THR Simulator – The Software for Generating Radiographs of THR Prosthesis

Presented by

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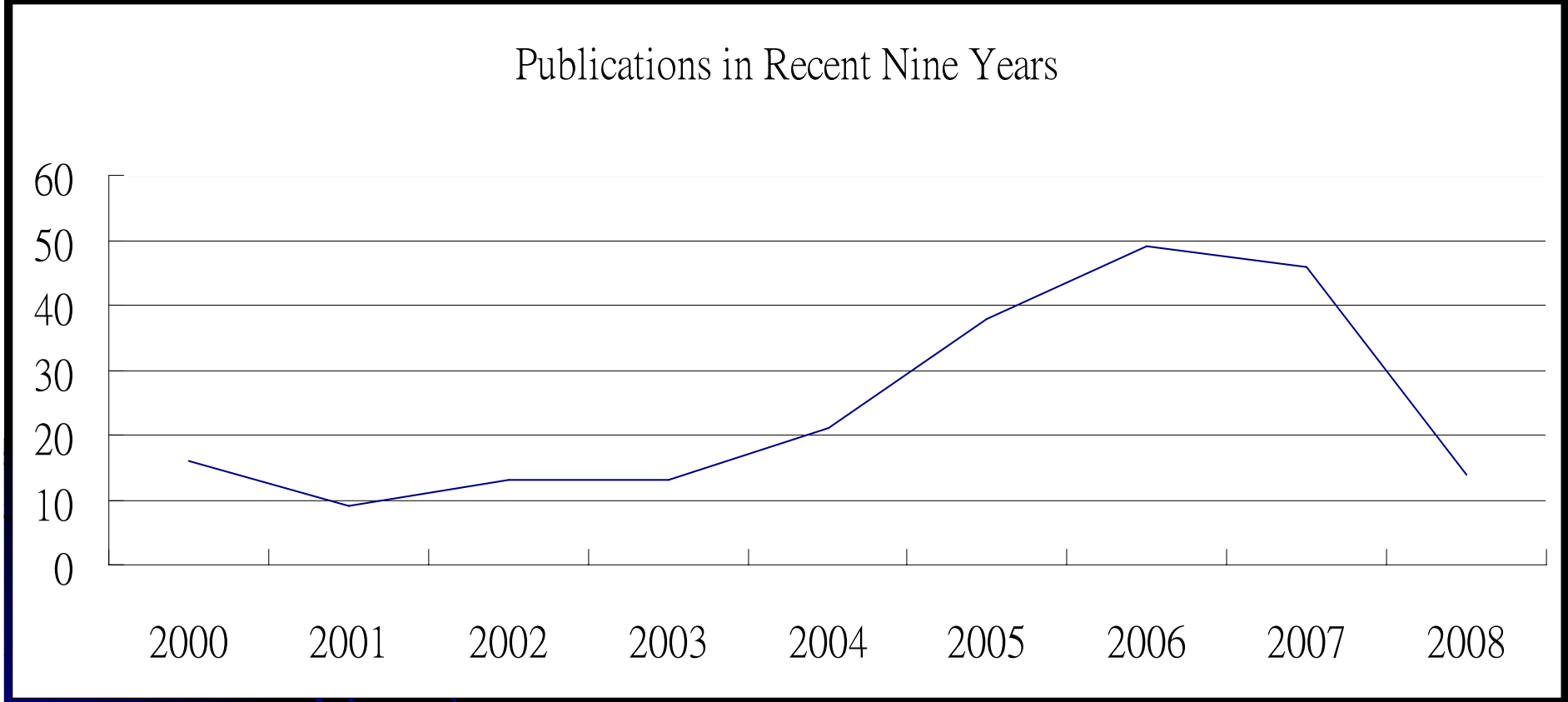
The Academic Importance of Acetabular Orientations

