Clinical Image Guidance and Imaging

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Overview

- Motivation: Why we need guidance
- Overview of an image guidance procedure
- Imaging considerations
- Registration and references for image guidance
- Quality assurance
- Summary

The Problem of Guidance

- Airplane
  - Pilot needs to guide a plane
  - Plot trajectory
  - Safely reach target
- The Problems
  - Where am I?
  - Where do I need to be?
  - What can I expect along the path?

Guidance Solutions

- Old Solutions
  - Use landmarks to determine position
  - Have a backup plan
  - Hope for the best

- Current Solutions
  - Radar
  - Global positioning systems (GPS)

Translation to Medical Image Guidance

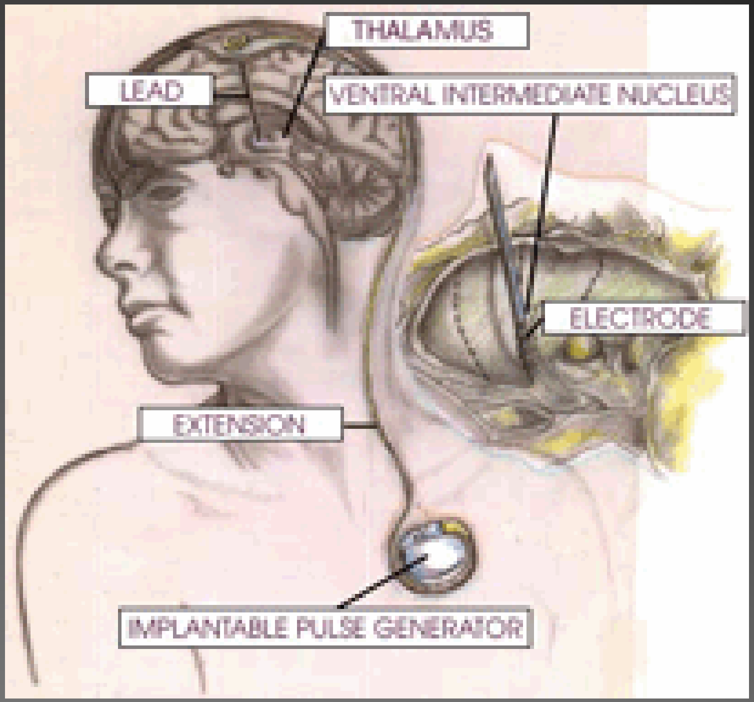
- Guide a therapy to a specific location
- In an optimal situation, landmarks work
- In reality, technology must be used
- Must be able to adapt to the situation as it changes

Image guidance process

- Pre (or intra) procedure imaging
- Registration of reference between imaging and patient
- Creation of plan for administration of therapy
- Quality control check
- Real-time tracking of therapy
- Execution of plan

Deep Brain Stimulation (DBS)

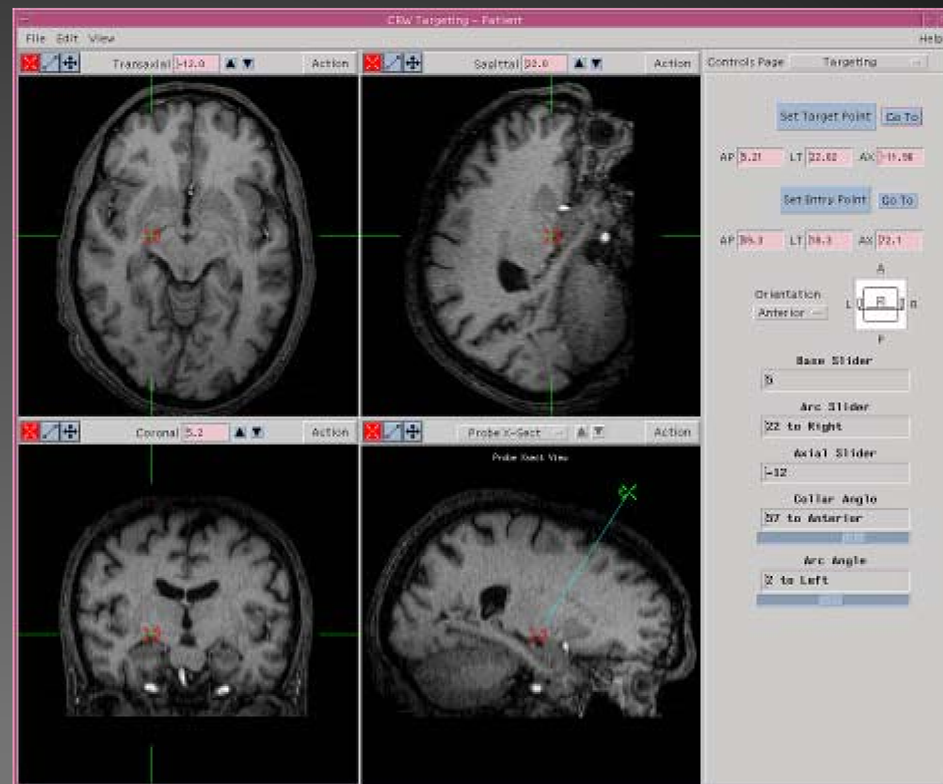
- Implantation of an electrode to electrically stimulate a specific region of the brain
- Effective in certain movement disorders such as Parkinson's Disease in relieving symptoms
- Replaces techniques such as ablation - which is non-reversible



http://nyneurosurgery.org/park_treat.htm

Preoperative Procedure

- Preoperative screening
- MR Imaging
- Placement of stereotactic head ring
- CT Imaging to establish stereotactic coordinates
- Image fusion of MR to CT



Intraoperative Procedure

- Target localization is estimated from MRI
- Microelectrode recording
  - More precise brain mapping
- Final stimulating electrode placement

Imaging for Image Guidance

- Pre-procedure
  - CT
  - MRI
- Intra-procedure
  - Cone-beam CT
  - Intraoperative MRI (less common)
  - Ultrasound
- Pre-procedure versus intra-procedure?
  - Account for changes from pre-procedure imaging
  - Provide local reference for positioning
  - Enhanced imaging on diagnostic machines
  - Time limitations during procedure

Imaging Considerations

- Image guidance accuracy is directly related to imaging accuracy
- Potential sources of spatial inaccuracy:
  - Image uniformity
  - Spatial resolution (in plane)
  - Slice thickness
- Achievable accuracies potentially worse for certain imaging modalities such as MRI

Spatial accuracy requirements

Resolution requirements

Sources of Errors

- AAPM TG 42
  - Errors from targeting based off CT
  - Does not explicitly include MRI
- MRI localization errors
  - Historically, thicker slices
  - Increased potential error contribution due to fusion
- Acquire as high of a resolution as feasible to minimize this error

CT Slice Thickness 1mm 3mm

TABLE II. Achievable Uncertainties in SRS

	1mm	3mm
Stereotactic Frame	1.0 mm	1.0 mm
Isocentric Alignment	1.0 mm	1.0 mm
CT Image Resolution	1.7 mm	3.2 mm
Tissue Motion	1.0 mm	1.0 mm
Angio (Point Identification)	0.3 mm	0.3 mm
Standard Deviation of Position Uncertainty (by Quadrature)	2.4 mm	3.7 mm

AAPM Task Group 42

+ Image Fusion Error?

For a stereotactic procedure such as radiosurgery, the largest contribution to the spatial uncertainty (error) is:

0%	1.	Stereotactic frame
3%	2.	Isocentric alignment
74% ✓	3.	CT image resolution (voxel size)
19%	4.	Tissue motion
3%	5.	Angio (point identification)

Answer – CT image resolution[3]

- Considering an in-plane pixel size of ~0.7 mm and a slice thickness of 1mm, the uncertainty is ~1.7 mm

