## Applications of Simulation, Morphometrics and Robotics in Craniofacial Surgery

**C. B. Cutting,**
**F. L. Bookstein**
**R. H. Taylor**

In *Computer-Integrated Surgery*, R. H. Taylor, S. Lavallee, G. Burdea and R. Mosges, Eds. Cambridge, Mass.: MIT Press, 1996, pp. 641-662.

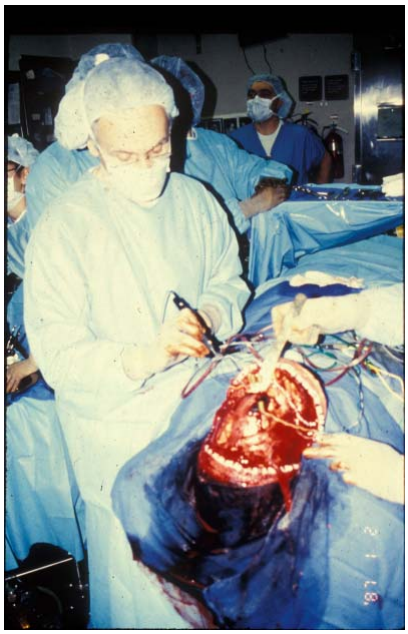
Click here for preop/postop pictures





## GOALS

- Computer-assisted planning of craniofacial osteotomies based on optimal approximation to “normal” (i.e., average) skull shape
- Accurate intraoperative tracking and 6-dof positioning of bone fragments



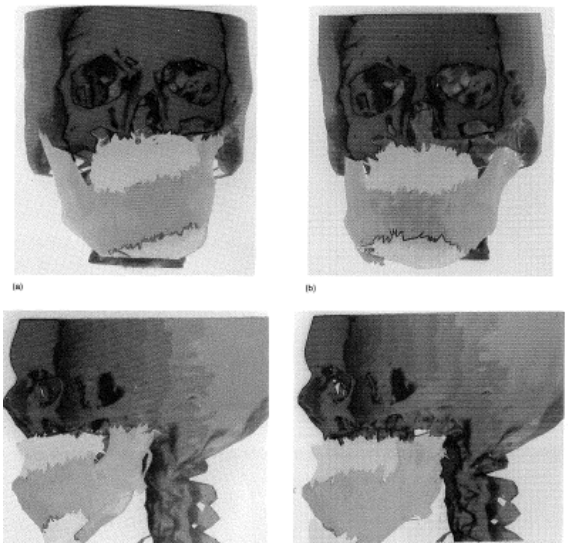
## Generations of CT-based Planning Programs

- ***1st*** - 3D "cut and move" simulators
- ***2nd*** - Adds fragment position optimization
- ***3rd*** - Adds automatic ranking of best surgical designs





## Cut and Move Simulators



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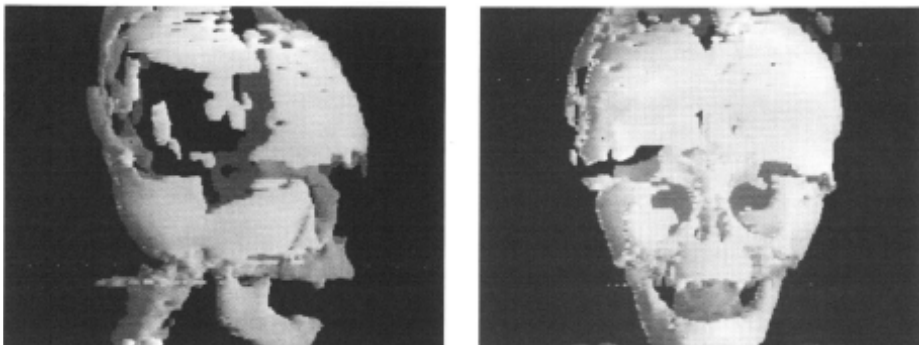