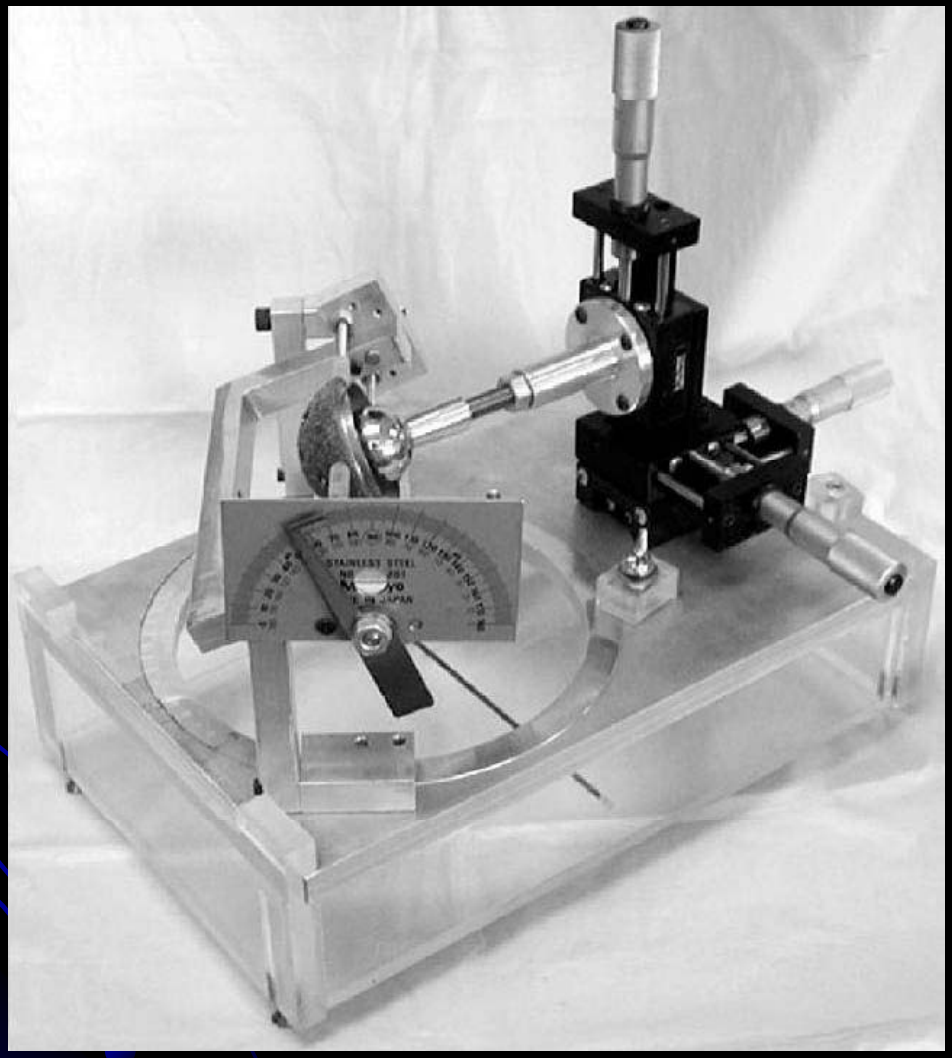


Searching in Medline with keywords of “Arthroplasty, Replacement, Hip” and (“version” or “anteversion”)

The THR Simulator

- Before developing measuring methods, we must develop the “gold standard”.
- Mechanical device is straightforward but is expensive and has an unpredicted precision.
- The method using mechanical simulator requires taking radiograph and then transforming to digital form.
- It takes many processes and every process may cause error thus interferes with the final precision.

The Mechanical Simulator



- *Ebramzadeh, E., et al., J Bone Joint Surg Am*, 2003. **85-A**(12): p. 2378-84.

The Digitalized Simulator

- Many published methods used Fourier transformation.
  - Speed (improved from $O(n^3)$ to $O(n^2)$)
  - n: the length of the 3D object
  - Precision: unpredictable
- Ray tracing
- Transform thickness to grey scale

Algorithm

- Build mathematical model of acetabulum with femoral head.
- Ray tracing every projected pixel on virtual film.
  - Calculate metal thickness where the X-ray beam passes.
  - Transform thickness to grey scale.
  - Draw in the virtual film.

Thickness

- Virtually, femoral head equals to a ball.
- $x^2+y^2+z^2<r_f^2$ (2)
- (x, y, z): the point of the simulated three-dimensional Cartesian coordinate system
  r_f: the radius of femoral head

Thickness

- $(x-d_x)^2+(y-d_y)^2+(z-d_z)^2<r_f^2$ (3)
- d_x, d_y, d_z: femoral head movement in three directions

Thickness

- Virtually, acetabulum is composed of two balls and one plane.
- $x^2+y^2+z^2<r_{ao}^2$ (4)
- $x^2+y^2+z^2>r_{io}^2$ (5)
- $ax+by+cz>0$ (6)
- r_{ao}: radius of acetabulum's outer shell
- r_{io}: radius of acetabulum's inner shell
- (a,b,c): the normal vector of the acetabulum

