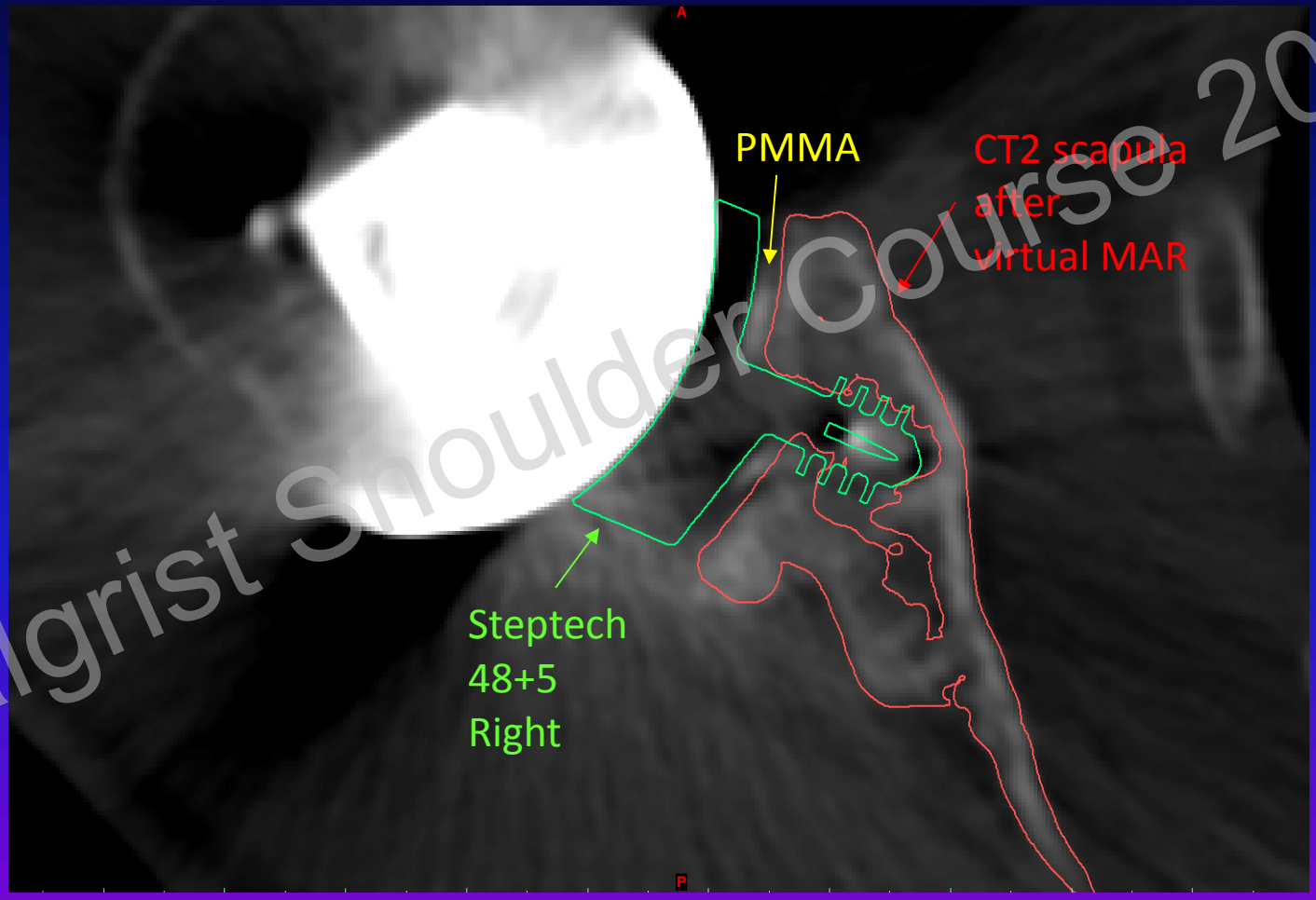


CT2: 3/19/2014

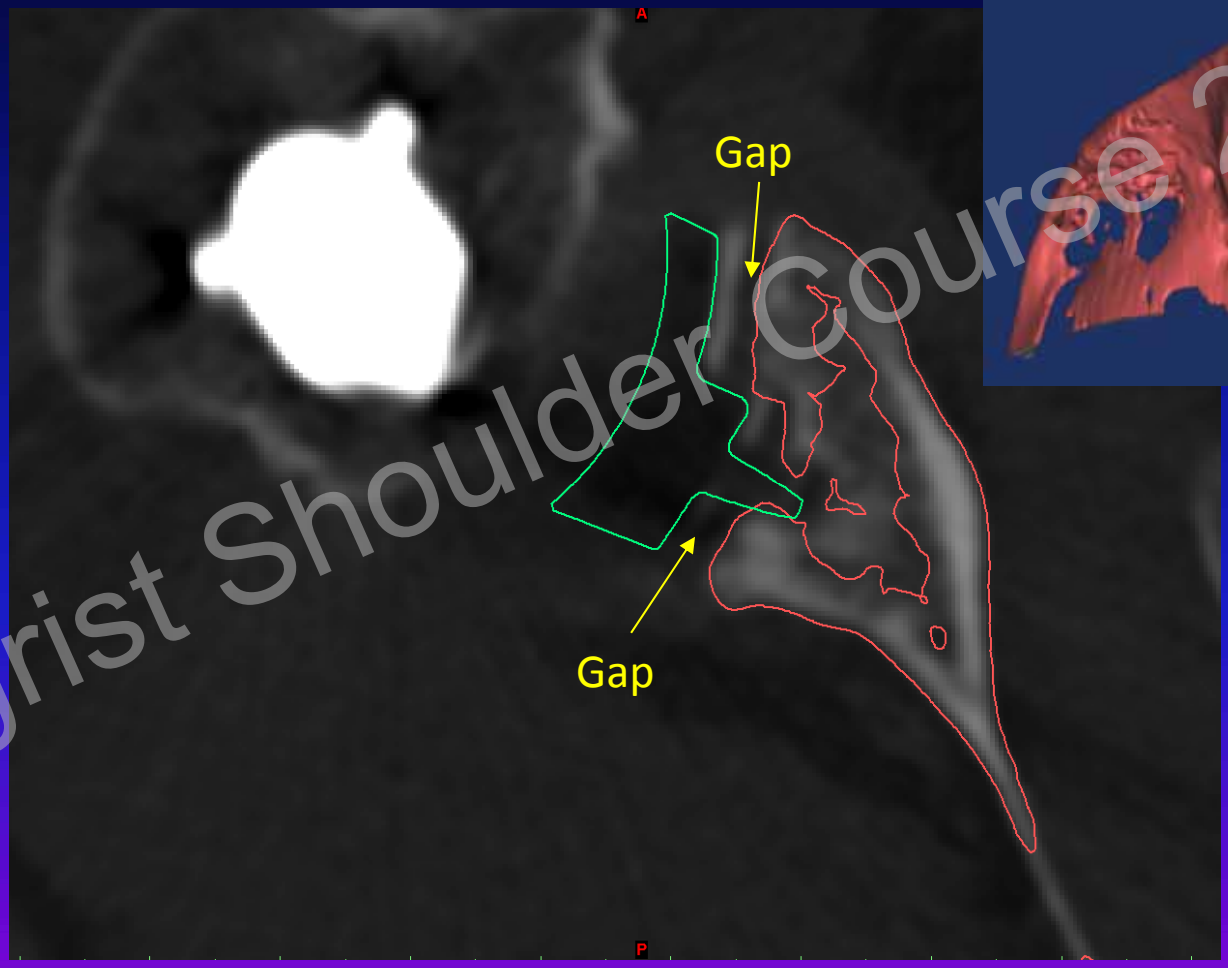
CT2 without MAR

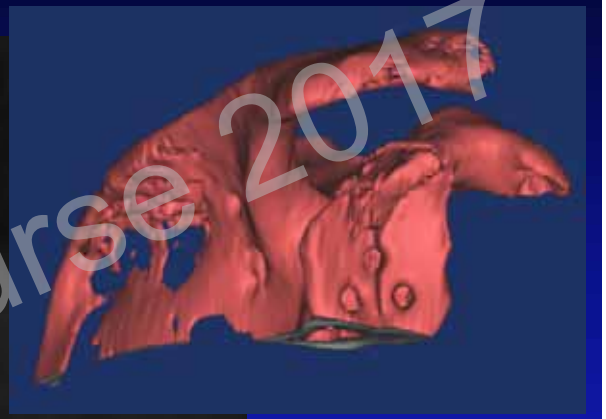
CT2 after virtual MAR

Cross-Sectional View: Center Peg

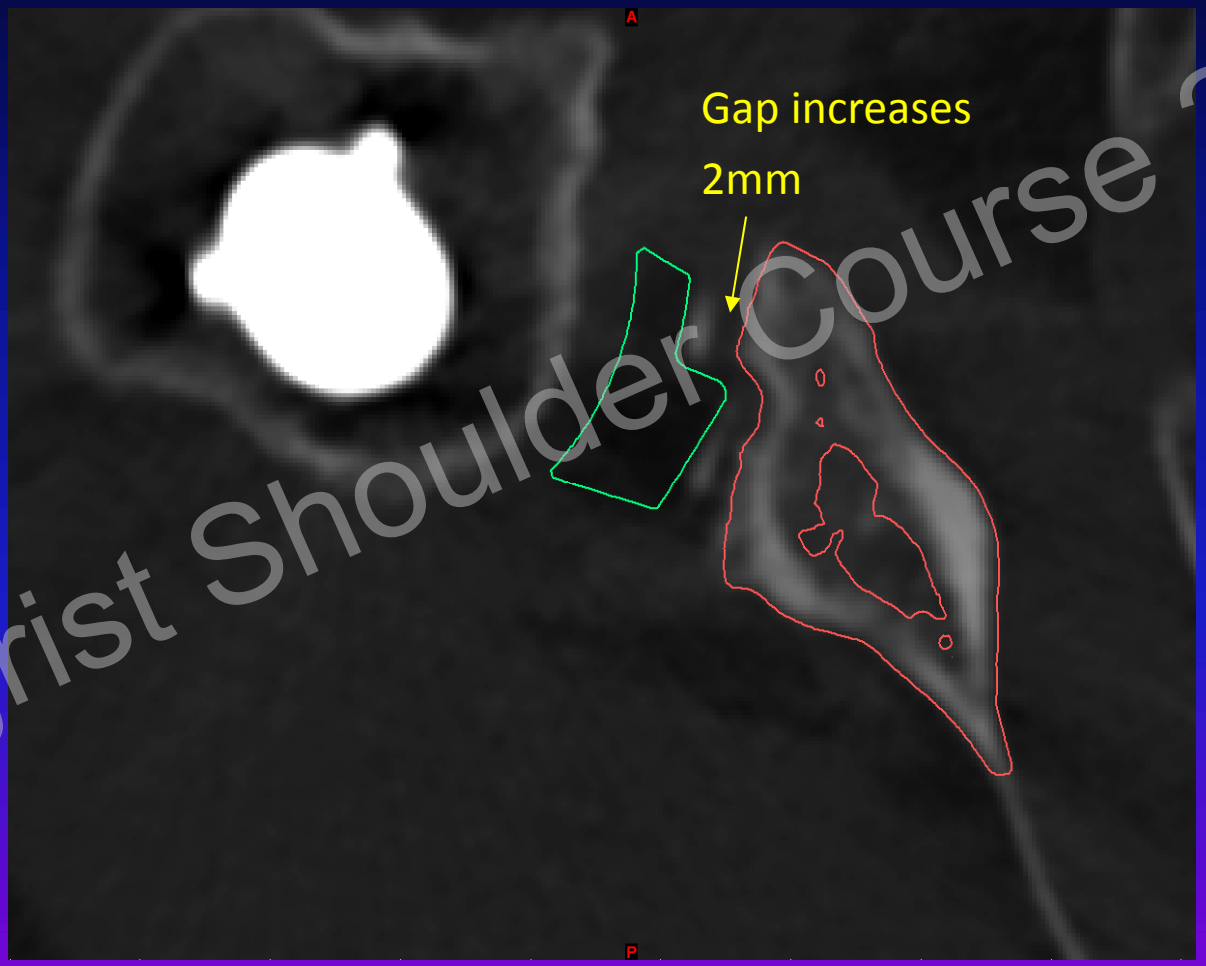