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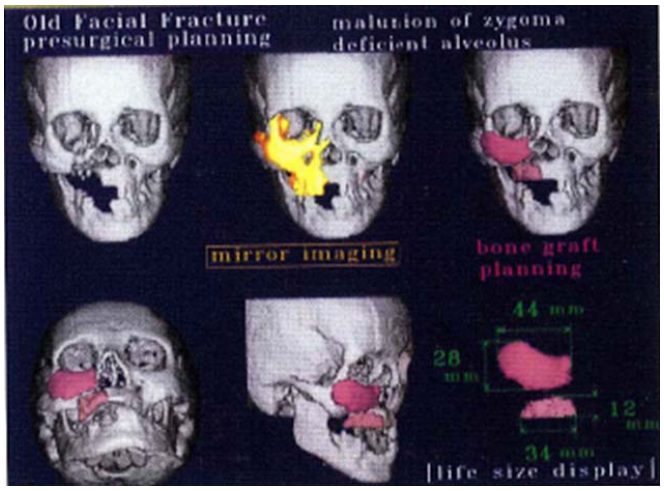
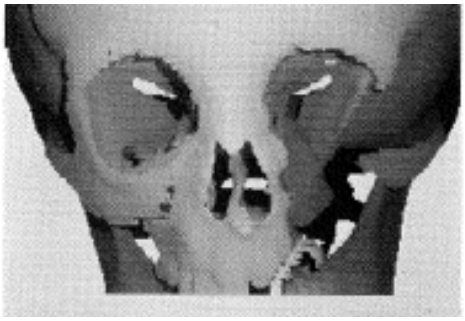
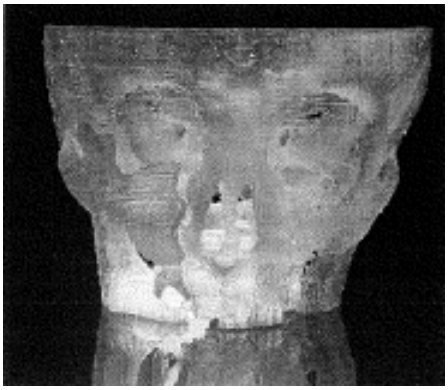
# Cut and Move Simulators




[R. A. Robb and D. P. Hanson, "The ANALYZE software system for visualization and analysis in surgery simulation," in Computer Integrated Surgery, E. S. Lavallee, R. Taylor, G. Burdea and R. Mosges, Eds.: MIT Press, 1996, pp. 175-189.

## Physical Simulators: Rapid Prototyping





L. Klimek, H.-M. Klein and R. Mosges, "Simulation of Surgical Procedures in the Craniofacial Region," in Computer-Integrated Surgery, R. H. Taylor, S. Lavallee, G. Burdea and R. Mosges, Eds. Cambridge, Mass.: MIT PRess, 1996, pp. 663-669..

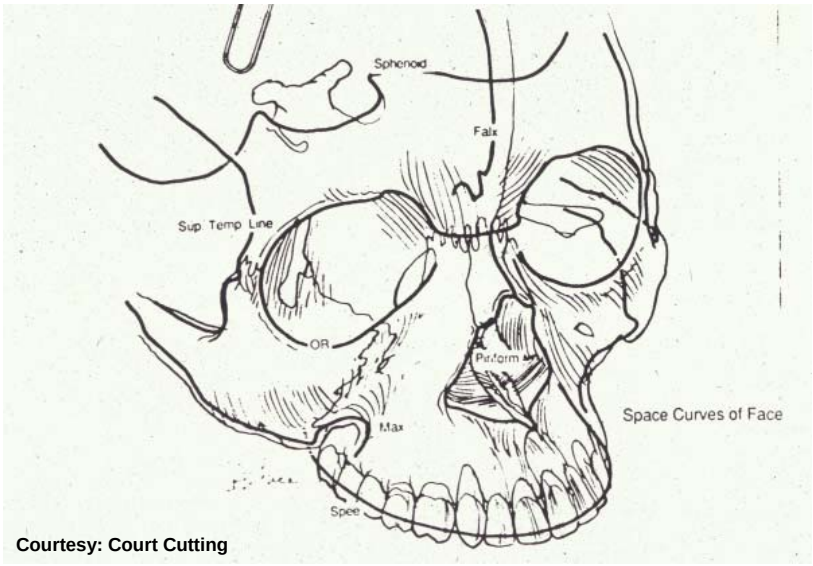




## Video Simulators

L. Klimek, H.-M. Klein and R. Mosges, "Simulation of Surgical Procedures in the Craniofacial Region," in Computer-Integrated Surgery, R. H. Taylor, S. Lavallee, G. Burdea and R. Mosges, Eds. Cambridge, Mass.: MIT PRess, 1996, pp. 663-669..