Thickness

- $(a,b,c) = (\sin\varphi \times \cos\theta, -\cos\varphi \times \cos\theta, \sin\theta)$ (6.1)
- Vector (a,b,c): the normal vector of the acetabulum
- φ: the inclination of acetabulum
- θ: the anteversion of acetabulum
- positive θ: anteversion
- negative θ: retroversion

Thickness

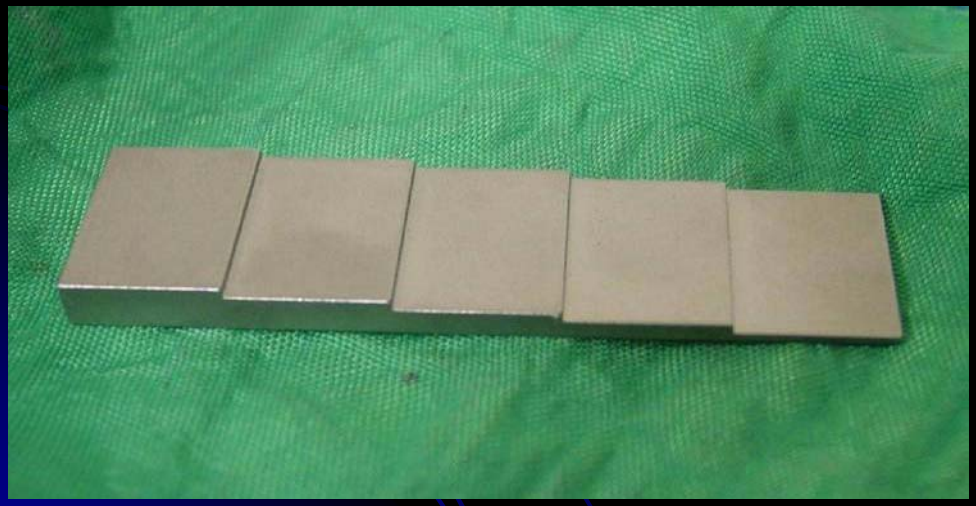
- The X-ray source is set at $(0,0,-d_t)$.
- d_t: tube distance (the X-ray tube to the acetabulum center)
- The points at film are (x_f,y_f,d_f).
- (x_f,y_f): point at film
- d_f: distance from film to the acetabulum center
- $(x,y,z) = (t * x_f, t * y_f, t * (d_f + d_t) - d_t)$ $0 < t < 1$ (7)