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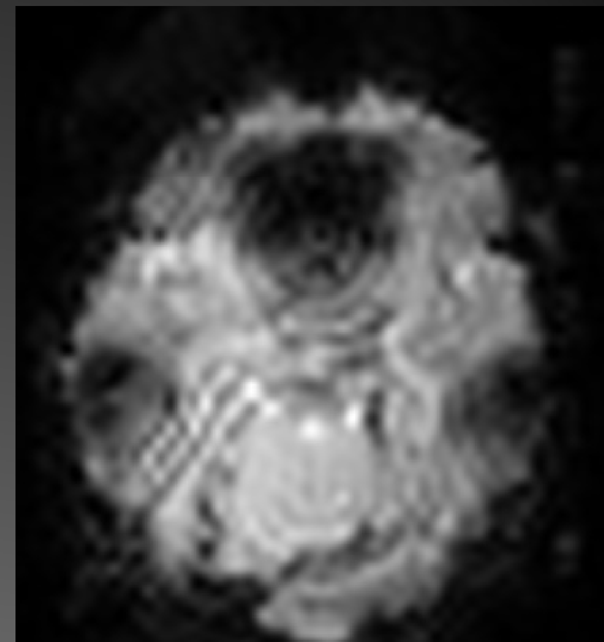
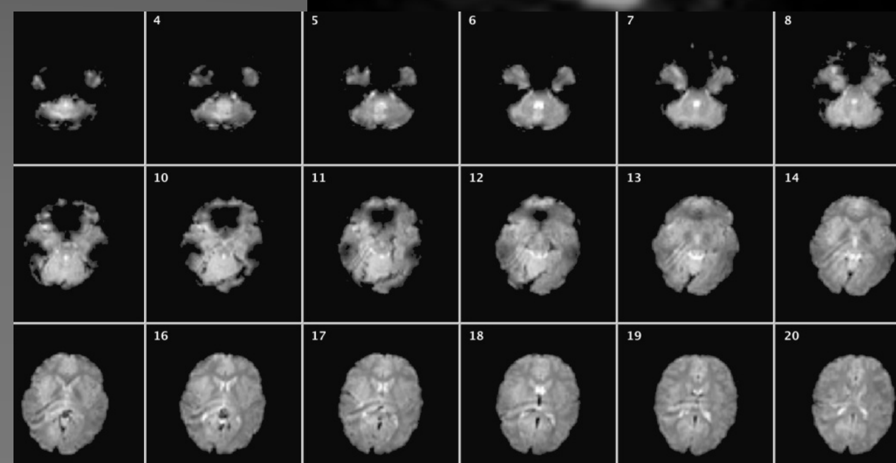
MRI considerations

- MRI is of direct interest to particular interest for soft tissue distinction but may have lower spatial accuracy.
- Sources of spatial distortions
  - Main magnetic field inhomogeneities
  - Gradient field nonlinearities
  - Patient/object-induced distortions
    - Chemical shift artifacts
    - Magnetic susceptibility





Courtesy of Jason Craggs

Minimizing Spatial Inaccuracy

- Scanner
  - Lower field strength result in less susceptibility
  - Certain sequences are less prone to distortion
    - 3D over 2D due to slice phase encoding
    - Increased bandwidth minimizes shifts
- Assessment and QC
  - ACR Weekly QC protocol tests geometric accuracy over an area of 148mm x 190mm
  - Error should be less than 2mm
  - More stringent QC (daily) may be necessary for procedures requiring high accuracy such as radiosurgery

ACR MRI accreditation requires a geometric accuracy (over an area of 148 mm x 190 mm) of:

19%	1.	1 mm
81% ✓	2.	2 mm
0%	3.	3 mm
0%	4.	4 mm
0%	5.	5 mm

Answer – 2 mm^2

- For an ACR accredited MRI system, this is the minimum spatial accuracy that is required on a "standard" scan (ie. high resolution T1).
- These inaccuracies can (and are) much higher for newer specialized sequences.

Registration and references

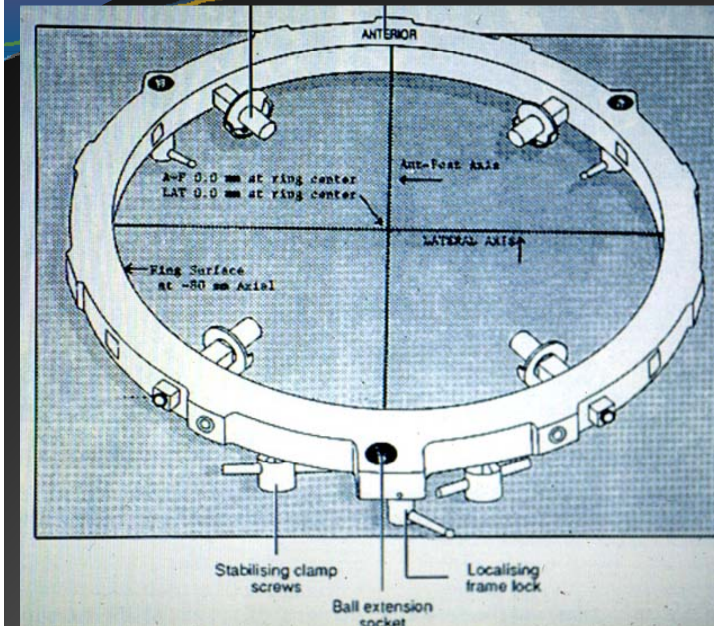
- Upon the completion of spatially accurate imaging, the images must be referenced back to the patient
- Known fiducials from the image set can be picked and located on the actual patient
- Alternatively, landmarks can be picked from anatomy
- External (introduced) reference points
  - Stereotactic headframes
  - Specifically placed fiducial markers
  - Biteplates

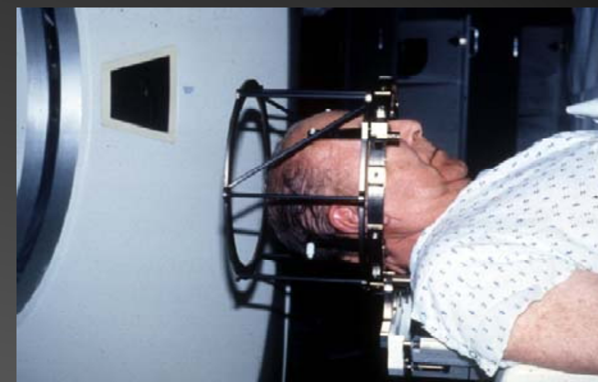
Accuracy Considerations

- Optical guidance accuracy
    - Camera system
        - Relatively accurate
    - Registration
        - Picking of fiducials
        - Uniqueness of fit

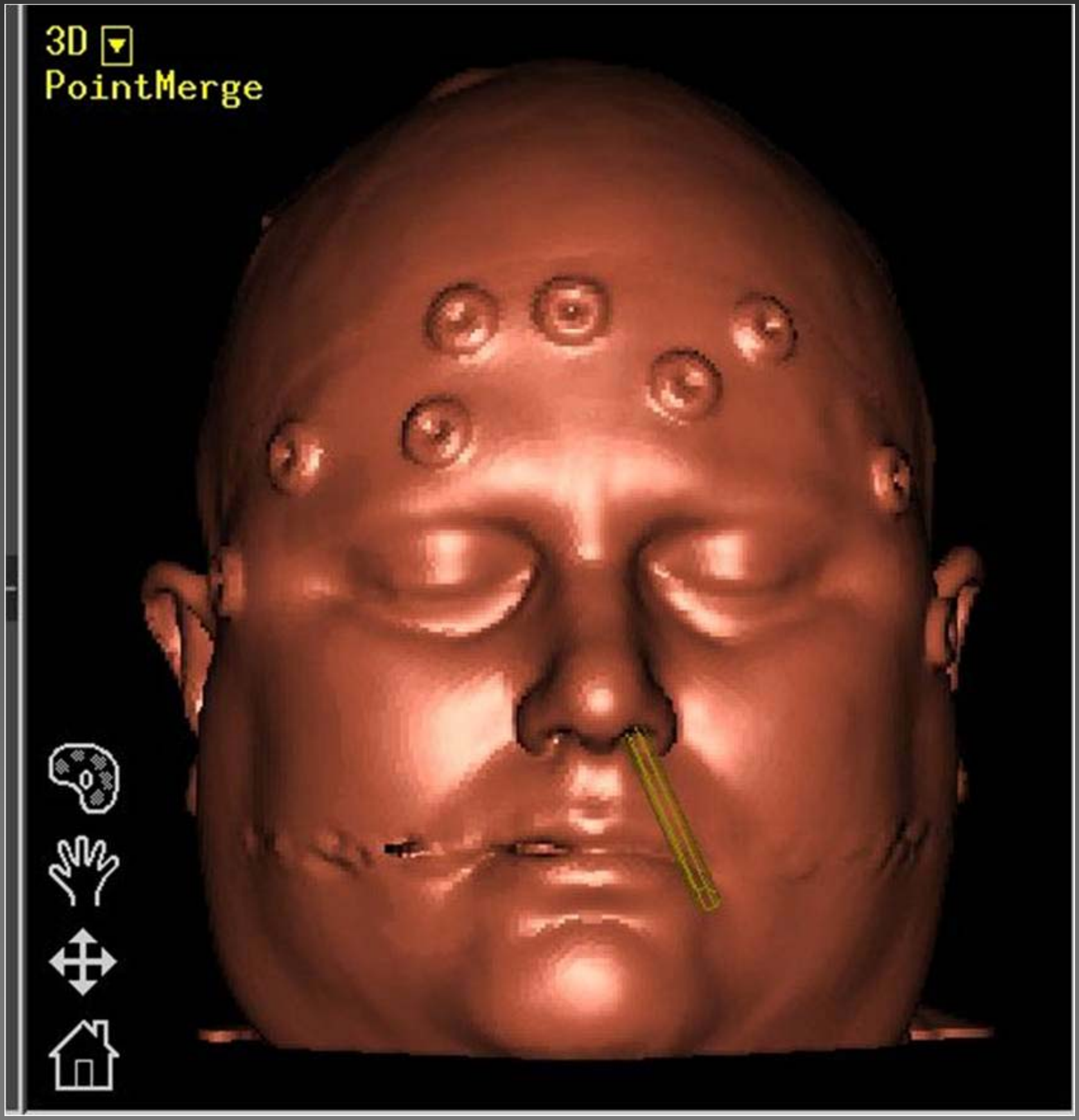
- Overall accuracy for head and neck is ~2mm or less.