Cross-Sectional View: Inferior



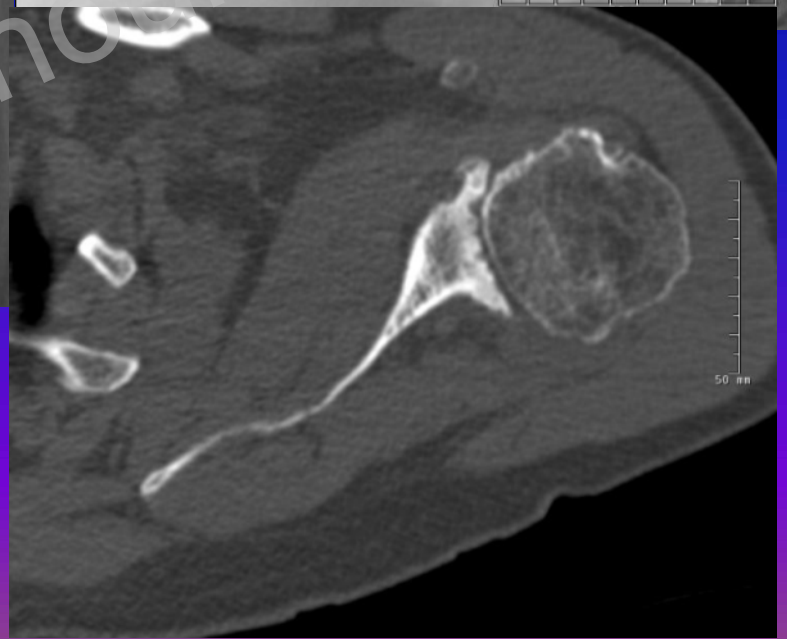


Cross-Sectional View: Lower Inferior

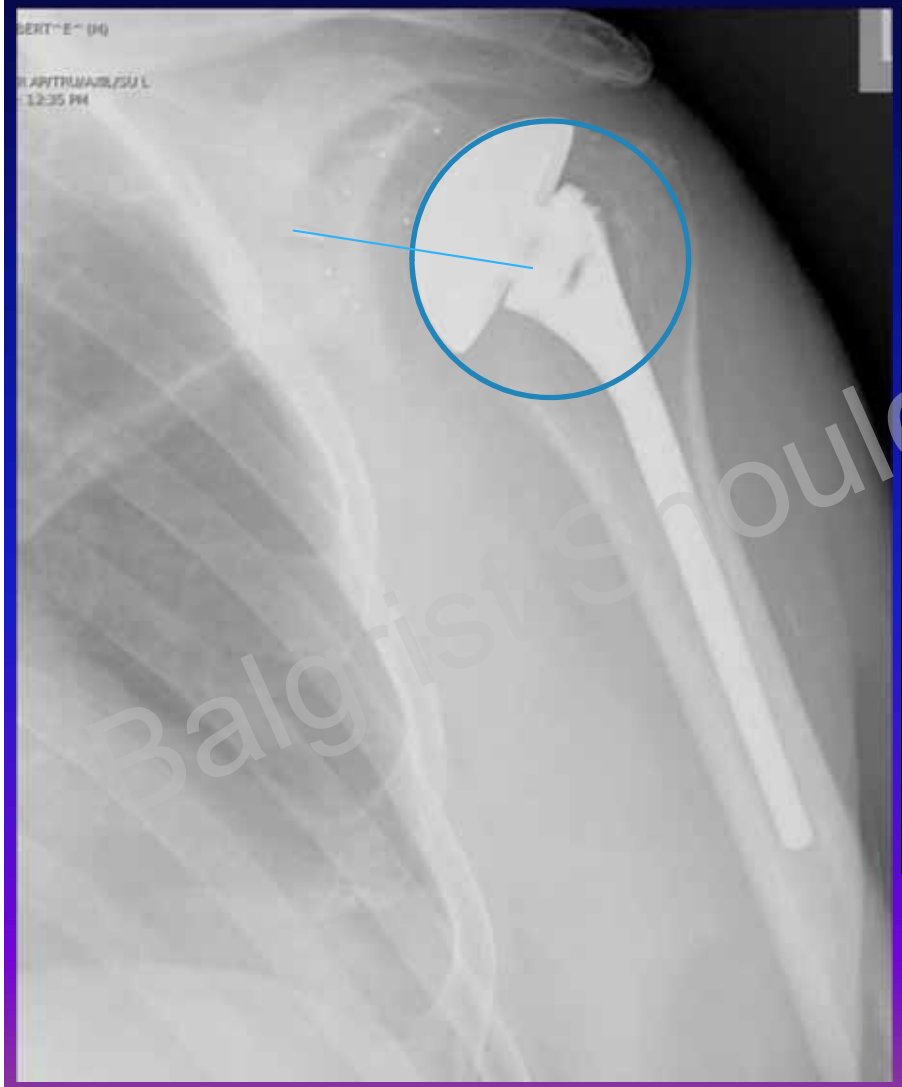


Case Example: What you are missing on x-rays
The Role of Sequential 3D Post – operative Imaging and Image Registration