Transforming Thickness to Grey Scale

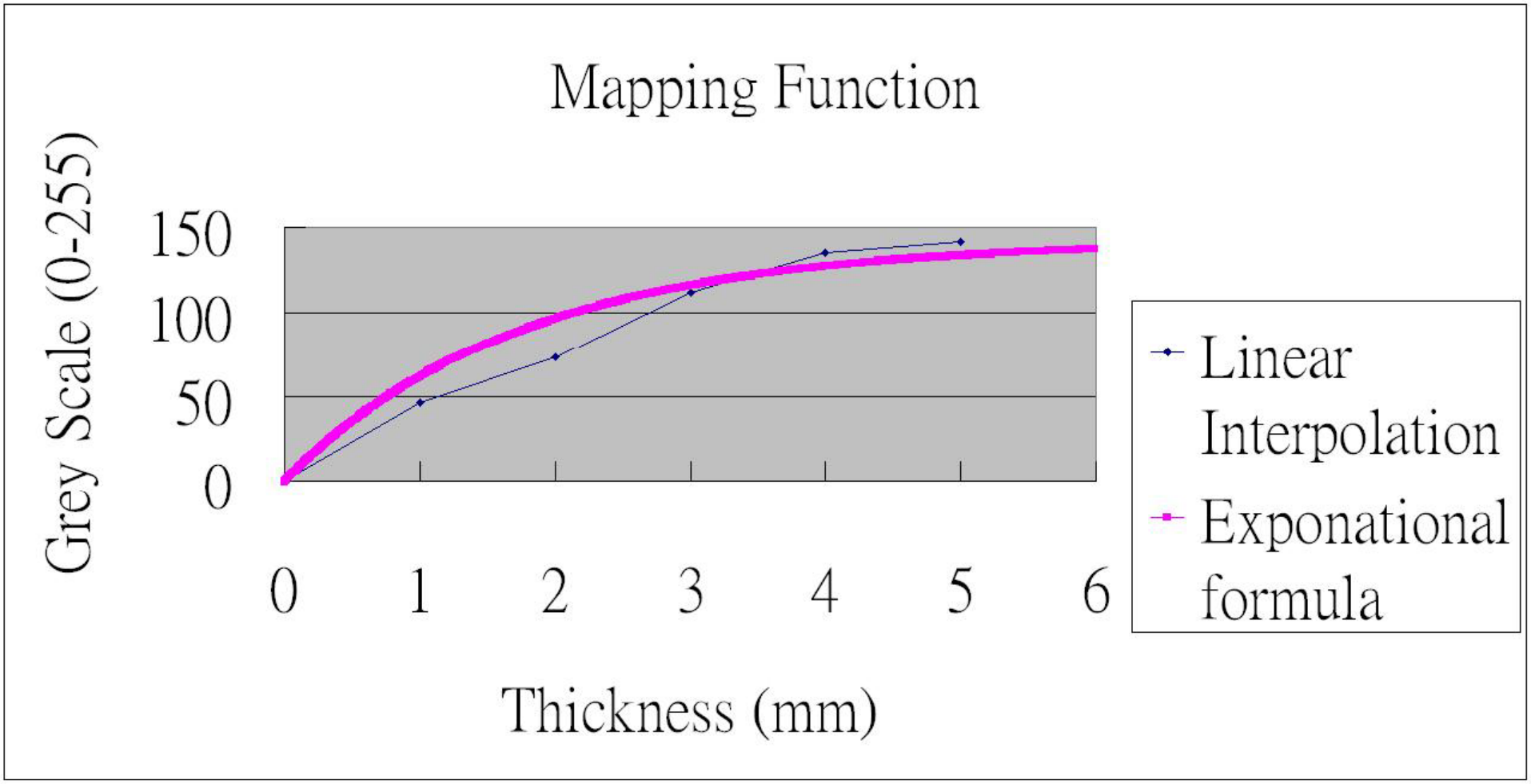
- Beer-Lambert law.
  - Penetration = e^{-kbc}
  - *k*: molar absorbability
  - *b*: path length
  - *c*: concentration
  - *k*: different in different materials and different radiation energy
  - Radiation energy from X-ray tube: normal distribution
- Lookup table method

Lookup Table Method

- We propose to implement *THR Simulator* by lookup table method.