## The ridge curves of the face

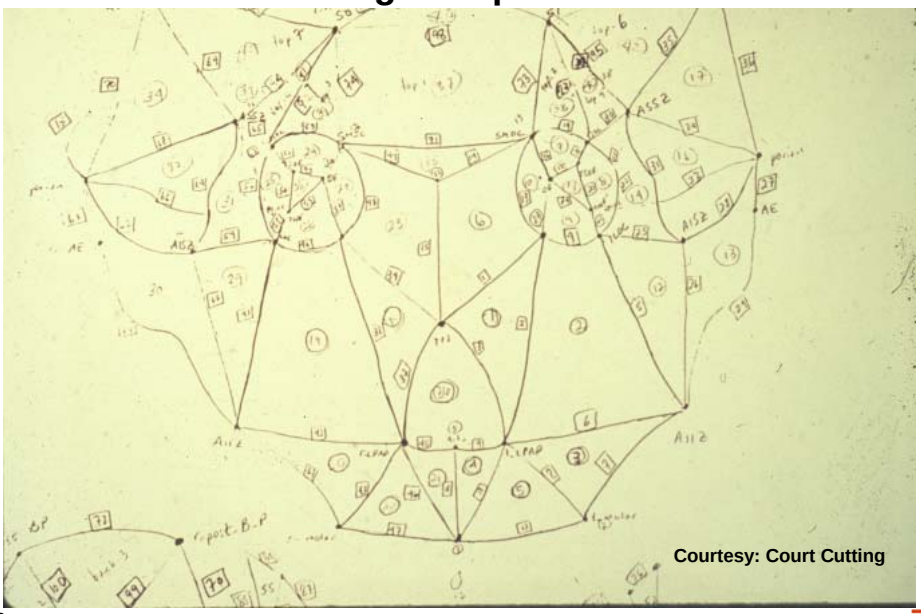



Courtesy: Court Cutting





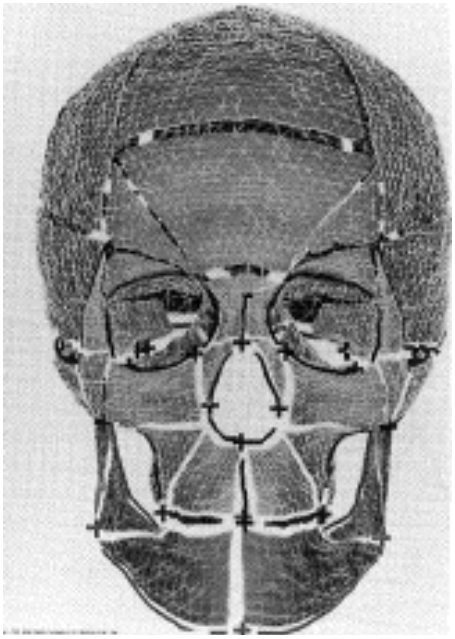
## Dr. Cutting's map of the face



Courtesy: Court Cutting

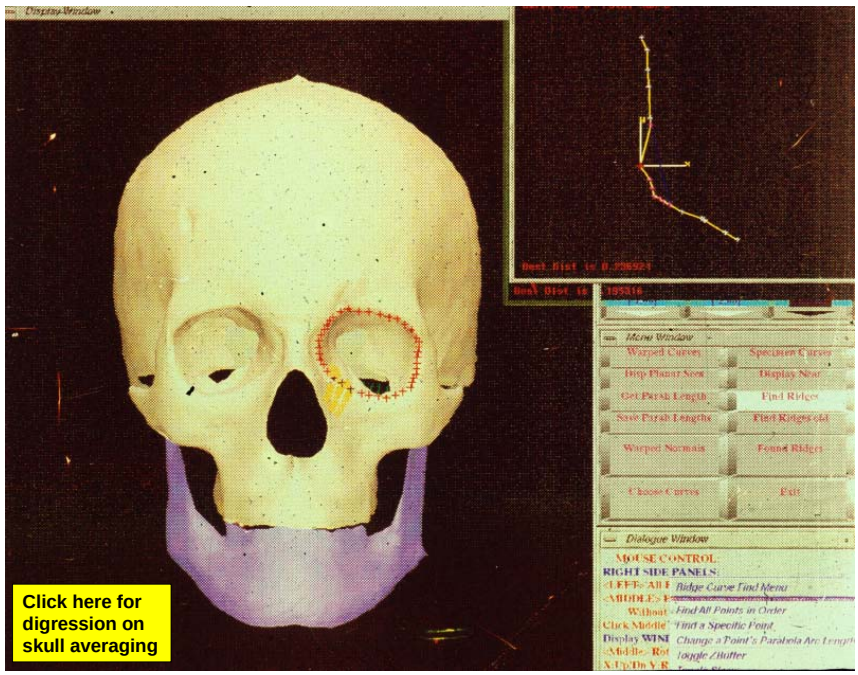
## Computer mesh corresponding to Dr. Cutting's map