External References





External Refernces



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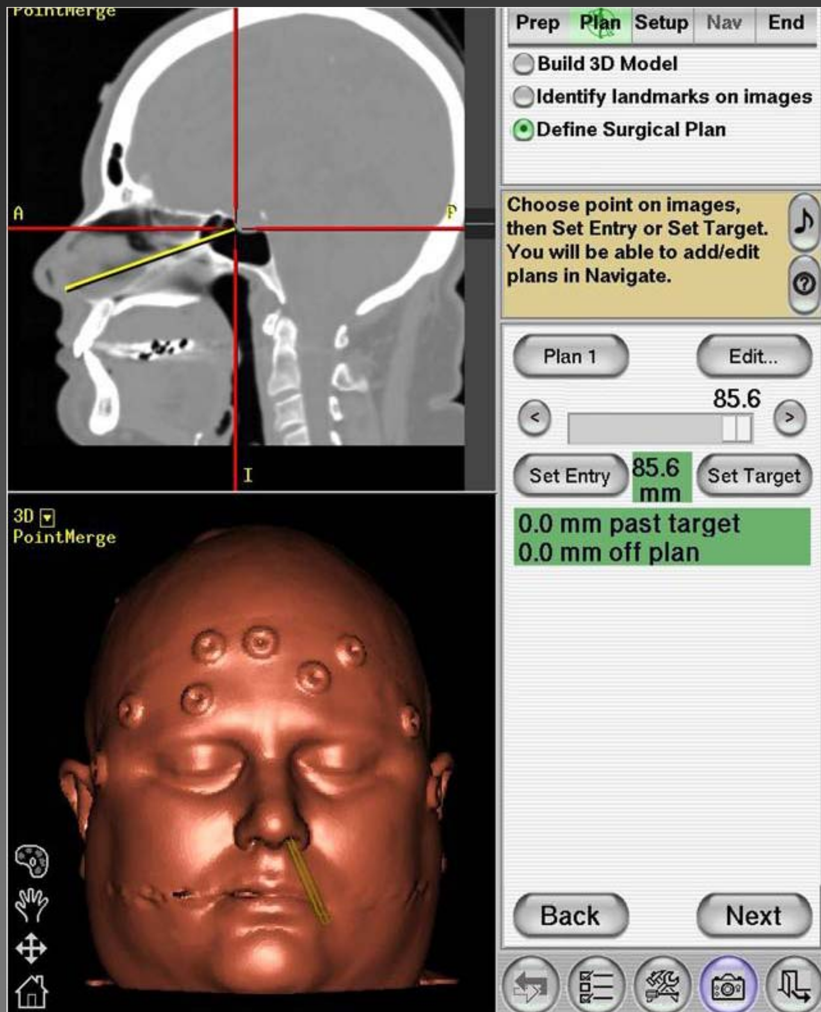
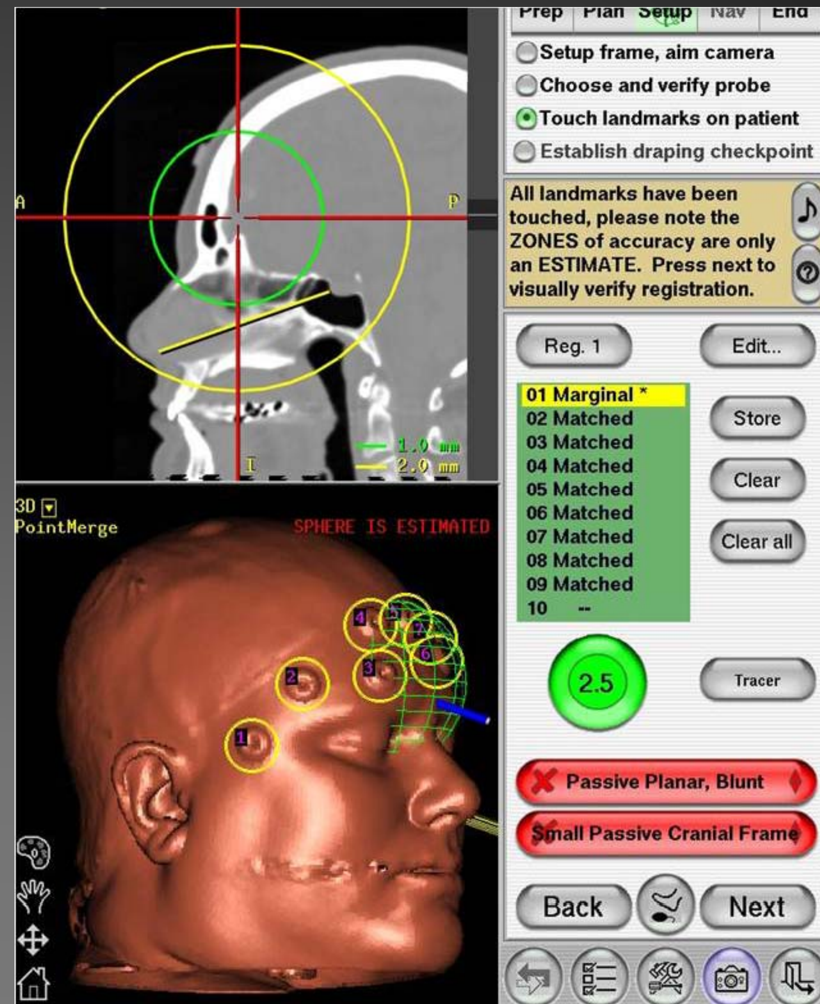


PointMerge
A
P
I
Prep
Plan
Setup
Nav
End
Build 3D Model
Identify landmarks on images
Define Surgical Plan
Choose point on images, then Set Entry or Set Target. You will be able to add/edit plans in Navigate.
Plan 1
Edit...
85.6
Set Entry
85.6 mm
Set Target
0.0 mm past target
0.0 mm off plan
3D
PointMerge
Back
Next



A
P
I
1.0 mm
2.0 mm
Prep
Plan
Setup
Nav
End
Setup frame, aim camera
Choose and verify probe
Touch landmarks on patient
Establish draping checkpoint
All landmarks have been touched, please note the ZONES of accuracy are only an ESTIMATE. Press next to visually verify registration.
Reg. 1
Edit...
01 Marginal *
02 Matched
03 Matched
04 Matched
05 Matched
06 Matched
07 Matched
08 Matched
09 Matched
10 --
Store
Clear
Clear all
2.5
Tracer
Passive Planar, Blunt
Small Passive Cranial Frame
3D
PointMerge
SPHERE IS ESTIMATED
Back
Next

For head & neck surgeries, the mean accuracy of image guidance systems (using skin landmarks) is roughly:

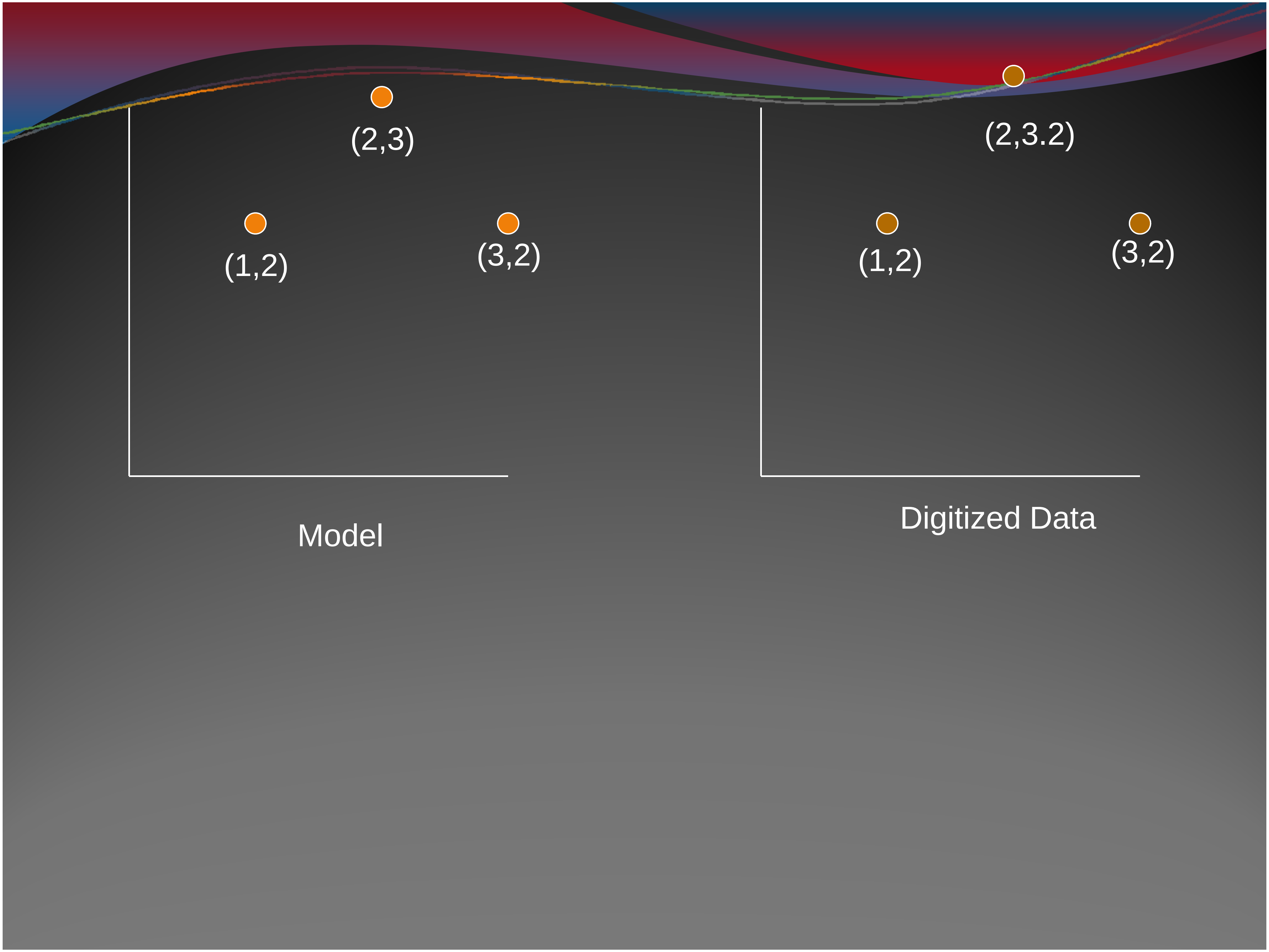
3%	1.	1 mm
84% ✓	2.	2 mm
10%	3.	3 mm
0%	4.	4 mm
3%	5.	5 mm

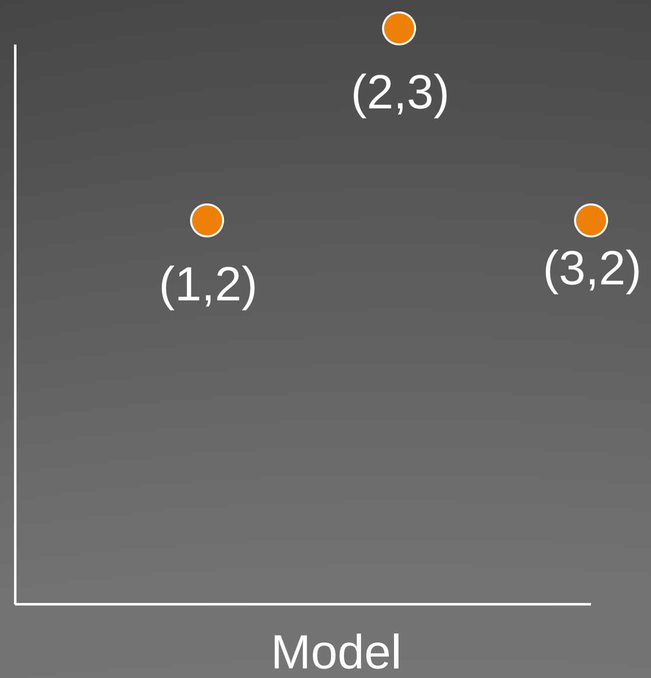
Answer – 2 mm[1]

- While the theoretical accuracy of camera based localization systems is very high, the usage of skin based landmarks can limit the overall accuracy.
- This accuracy may not hold true for other sites such as brain and spine where shifts may occur relative to pre-operative imaging.

Anatomic Landmarks

- Surface matching
  - Points are picked from the patient's anatomy
  - Optimally, points should have:
    - Non-linear point configurations
    - Increase of spatial distance between the points
    - Increase of number of points
    - Reduction of distance from the points to the target
  - Around 6 points seems to be optimal with diminishing returns for more


(2,3)
(1,2)
(3,2)
Model
(2,3.2)
(1,2)
(3,2)
Digitized Data


(2,3)
(1,2)
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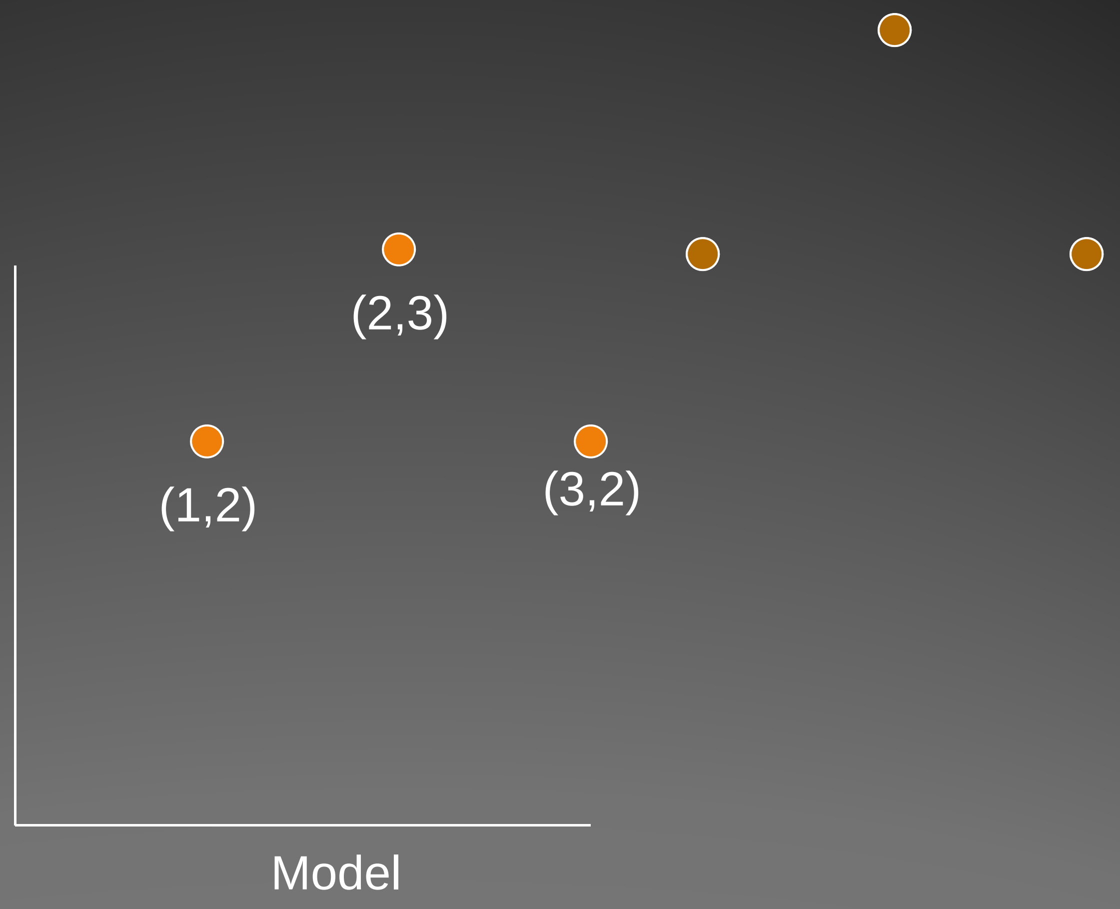
Model