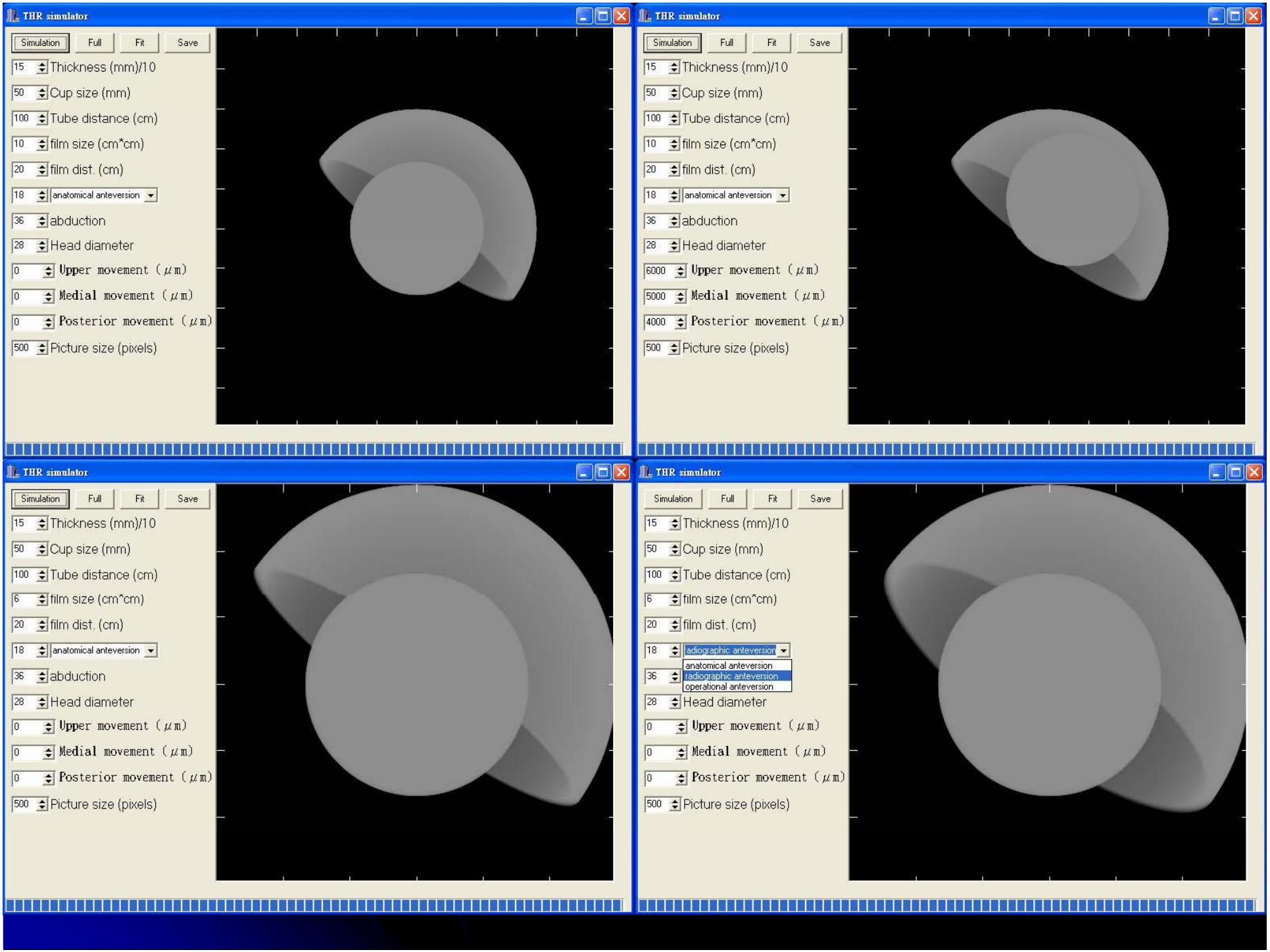


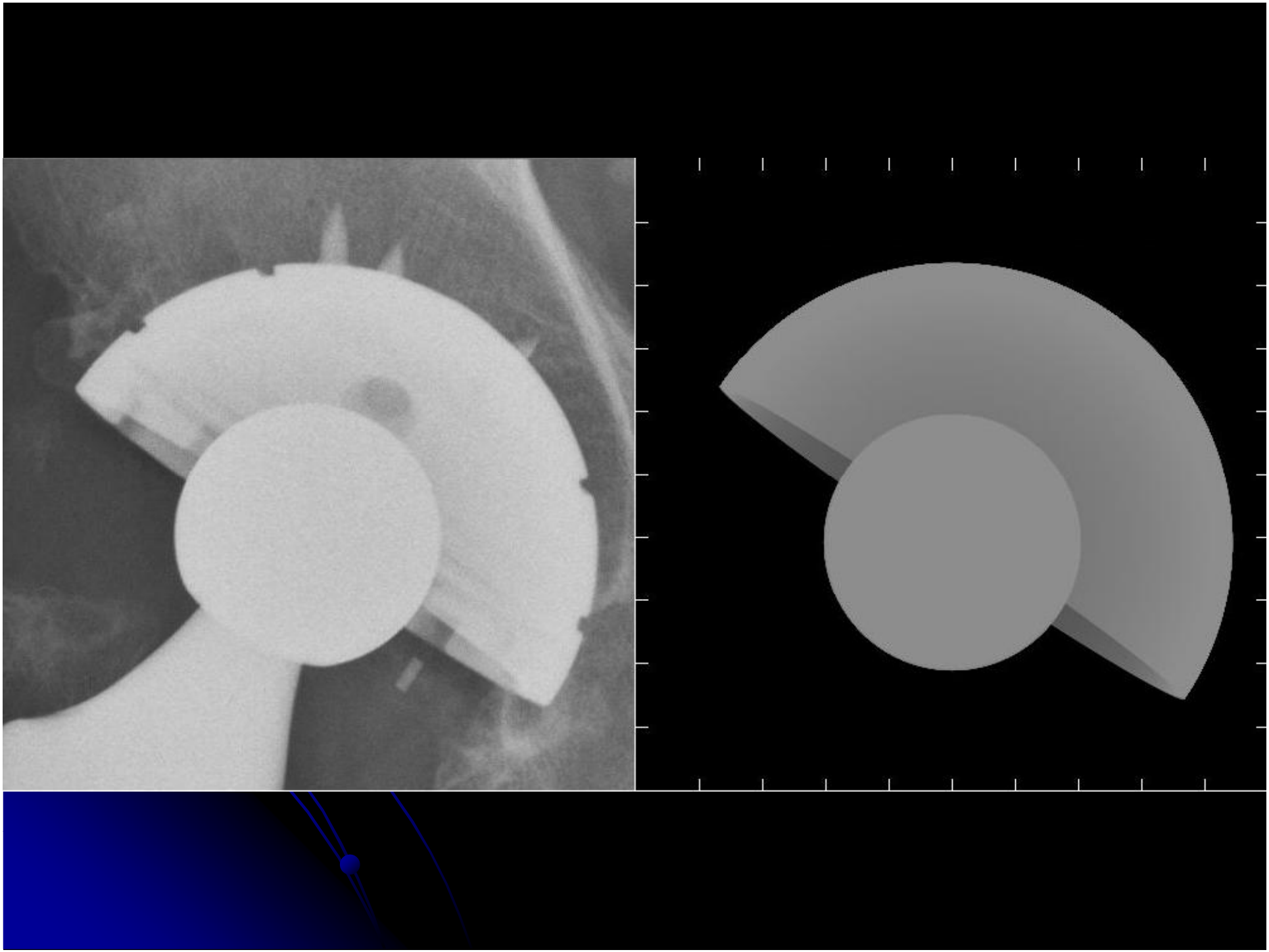
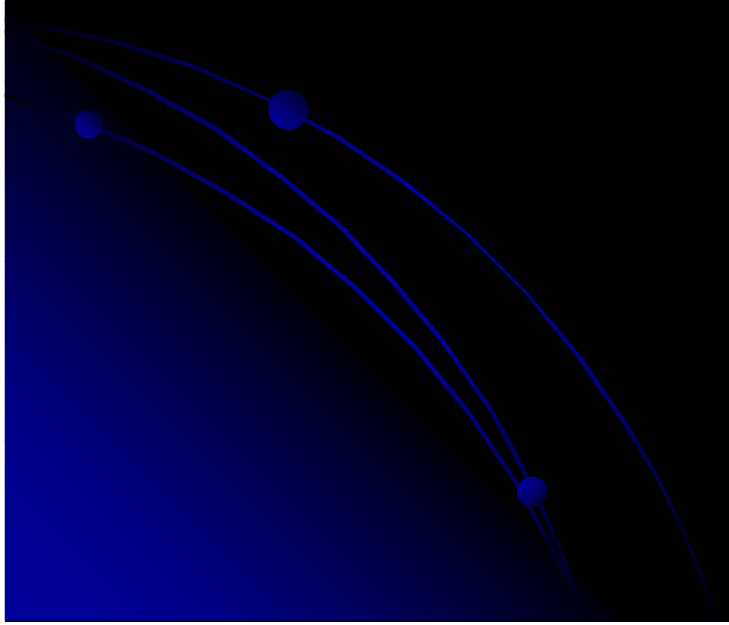
Lookup Table Method