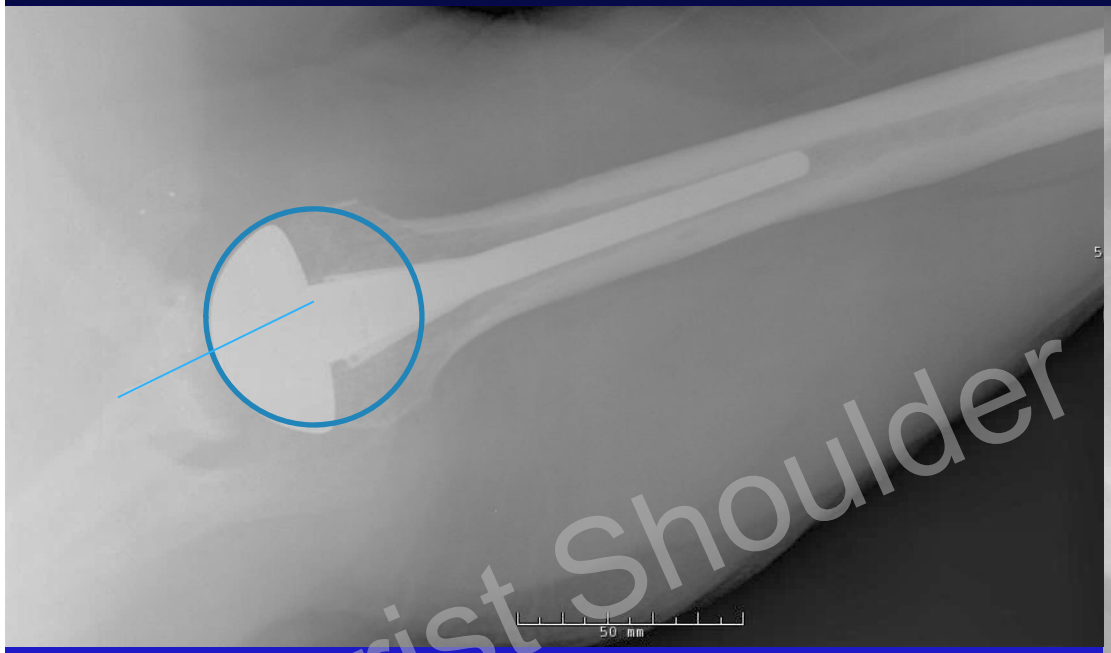
Pre op 1/13



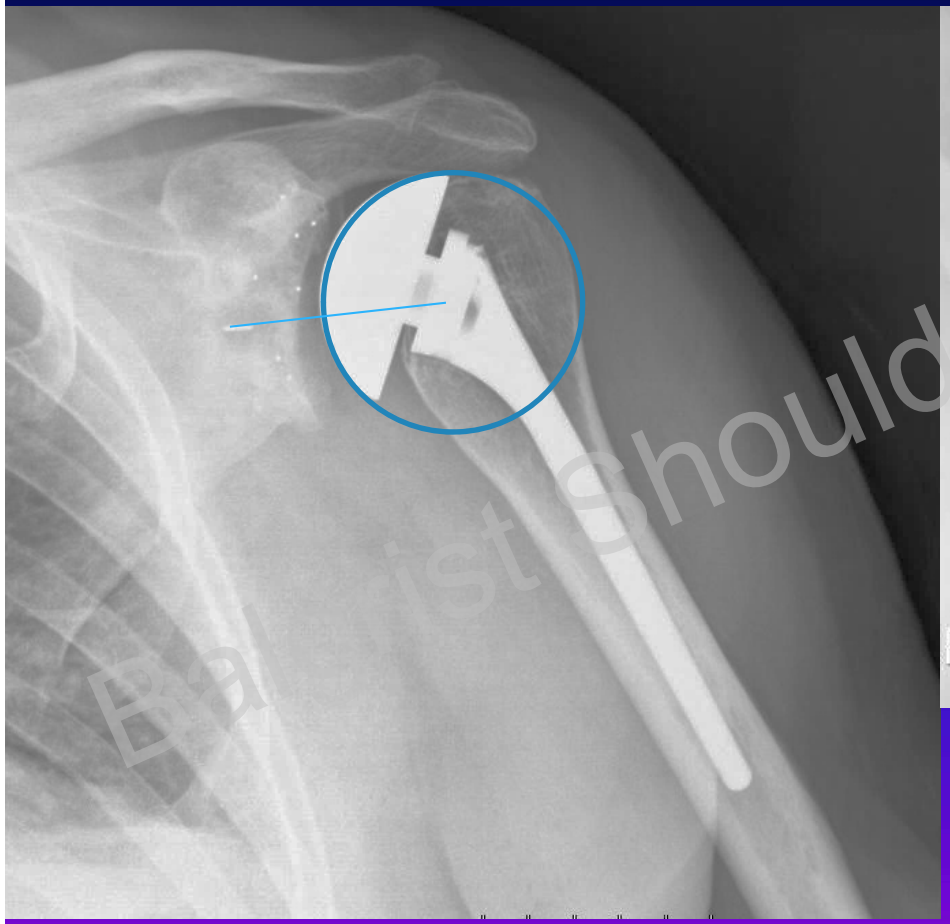
1 month post op

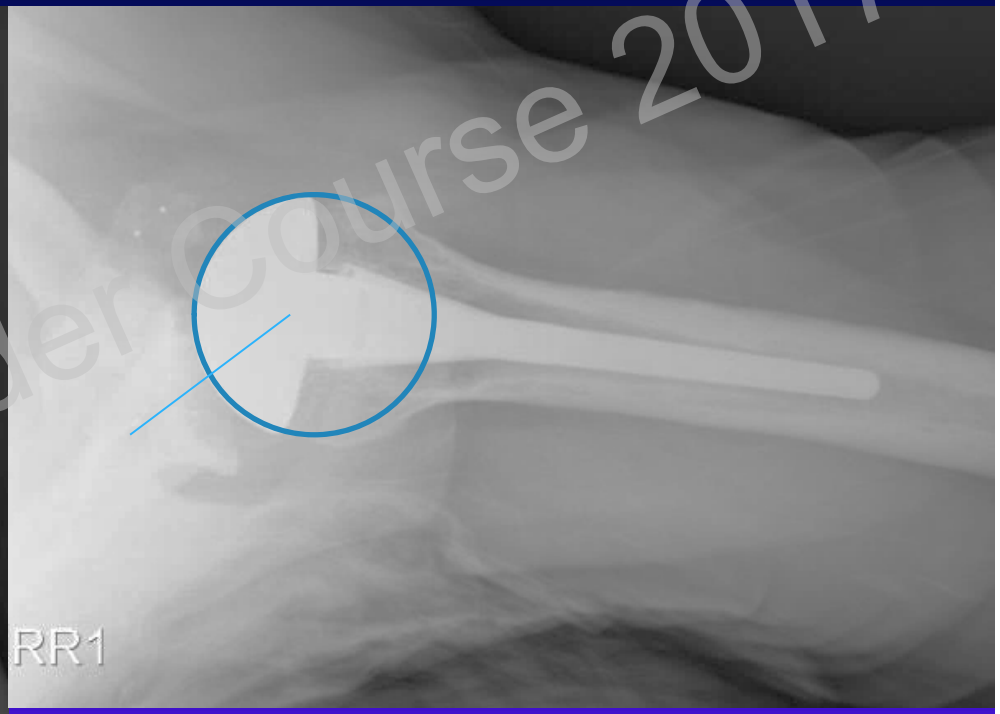


1 year post op



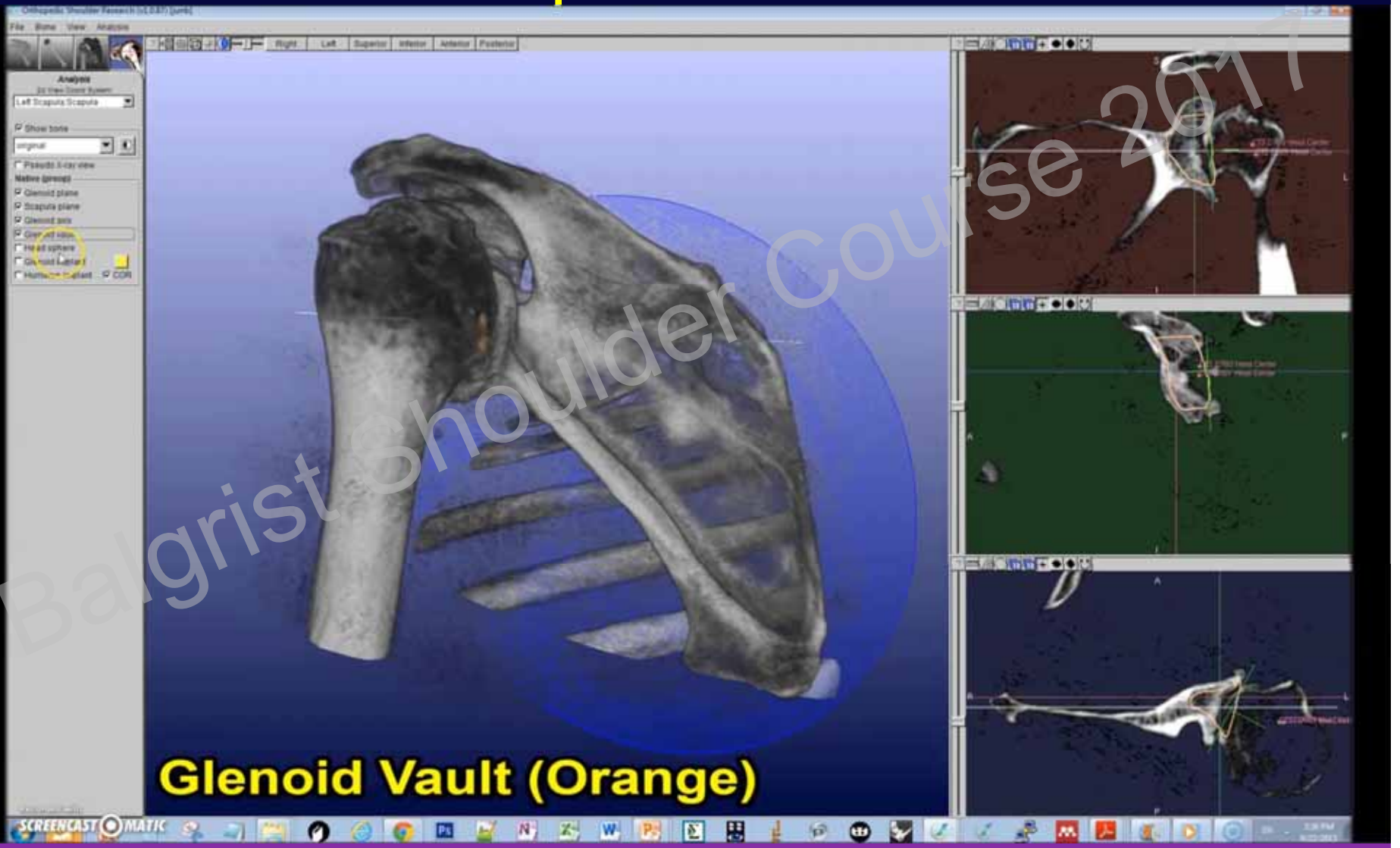
2 year post op



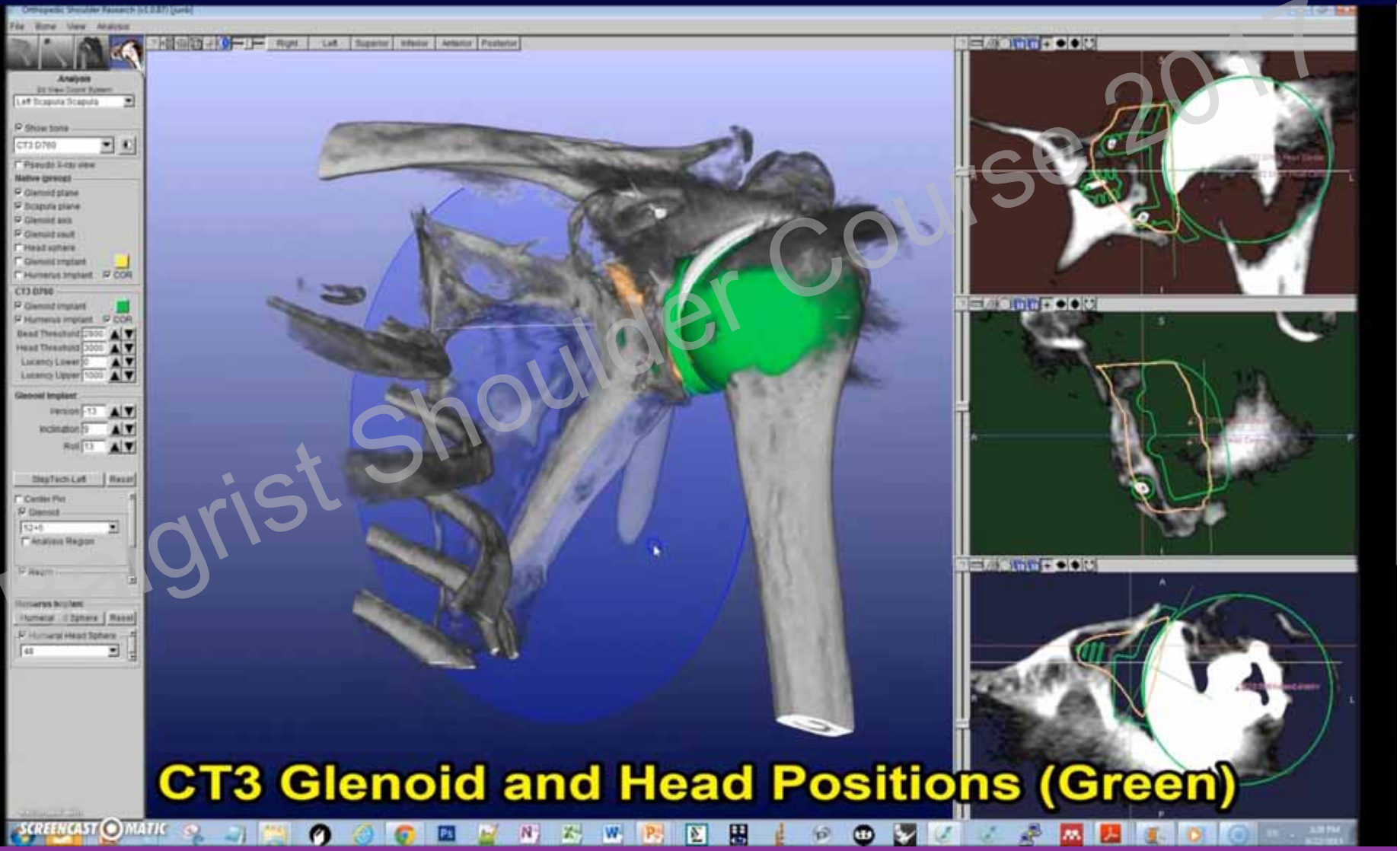


- Shoulder score = 100/100 points