- Point landmarks
- Ridge curves
- Additional curves along geodesic lines between landmarks
- Triangular and quadrangular patches
- Take this data for many patients and average to make atlas

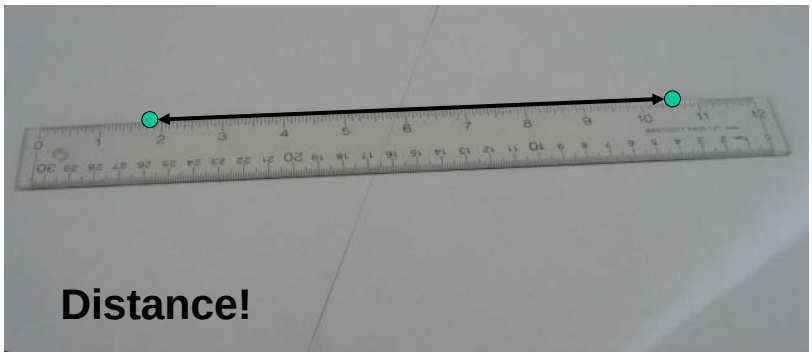








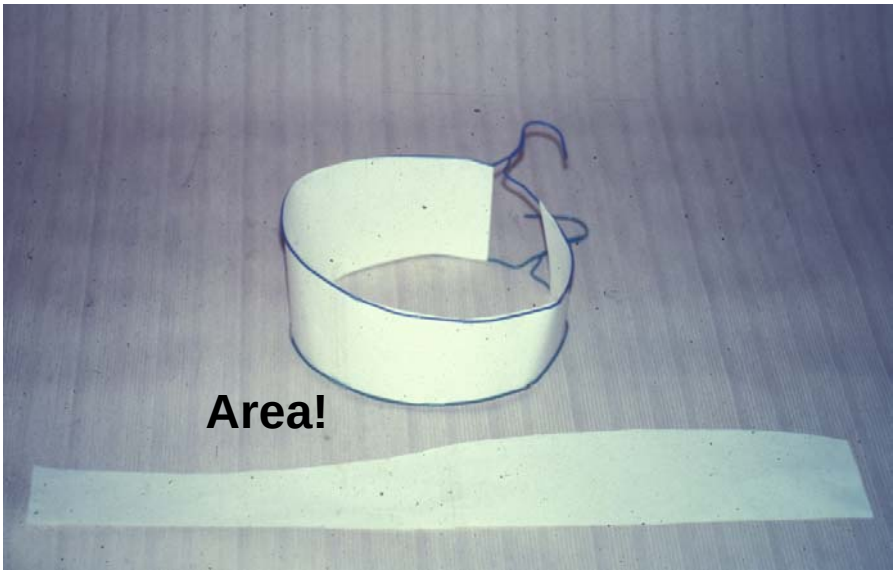
## Fitting Error for Landmark Points








## Fitting Error for Ridge Curves



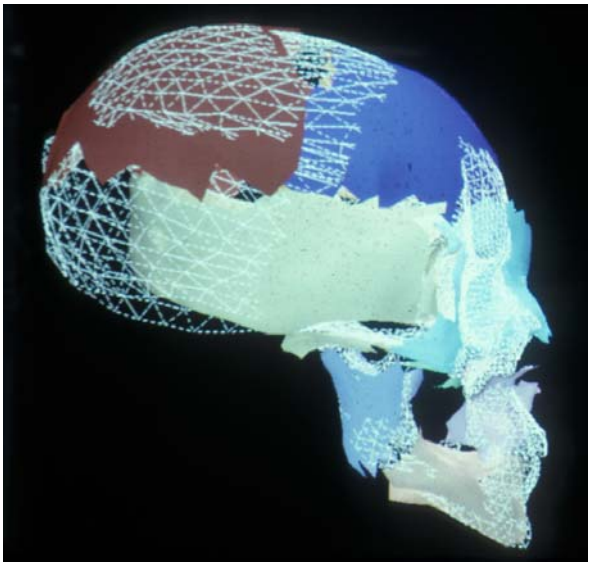
## Fitting Error for Surfaces

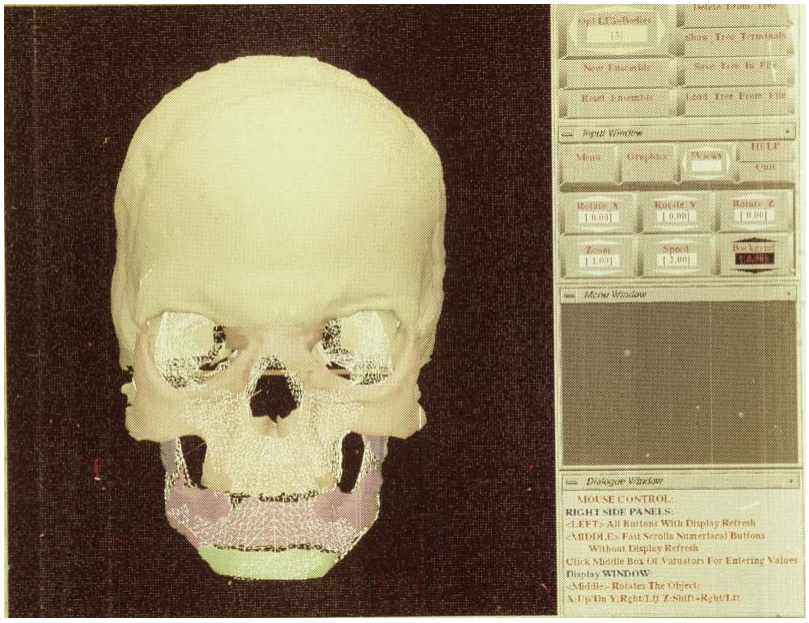





## Optimization

Given models bone fragments corresponding to parts of an ideal skull, the computer minimizes a weighted sum of these three distance metrics



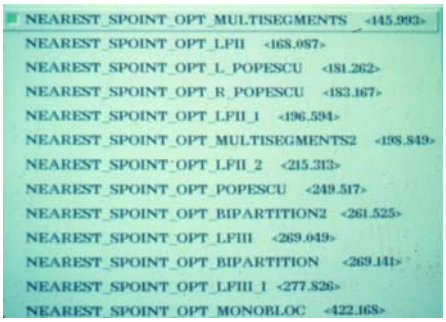



 600.445 Fall 2006



## Automated Osteotomy Ranking

- Computer plans all common osteotomies
- Computer optimizes bone fragment motion and computes error score
- Systematically remove osteotomy lines one at a time in score order. Re-optimize positions and rescore
- Show clinician the plans
- Clinician picks desired plan and further refines based on anatomical/clinical knowledge