Approximation with Exponational Function

- GreyScale = $S * (1-e^{-kb})$
  - *S*: GreyScale of saturation
  - *b*: total thickness of metal


THR simulator
Simulation
Full
Fit
Save
15 Thickness (mm)/10
50 Cup size (mm)
100 Tube distance (cm)
10 film size (cm*cm)
20 film dist. (cm)
18 anatomical anteversion
36 abduction
28 Head diameter
0 Upper movement (μm)
0 Medial movement (μm)
0 Posterior movement (μm)
500 Picture size (pixels)
THR simulator
Simulation
Full
Fit
Save
15 Thickness (mm)/10
50 Cup size (mm)
100 Tube distance (cm)
10 film size (cm*cm)
20 film dist. (cm)
18 anatomical anteversion
36 abduction
28 Head diameter
6000 Upper movement (μm)
5000 Medial movement (μm)
4000 Posterior movement (μm)
500 Picture size (pixels)
THR simulator
Simulation
Full
Fit
Save
15 Thickness (mm)/10
50 Cup size (mm)
100 Tube distance (cm)
6 film size (cm*cm)
20 film dist. (cm)
18 anatomical anteversion
36 abduction
28 Head diameter
0 Upper movement (μm)
0 Medial movement (μm)
0 Posterior movement (μm)
500 Picture size (pixels)
THR simulator
Simulation
Full
Fit
Save
15 Thickness (mm)/10
50 Cup size (mm)
100 Tube distance (cm)
6 film size (cm*cm)
20 film dist. (cm)
18 radiographic anteversion
anatomical anteversion
radiographic anteversion
operational anteversion
36
28 Head diameter
0 Upper movement (μm)
0 Medial movement (μm)
0 Posterior movement (μm)
500 Picture size (pixels)



Thank you for your attention!