Implant position at 3 months post operative

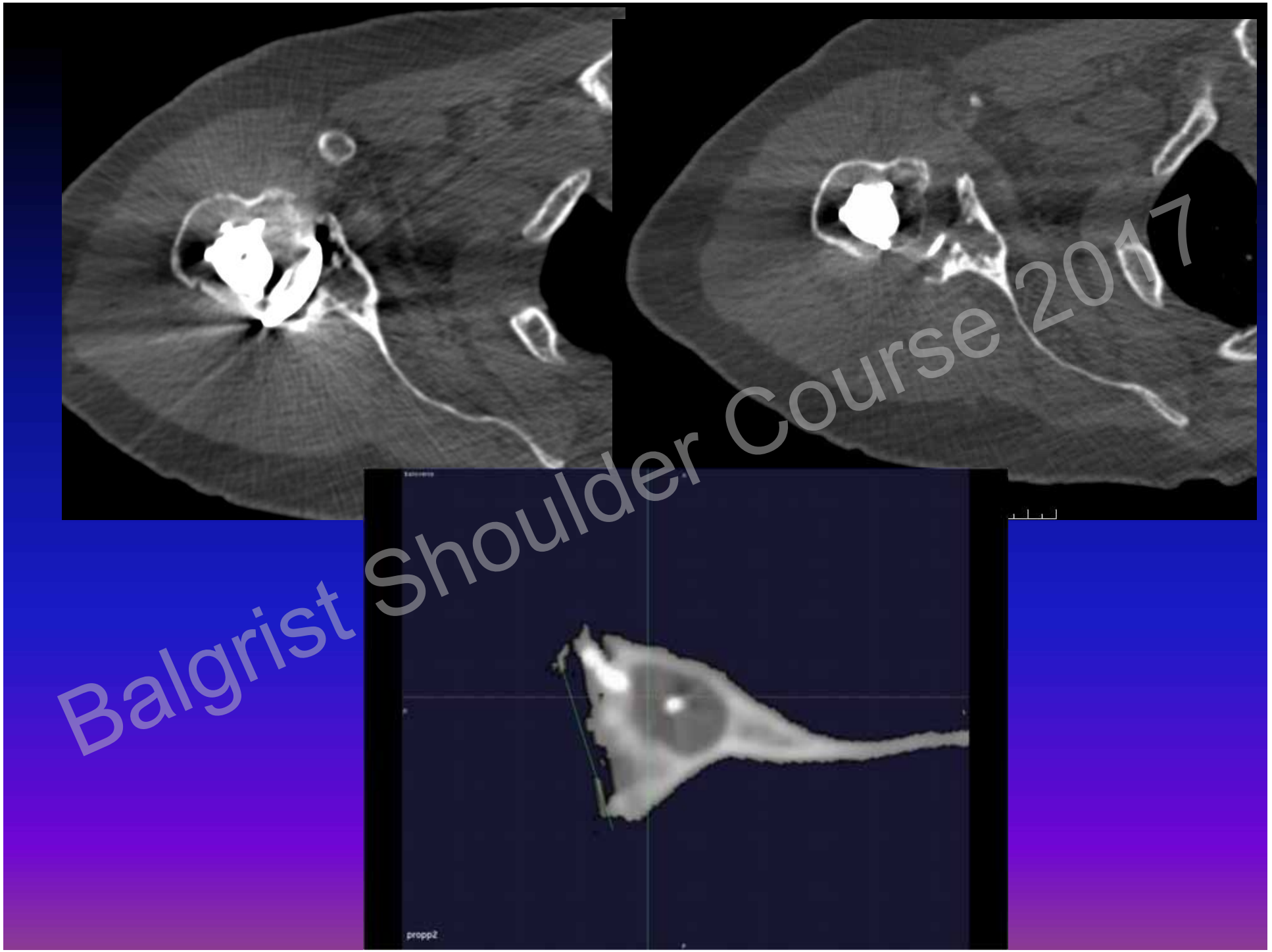


Implant Migration at Two Year Follow up



56 yo 6 years post op. mild pain perfect function no infection

58yo 8 years post op mild pain perfect function, no infection weak subscap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proppZ