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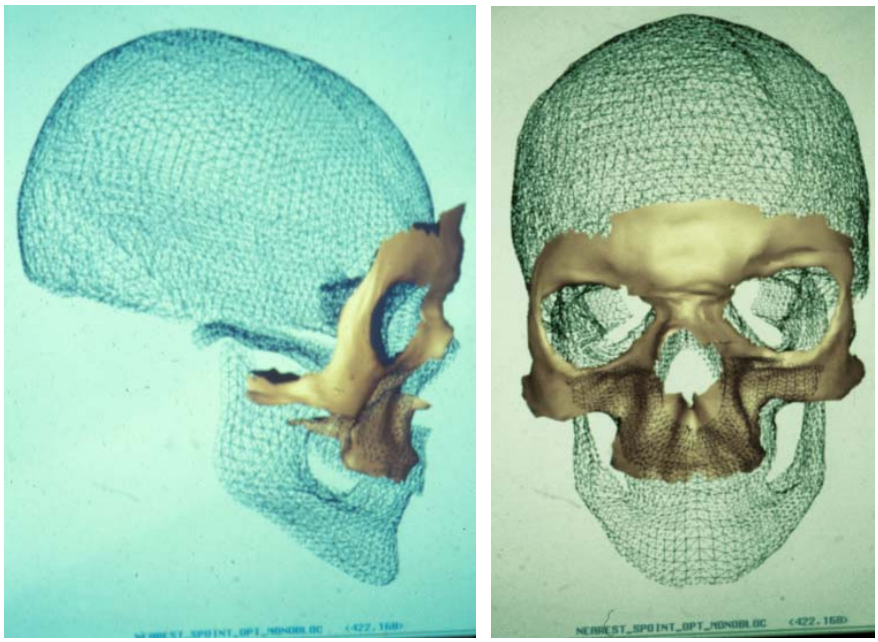
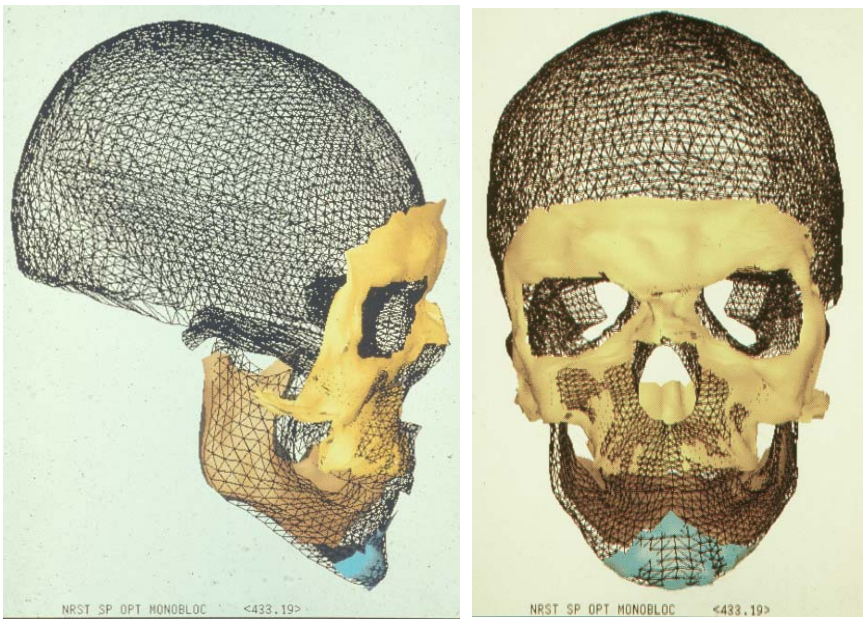
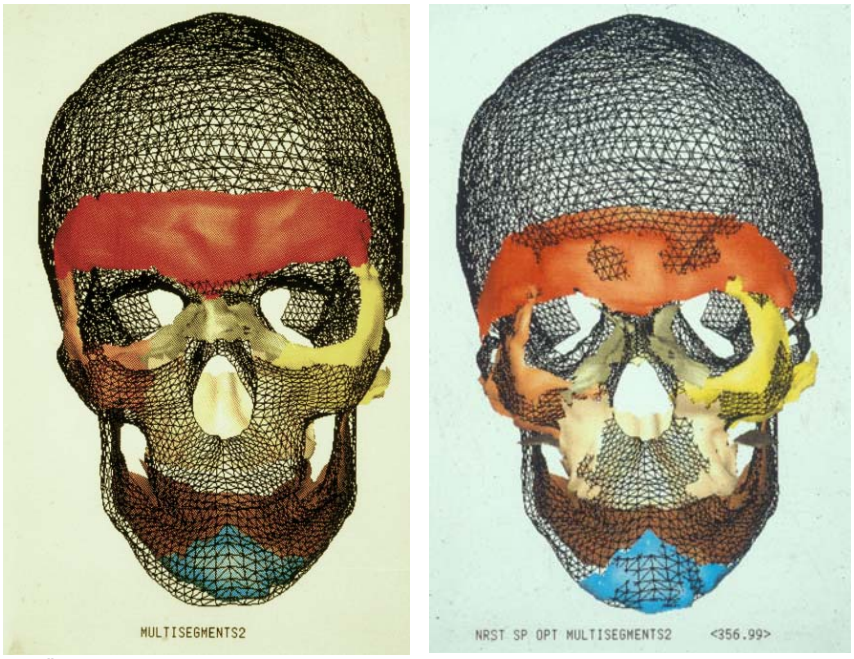