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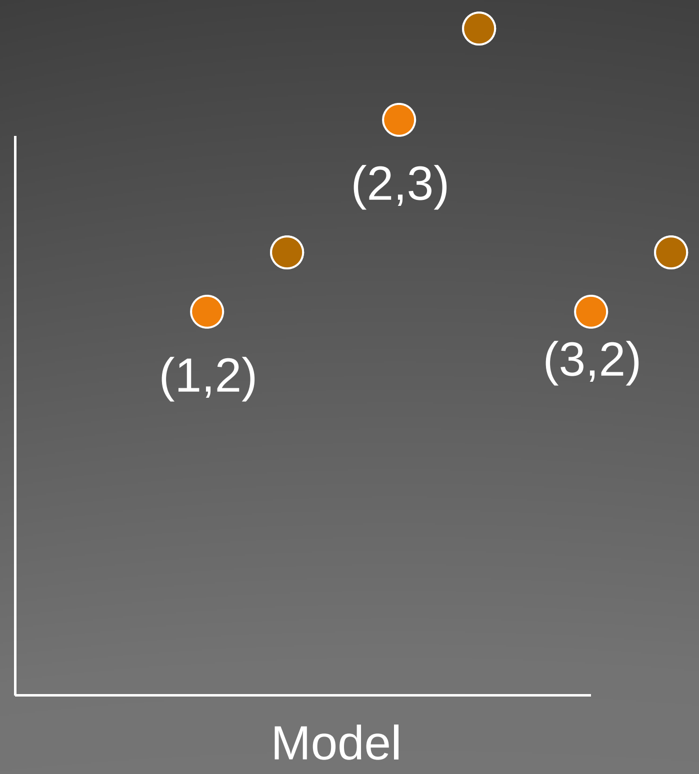
(3,2)
Model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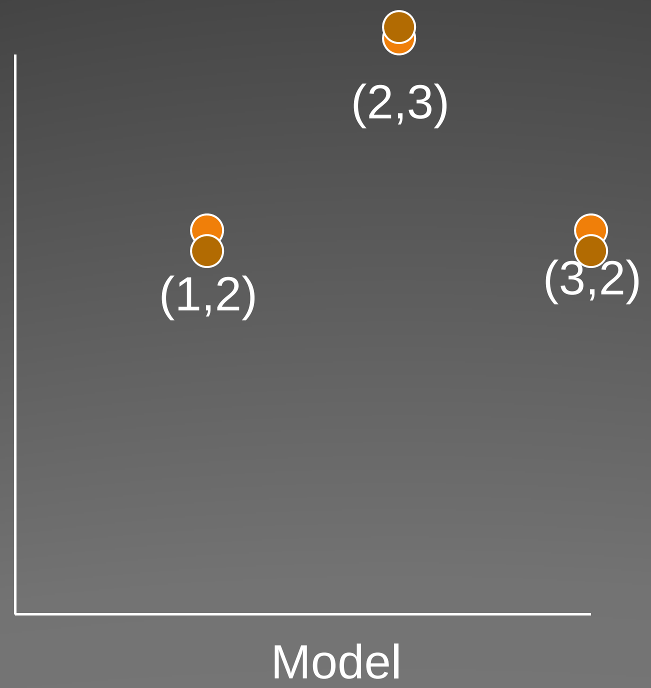
(1,2)
(3,2)
Model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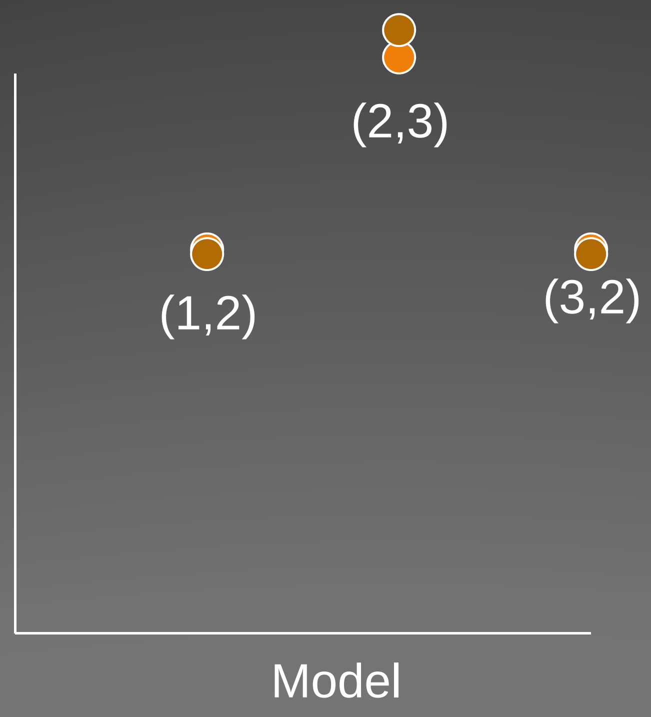
Model