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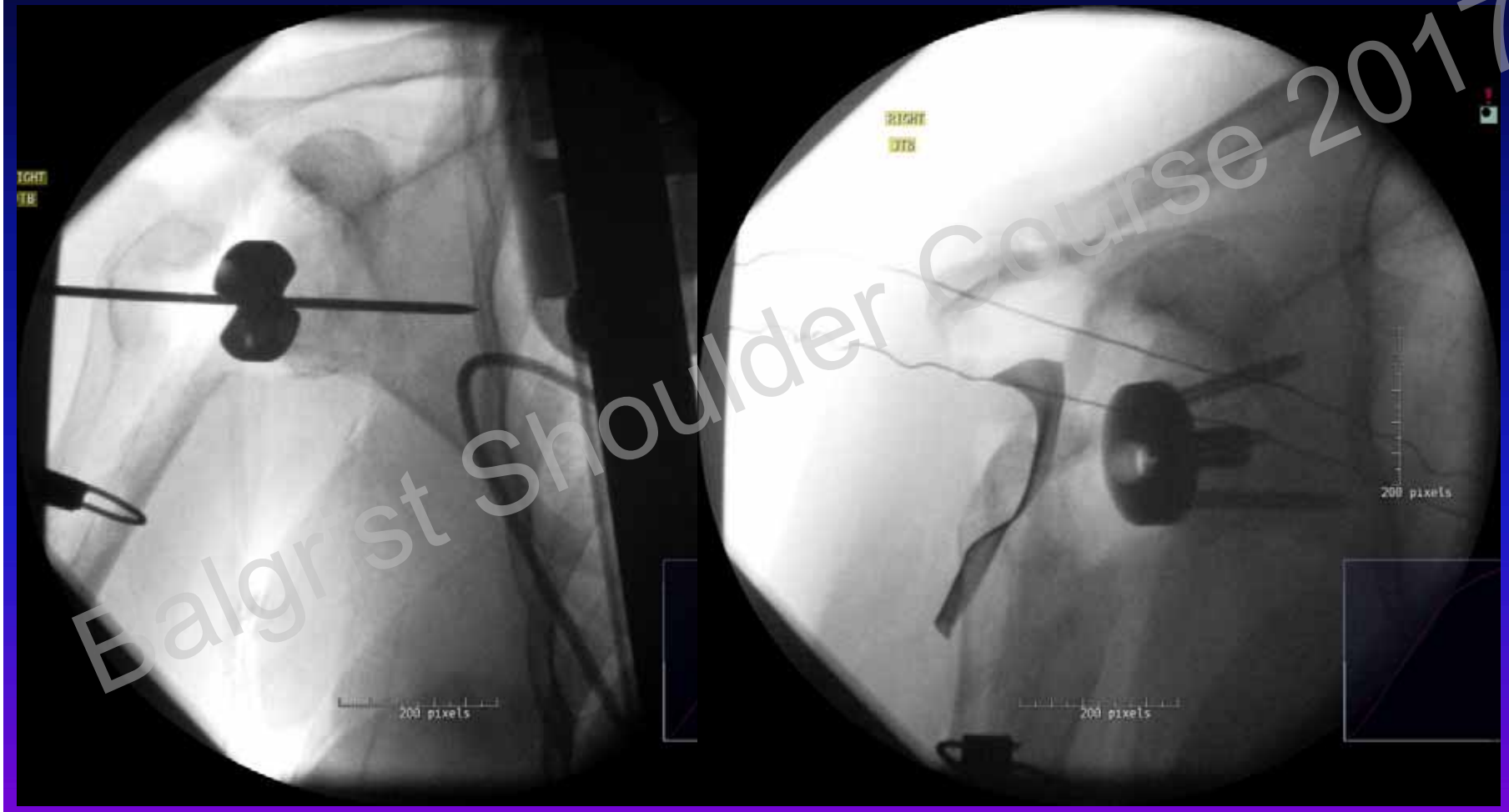
Iliac Crest Graft with intra op positioning of the guide pin

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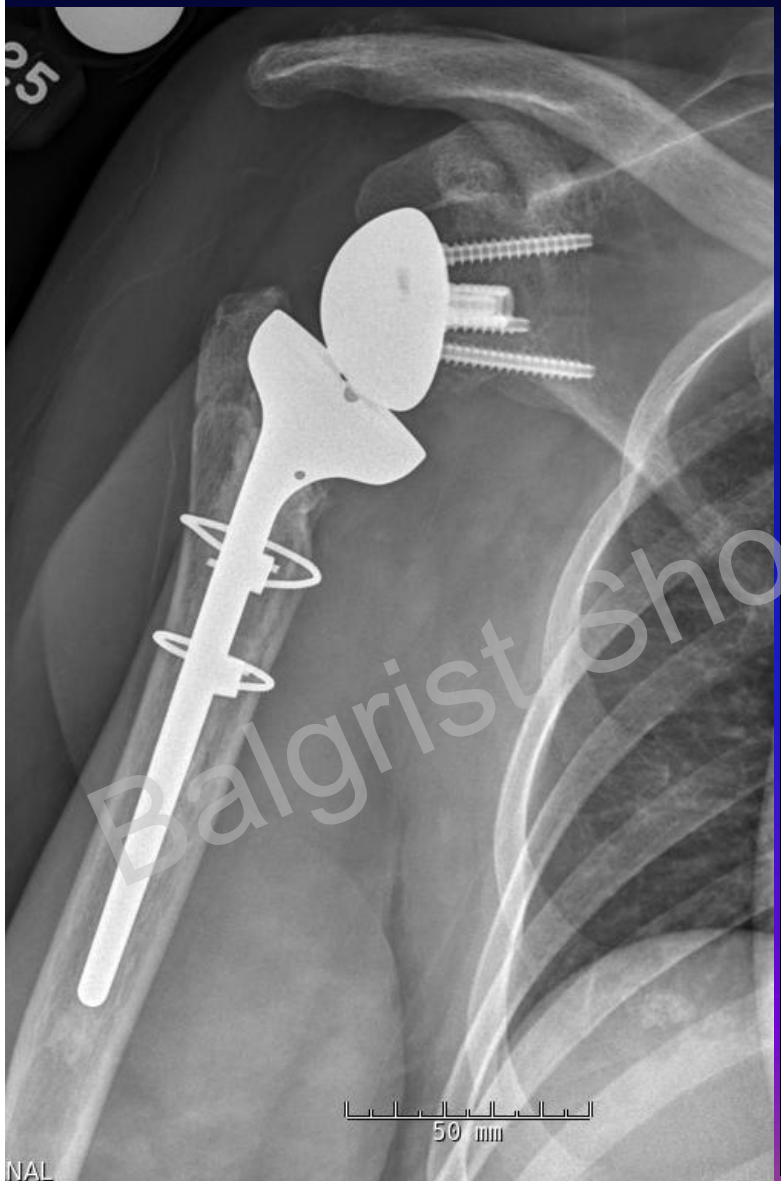
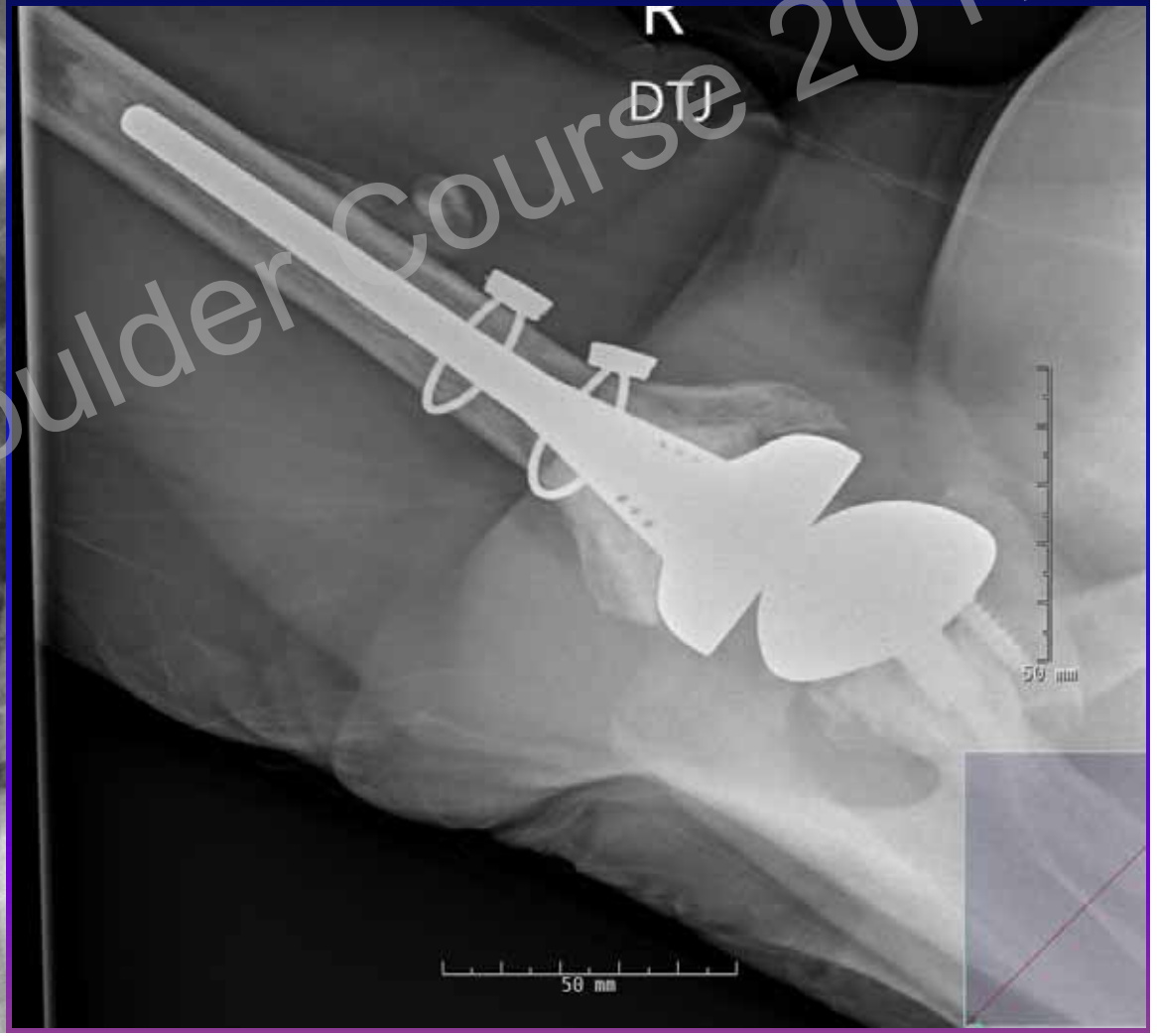
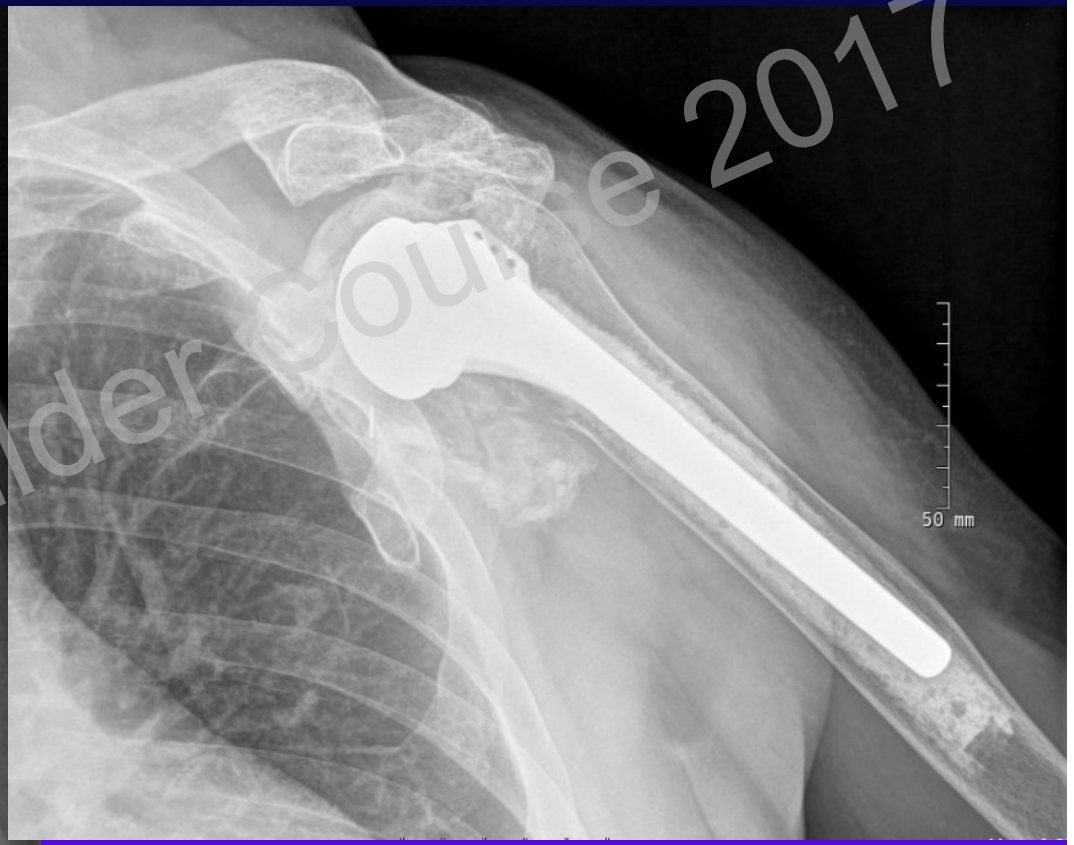
4 months post op