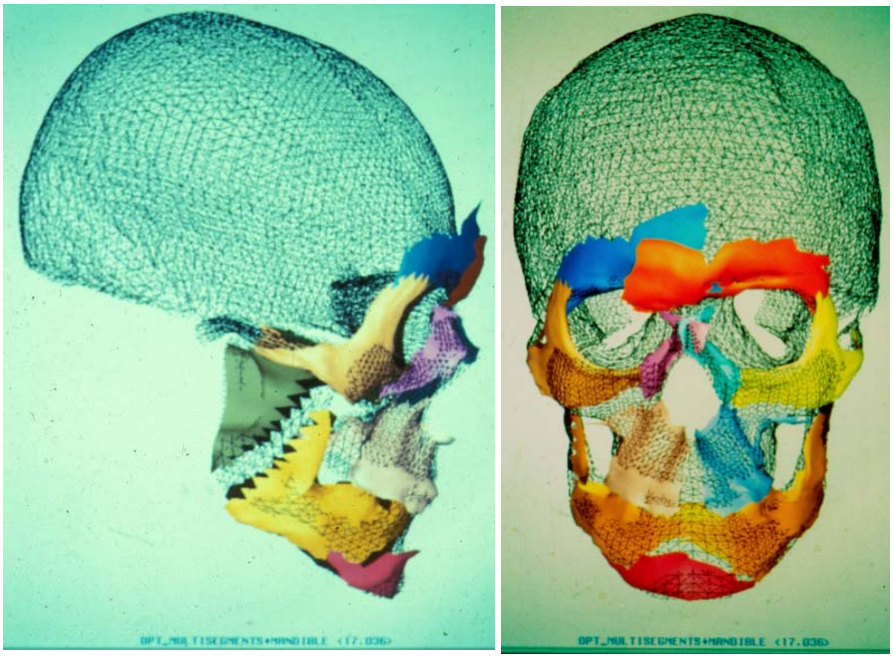


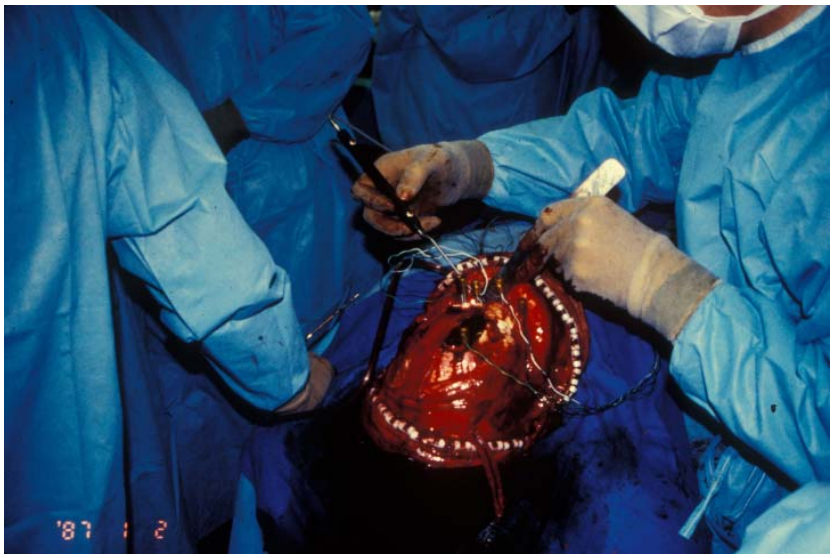






## Surgical Execution

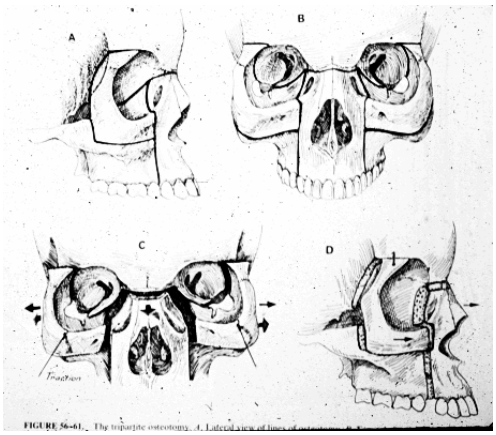






## Tripartite Osteotomies

- Proposed by Converse in 1971 to improve flexibility in shaping the midface.
- Abandoned due to technical difficulty of fragment positioning and fixation