(2,3)
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(3,2)
Model


(2,3)
(1,2)
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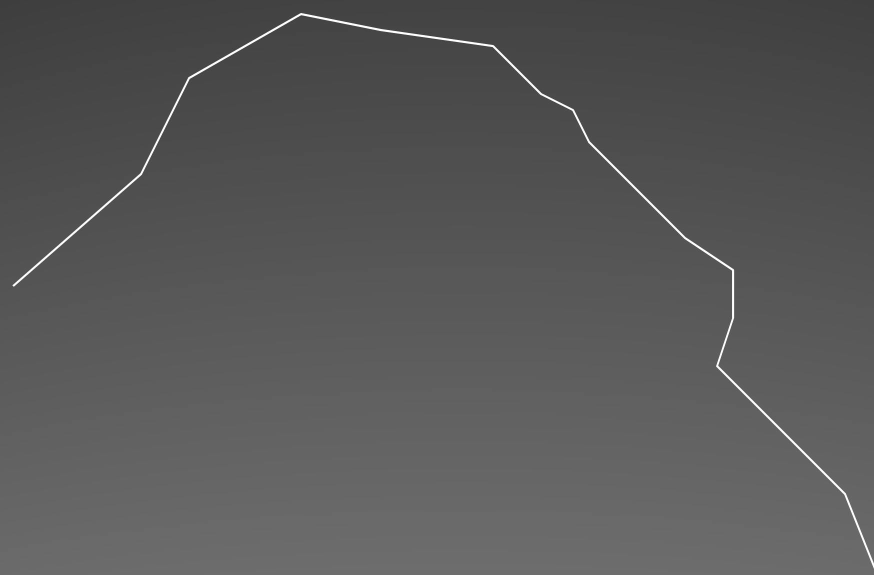
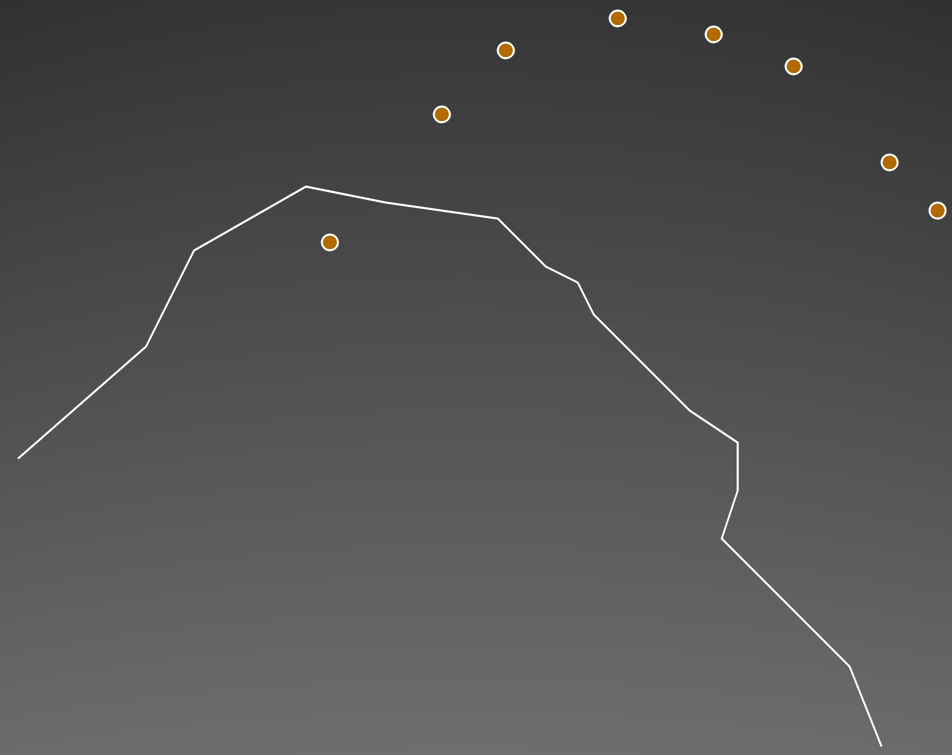
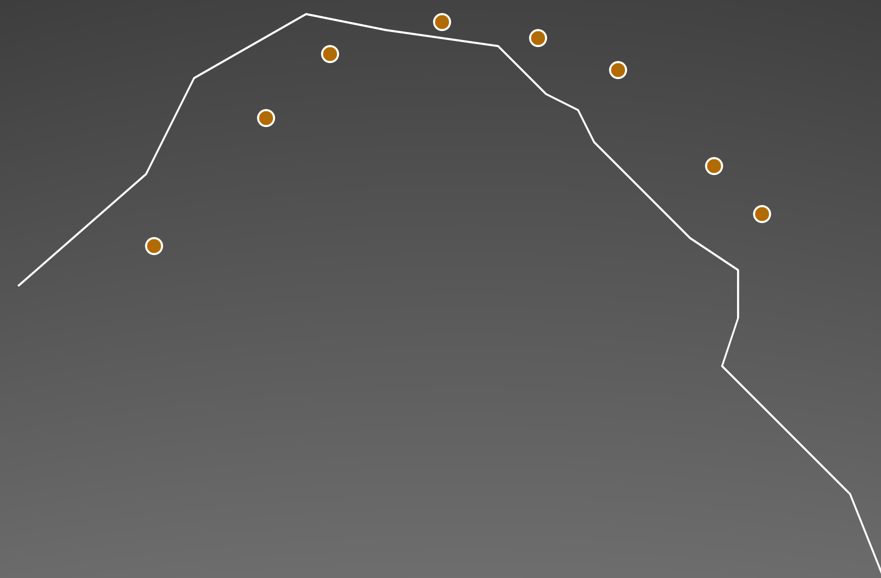
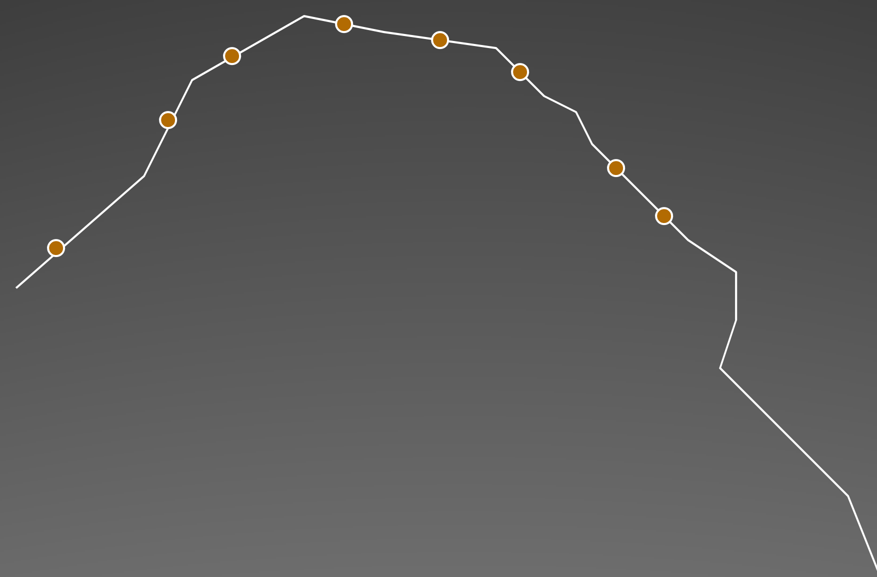
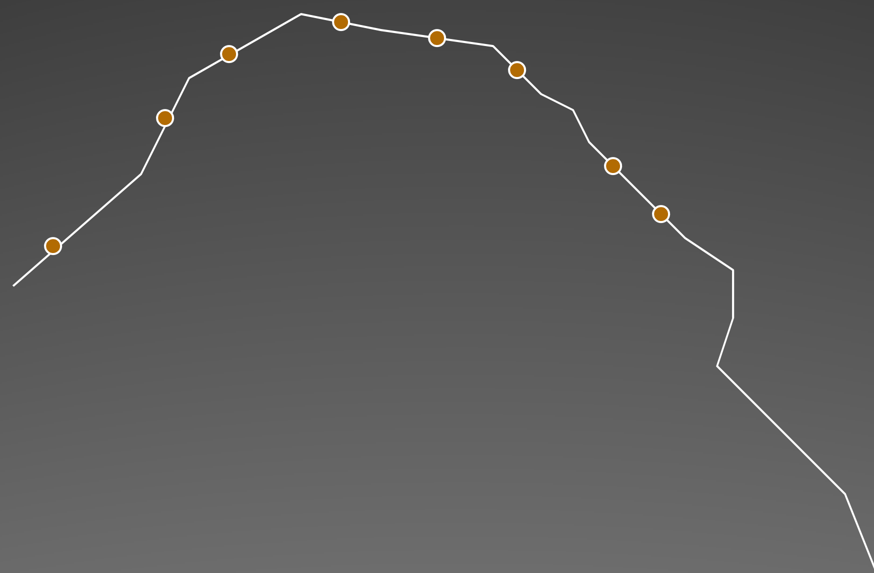
Model











Which of the following techniques does NOT significantly improve registration of markers on a patient to an image:

0%	1.	Non-linear point configurations
0%	2.	Increase of spatial distance between the points
0%	3.	Increase of number of points
6%	4.	Reduction of distance from the points to the target
94%	5.	Usage of greater than six markers

Answer – Using above six markers[4]

- It is important to create a set of points that is unique and well separated in space
- The minimum number of points required is 3 but at least 4 are typically chosen
- Greater than 6 points results in diminishing returns

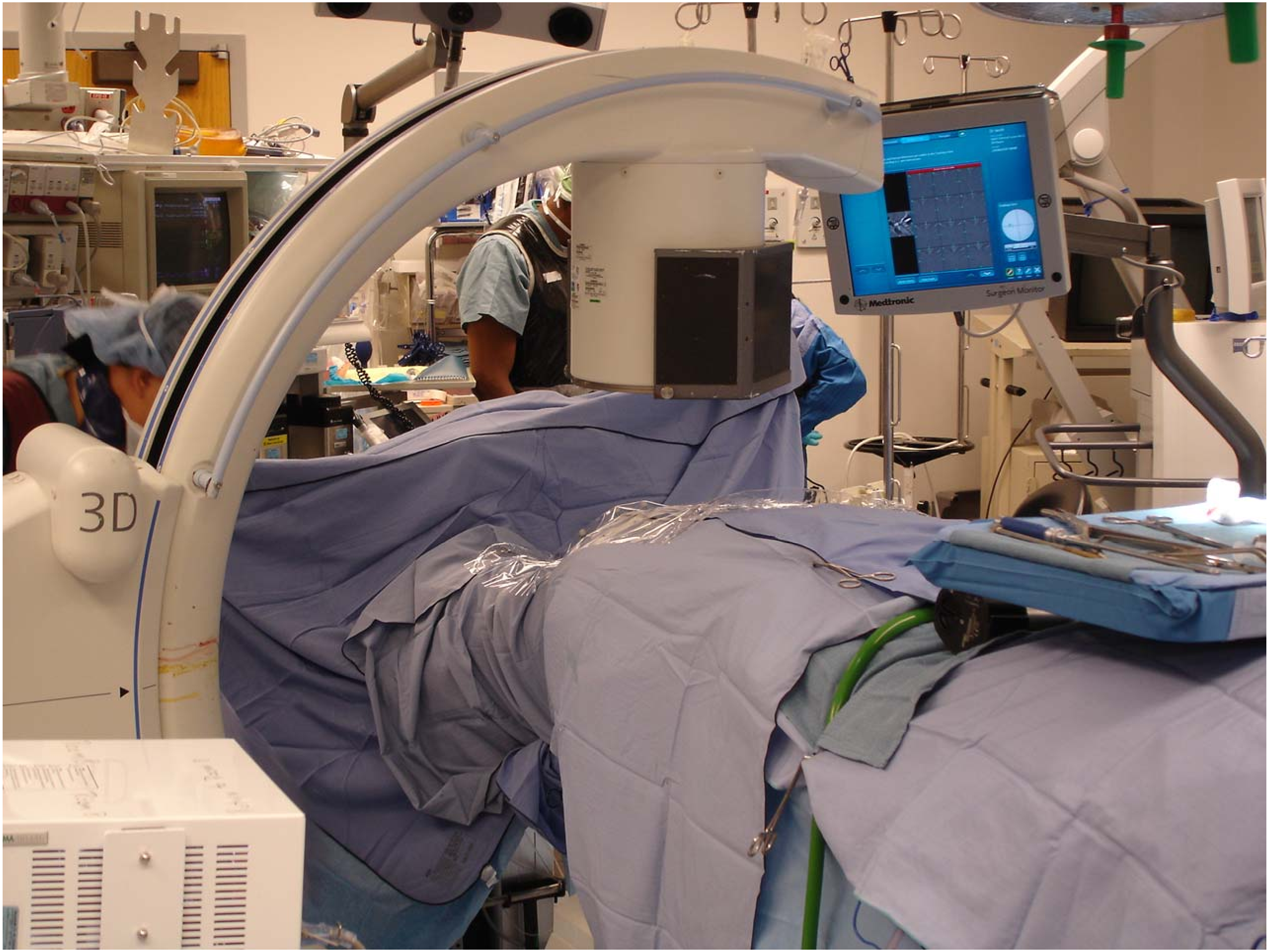
Intra-operative CT imaging

- Alternatively, imaging can be acquired during the procedure
- Cone-beam CT (CBCT)
  - Spinal surgery often involves implantation of hardware into the vertebral body
  - Pre-operative imaging may not be accurate after exposing
  - The solution?
    - CBCT
    - Dynamic reference