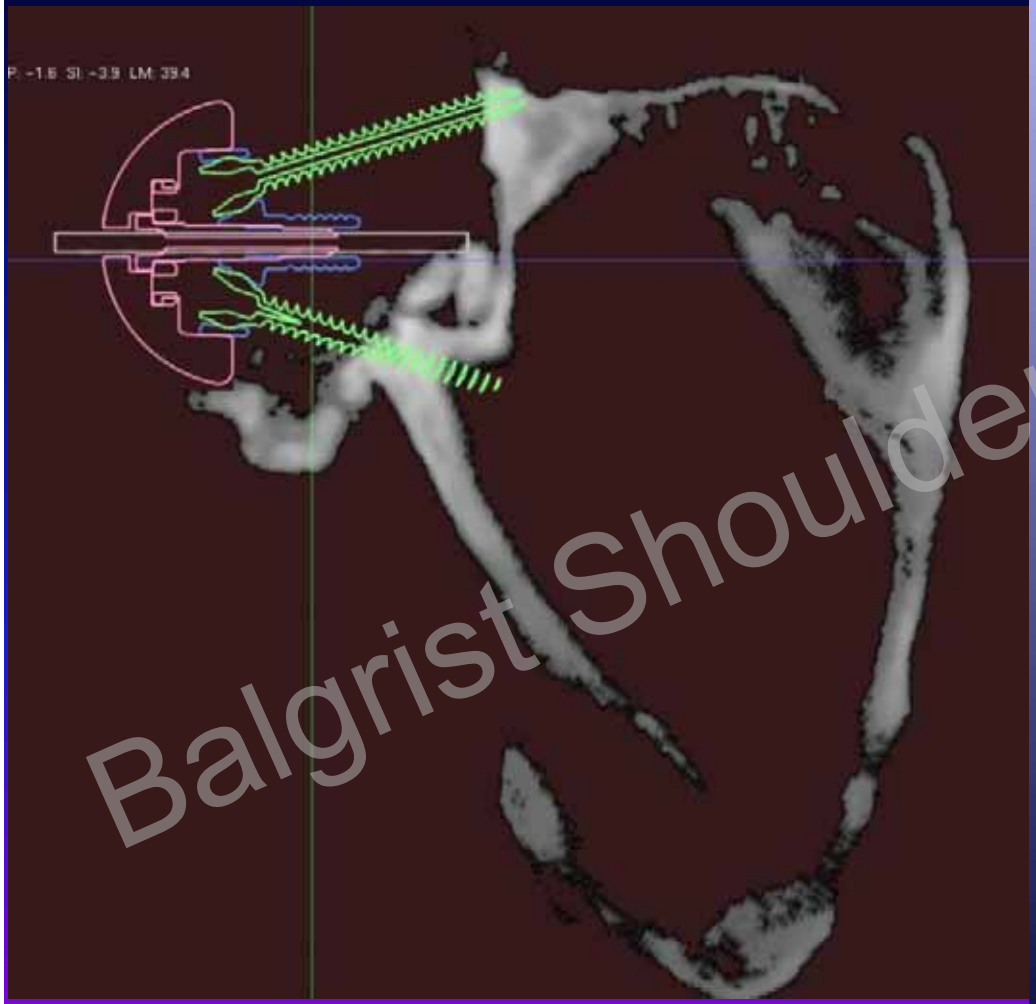


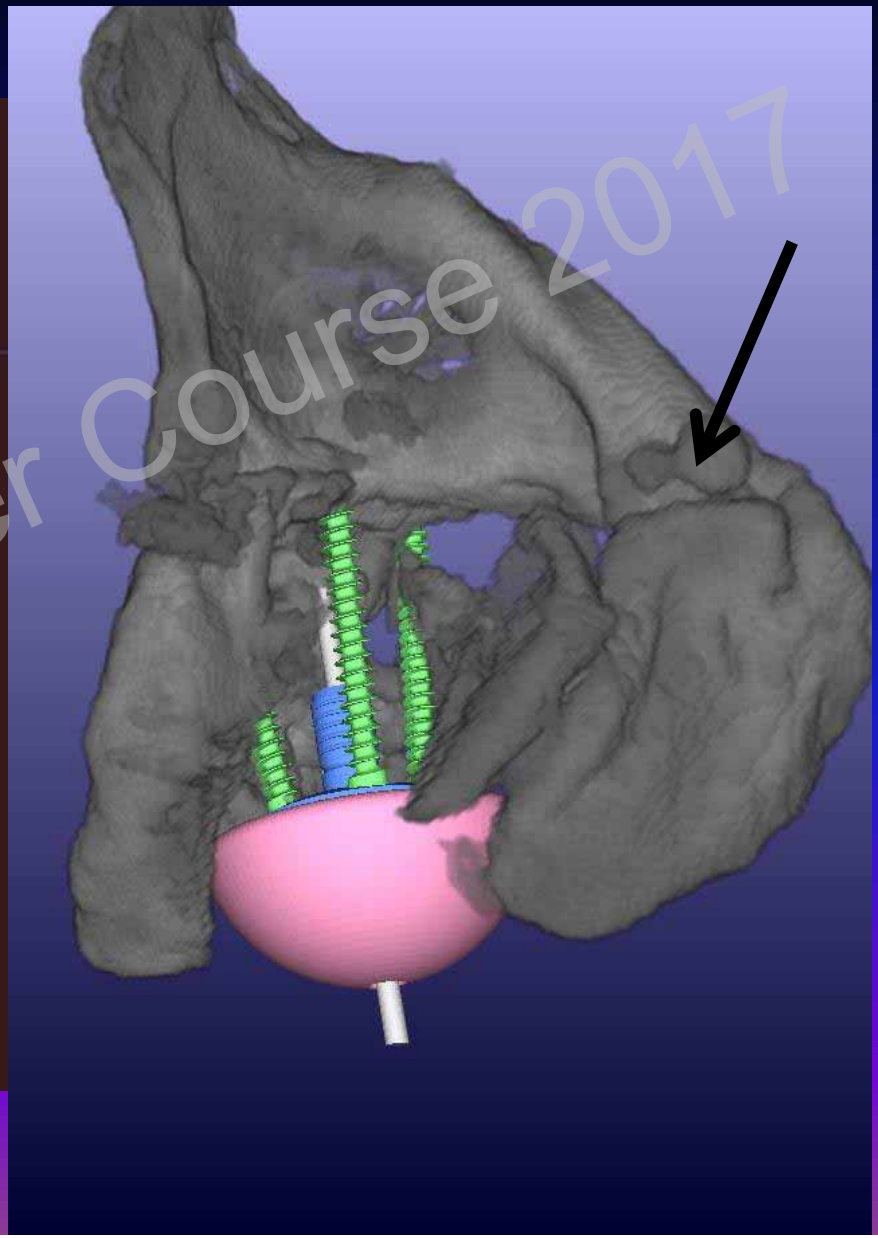
Severe Glenoid Bone Loss and Secondary Spine Fracture