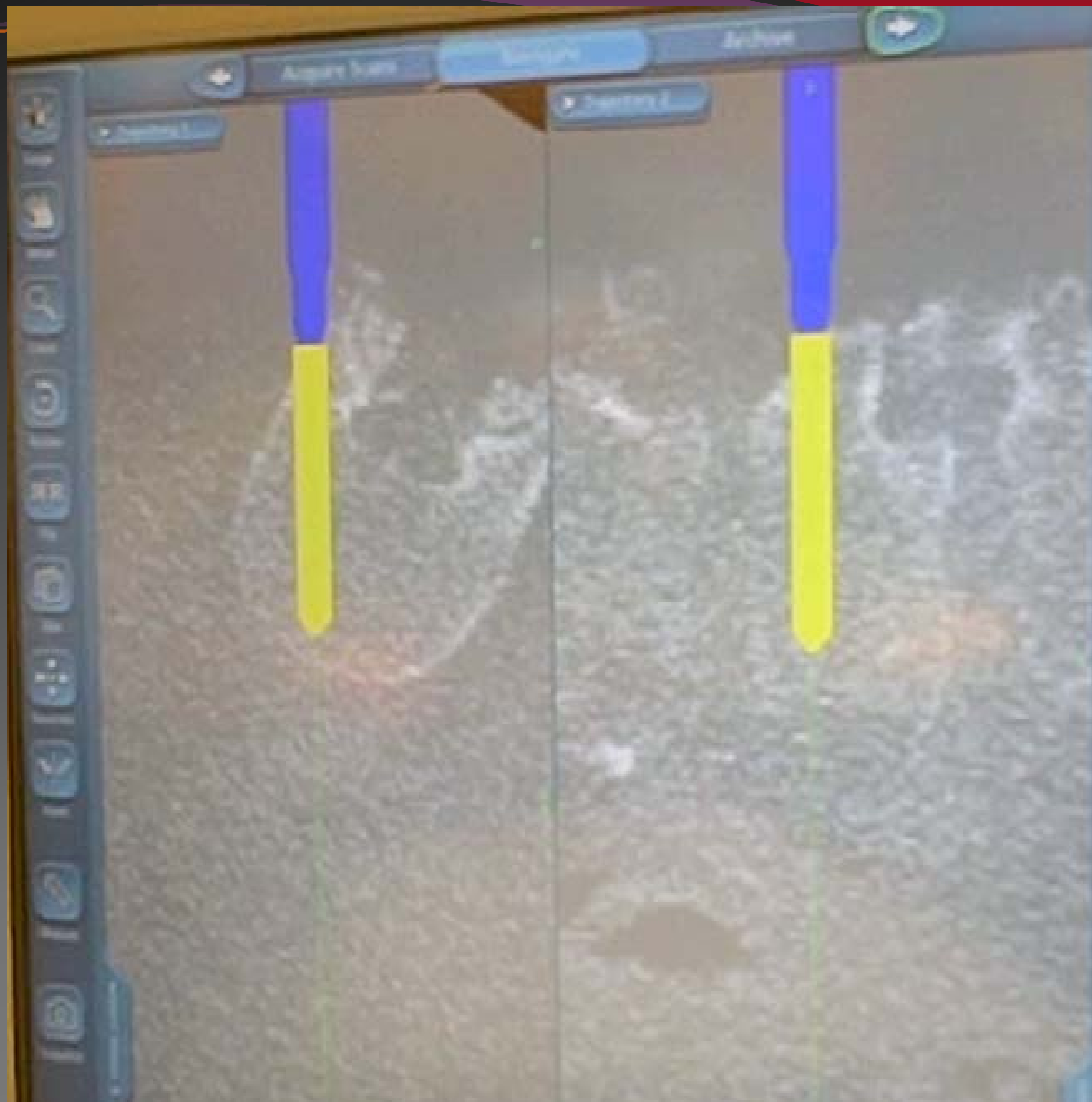
Dynamic Reference

Advantages/Disadvantages

- Advantages
  - Intra-procedure imaging results in more current representations of anatomy
  - Localization can be more accurate
  - Loser dose to the patient, same dose to personnel
- Disadvantages
  - Typically worse image quality
  - Lower contrast
  - Added time during a procedure
  - Equipment size may get in the way


3D
Medtronic
Surgeon Monitor

O-arm
Suture Bag


Archive

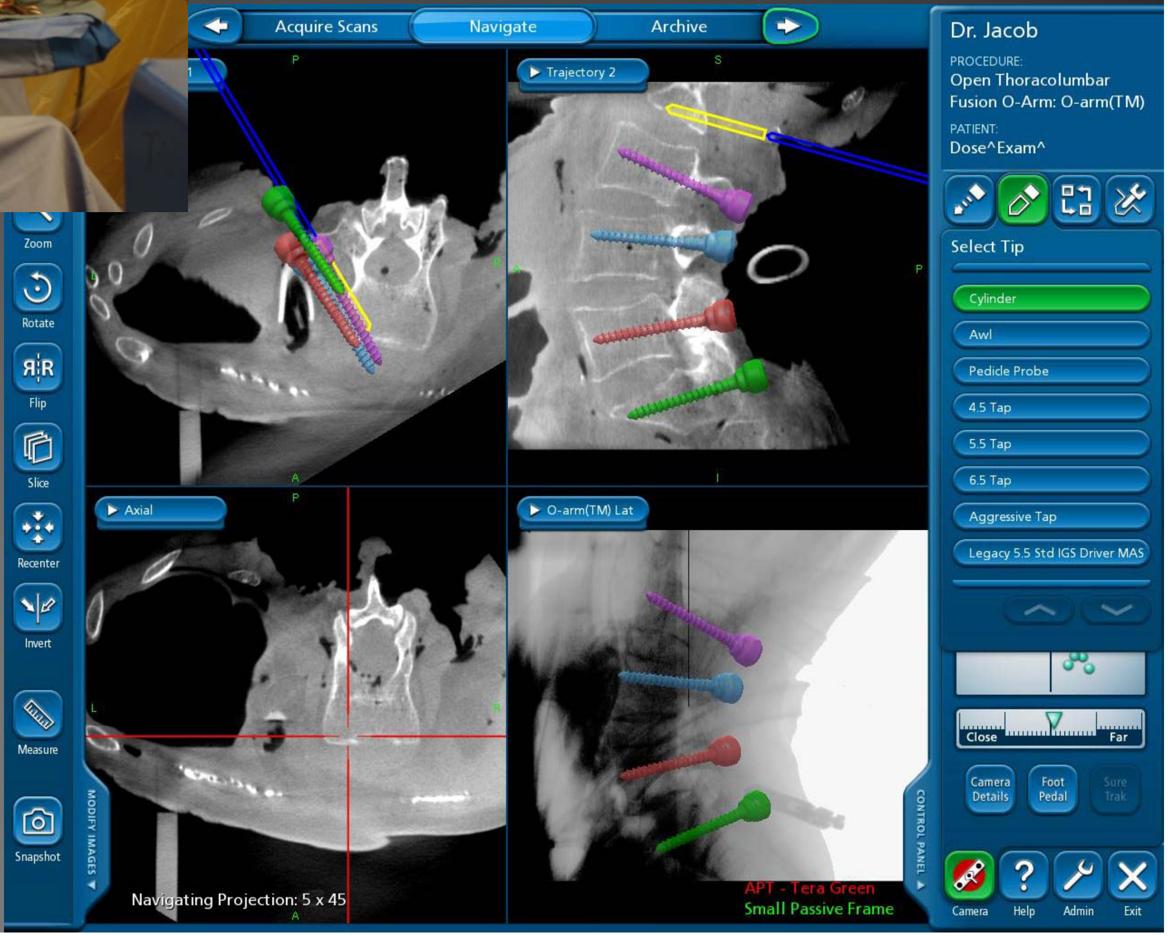
Intraoperative cone-beam CT imaging systems (such as the O-arm™) produce dose to the patient and scattered dose to personnel that (versus a 64 slice CT) roughly is:

10%	1.	Greater to the patient and to personnel
13%	2.	Greater to the patient and equal to personnel
3%	3.	Equal to the patient and equal to personnel
65%	4. ✓	Less to the patient and equal to personnel
10%	5.	Less to the patient and less to personnel