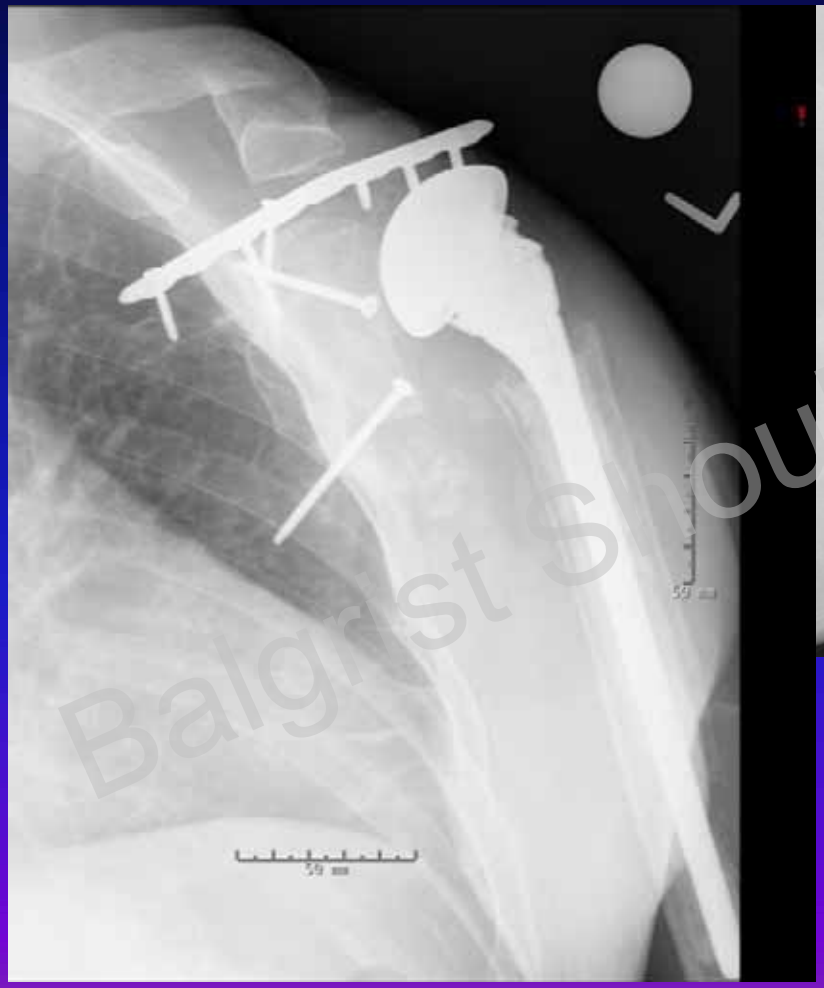
- 75 year old pain and loss function

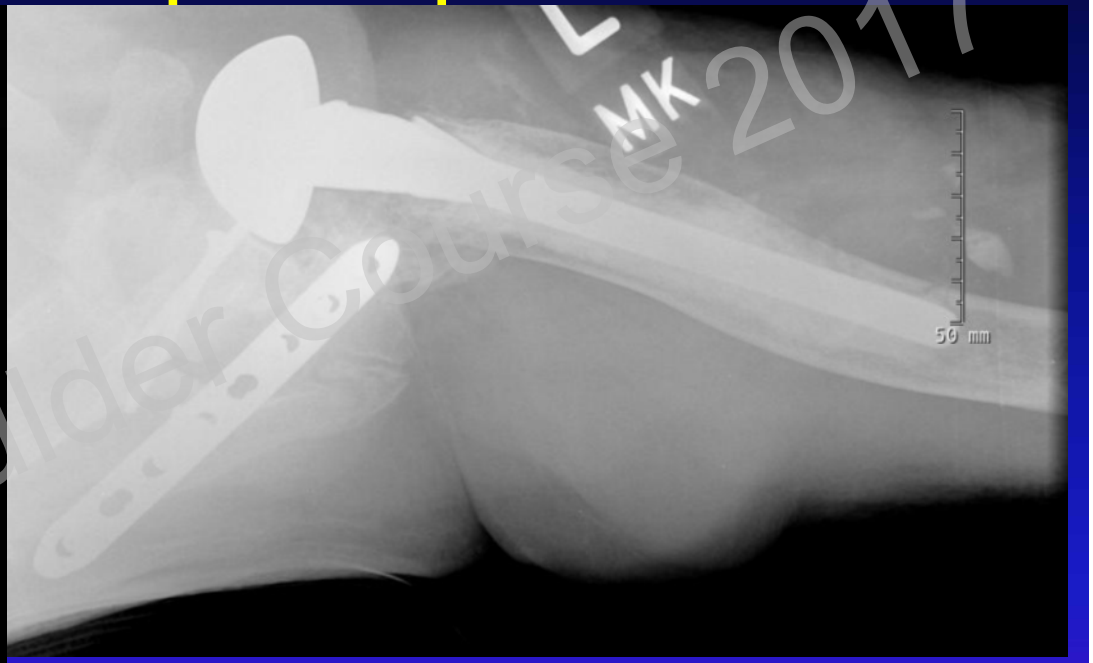
Not enough bone for reverse fixation



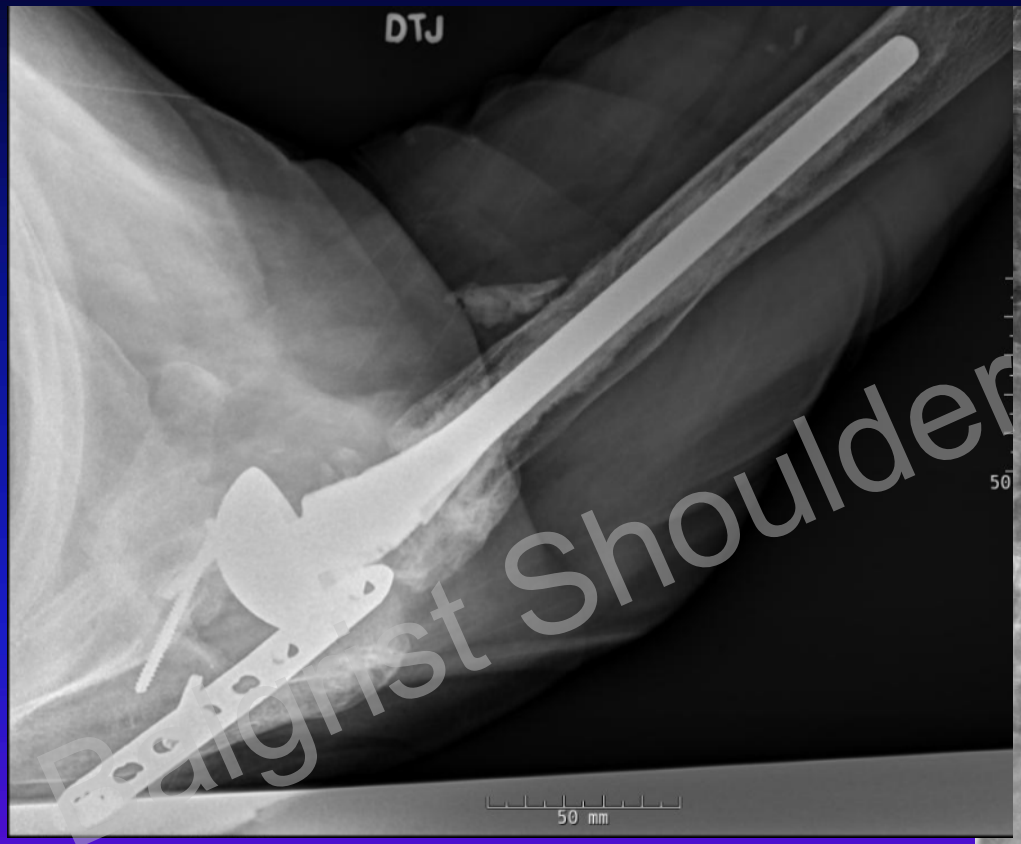


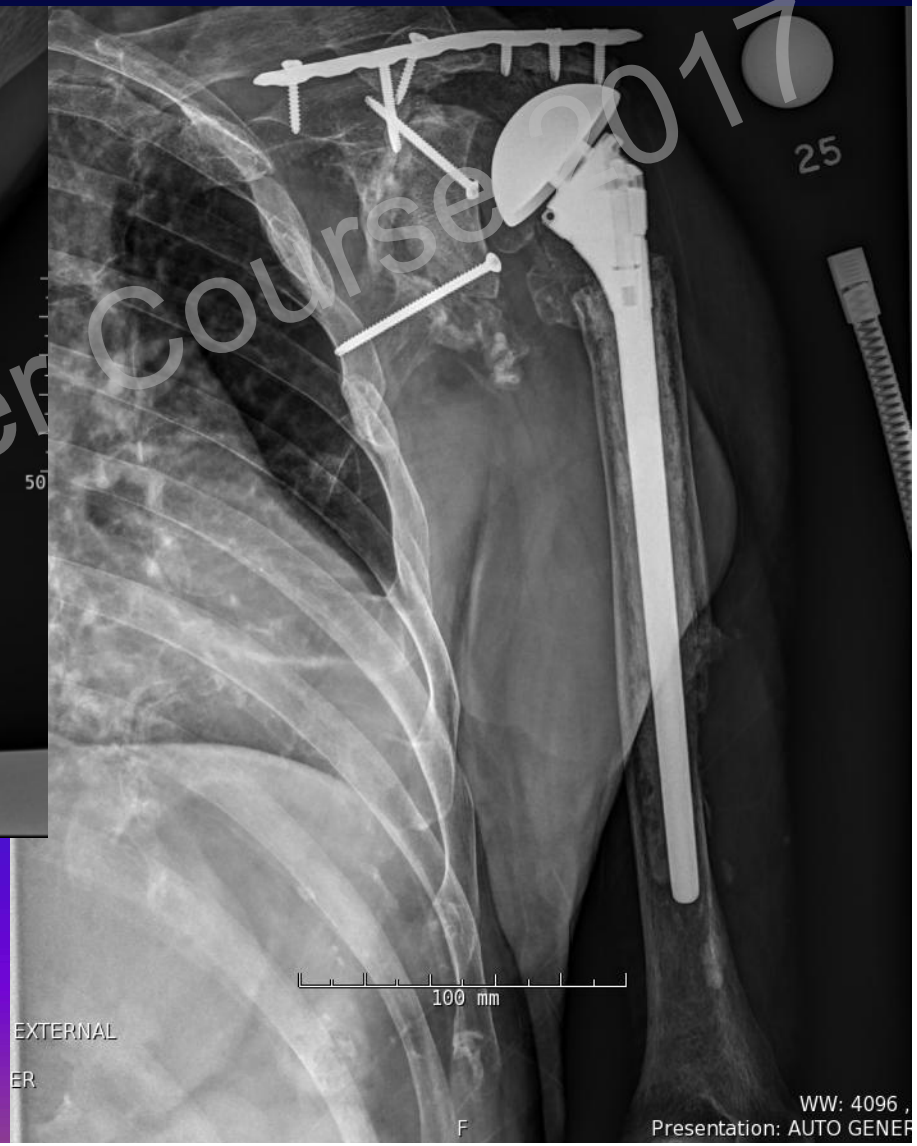
Allograft femoral head: Platform Stem
ORIF Spine of the scapula
1 month post op



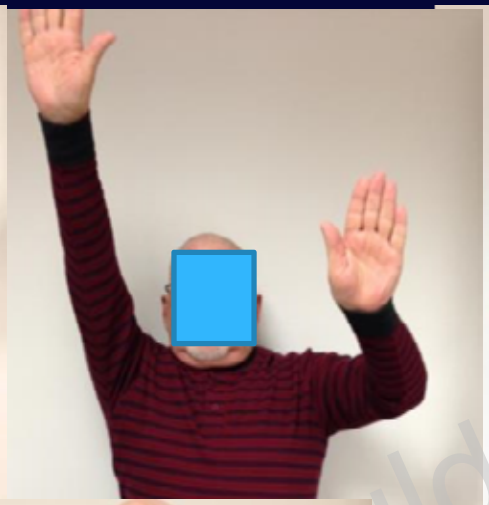


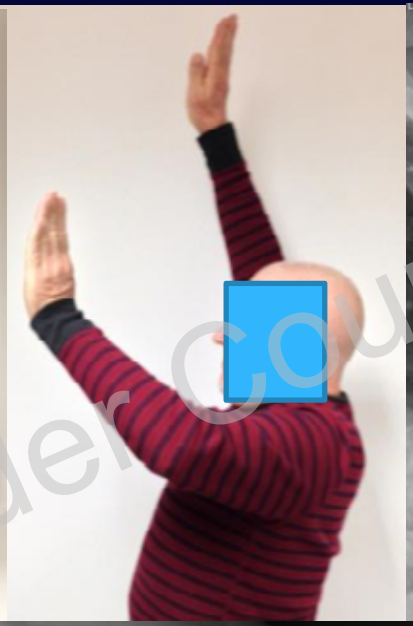
8 month post op



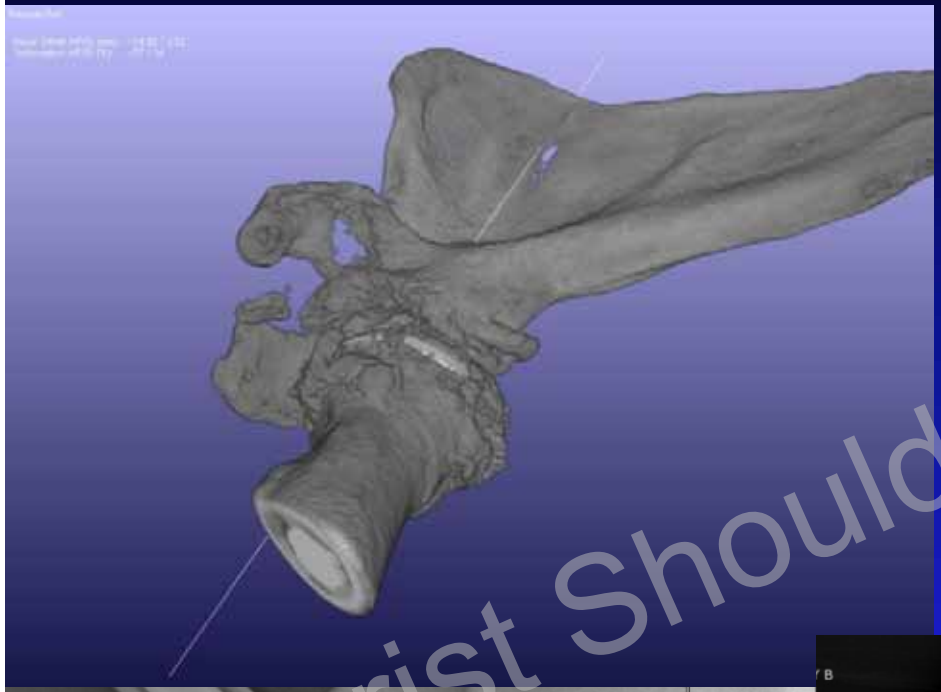


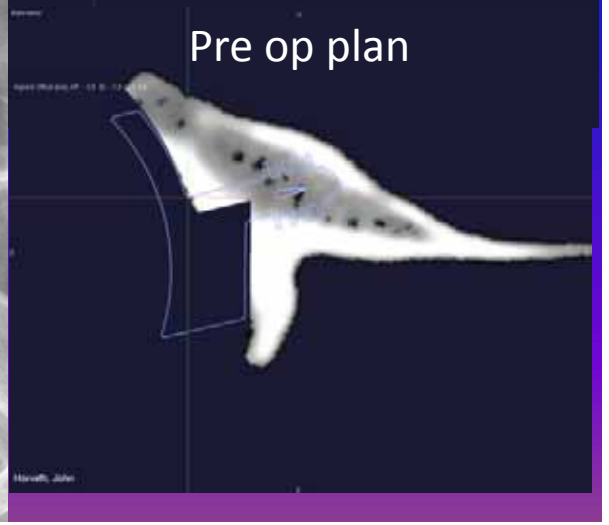
One year post op





Consequences of incomplete correction of version: Poor GH registration: Loose Glenoid





Other Applications 3D IMAT CT Imaging

- Defining the accuracy of patient specific instrumentation
- Defining glenoid implant loosening

Thank You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