Answer – Less dose to the patient and equal dose to personnel[5]

- Image quality is lower for intra-operative CBCT devices so diagnostic CT images should still be acquired in cases where low contrast structures need to be visualized.
- There are significant advantages for localization to using intra-operative scanning systems

Plan Creation & Execution



Quality assurance (QA)

- Pre-procedure quality assurance
  - Knowledge of imaging accuracy
  - End to end tests – from imaging to navigation on a phantom
- Per-procedure quality assurance
  - Reference/tools quality check
  - Examples: headring localizer check and biteplate geometry check
  - Check to patient anatomic positions

Pre-procedure QA

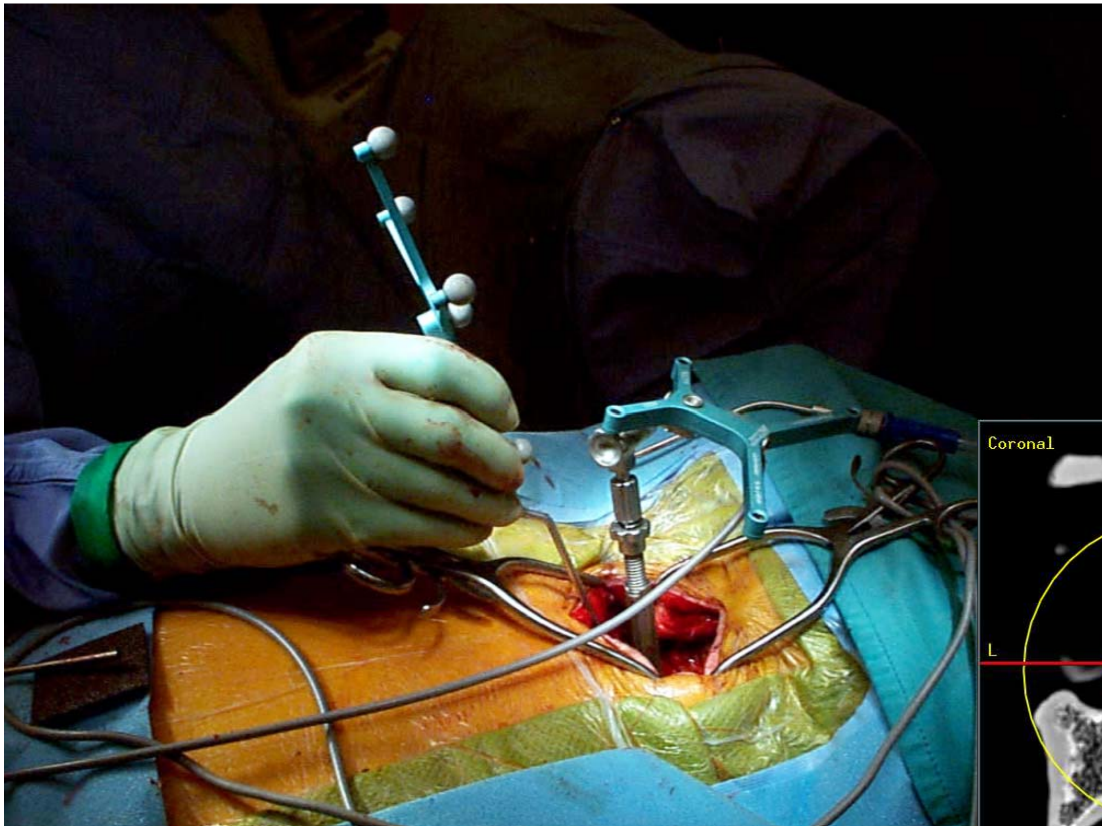
- Knowledge of imaging accuracy
  - Spatial accuracy of imaging modalities
  - Accuracy of potential registration (if applicable)
  - Ability to delineate target
  - General knowledge of deformation from pre-procedure to intra-procedure
- End to end test
  - Image phantom
  - Track using standard method (real-time camera, stereotactic, etc)
  - Position to known positions and determine errors

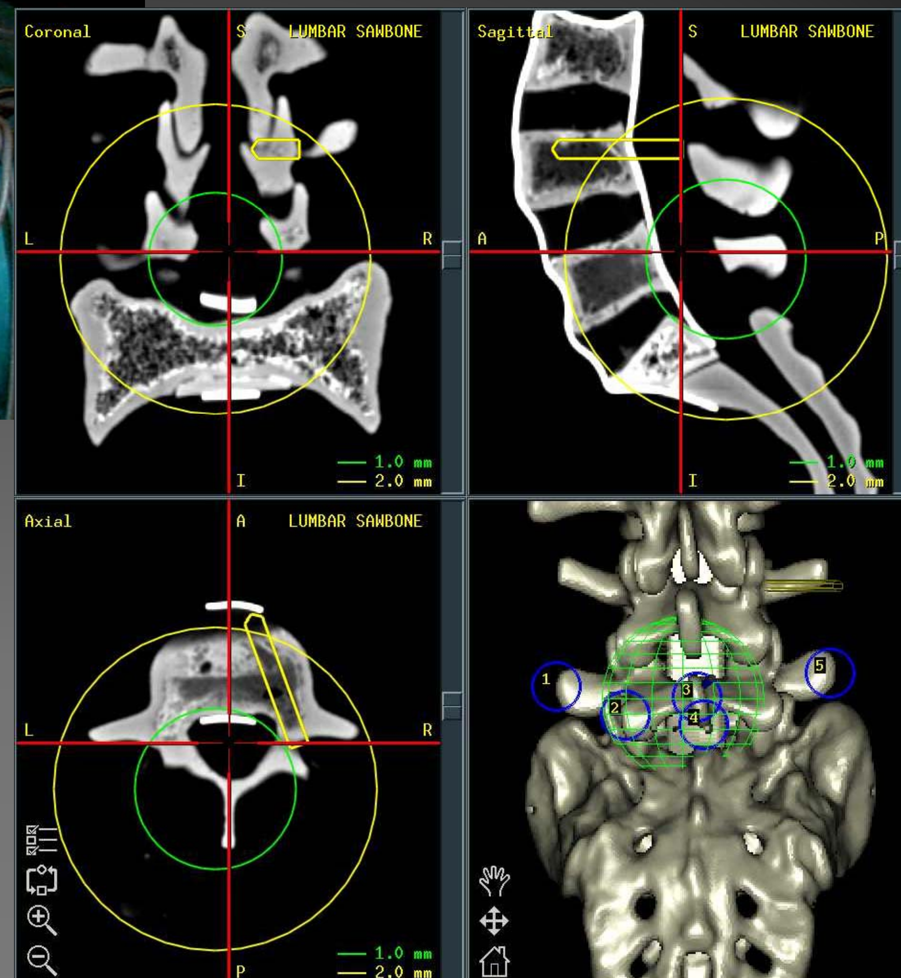
Intra-procedure QA

- Geometric check of equipment
  - For optical procedures, tracking spheres geometry check
    - Each device should have known geometry
    - If spheres become damaged, that geometry may change
  - For stereotactic procedures, localizer geometry check
- Image uniformity/accuracy check
  - For stereotactic procedures, non-uniform image set may trigger problem
  - For optical procedures, localization of optical tracking spheres within the image set may be useful in determine imaging issues

Anatomic Position Check

- Final check on actual patient
  - Use known landmarks to determine overall error similar to as on end-to-end test
  - Use your best judgment relative to the required accuracy
- Skin shifts
  - Mean skin shift from pre-operative imaging to intra-procedure may be around 5 mm
  - Will limit the ability to determine accuracy of final check
  - Recommendation: Try to position for imaging and test as neutral as possible




Coronal
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Axial
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R
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1.0 mm
2.0 mm
1
2
3
4
5

The mean skin shift from pre-operative imaging to the patient’s current anatomy is roughly:

3%	1.	1 mm
13%	2.	2 mm
19%	3.	3 mm
0%	4.	4 mm
66%	5.	5 mm

Answer – 5 mm of skin shift[6]

- Skin shift is a major cause of concern for picking of landmarks
- For pre-operative scanning, a “natural” position is typically preferred to minimize shifts of ears, nose, etc.
- A final check to various anatomic positions can be useful in determining if skin shift is negatively affecting accuracy

Summary

- Accurate image guidance requires great care
- The physicist should be aware of imaging limitations on the procedure
- The image set to patient registration methodology is important and should be carefully considered
- Final QA both for the overall procedure and for each patient should be followed

Questions?

References

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6. Mitsui T, Fujii M, Tsuzaka M, Hayashi Y, Asahina Y, and Wakabayashi T. Skin shift and its effect on navigation accuracy in image-guided neurosurgery. Radiol Phys Technol. 2011 Jan;4(1):37-42. Epub 2010 Sep 10