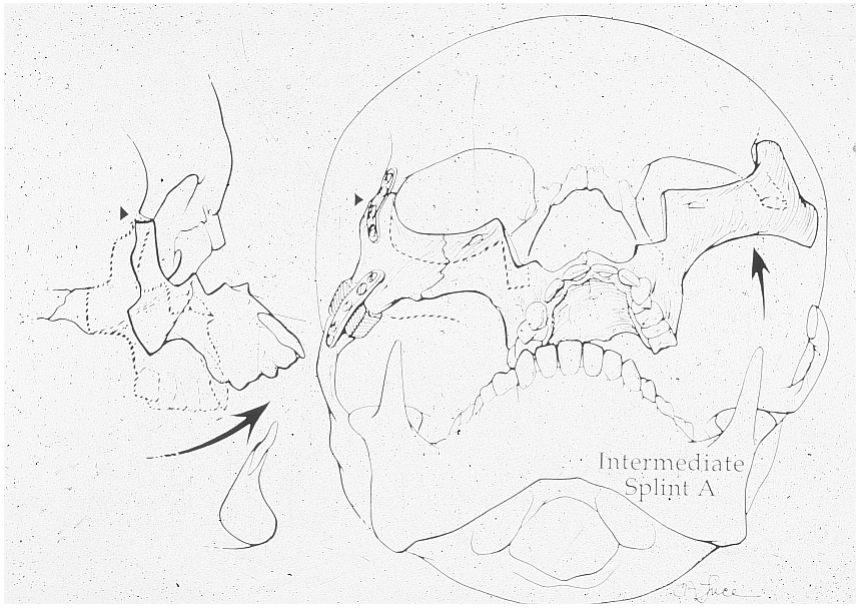


## Cutting and Grayson Technique: Inter-occlusal stents

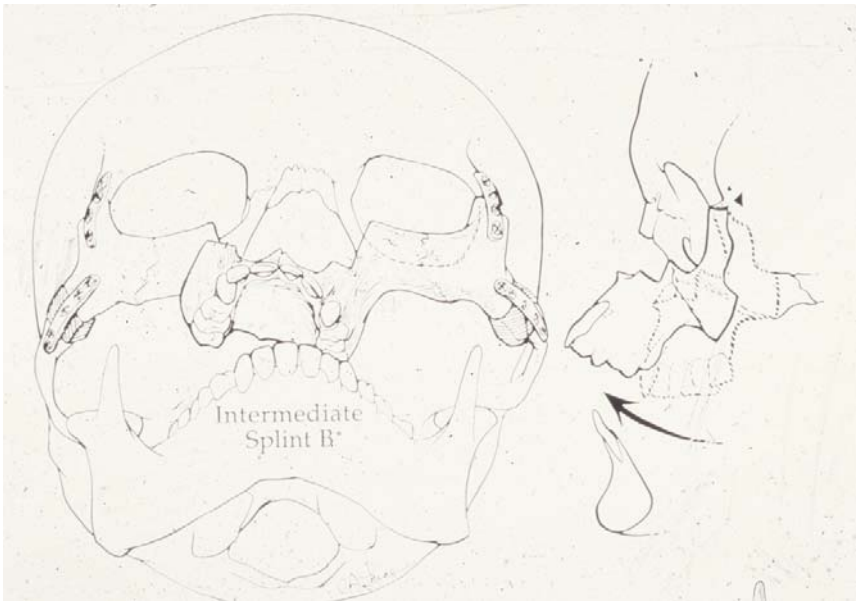




## First Move



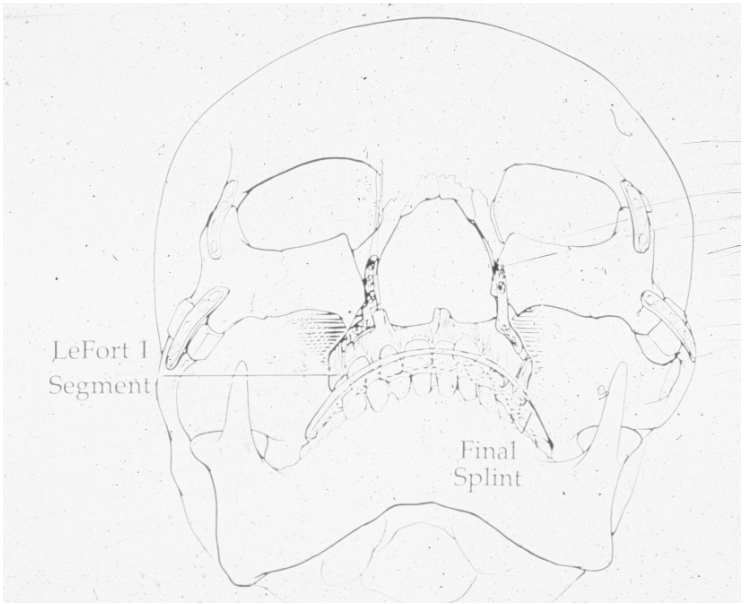
## Second Move








## Third Move



## Enter robotics …

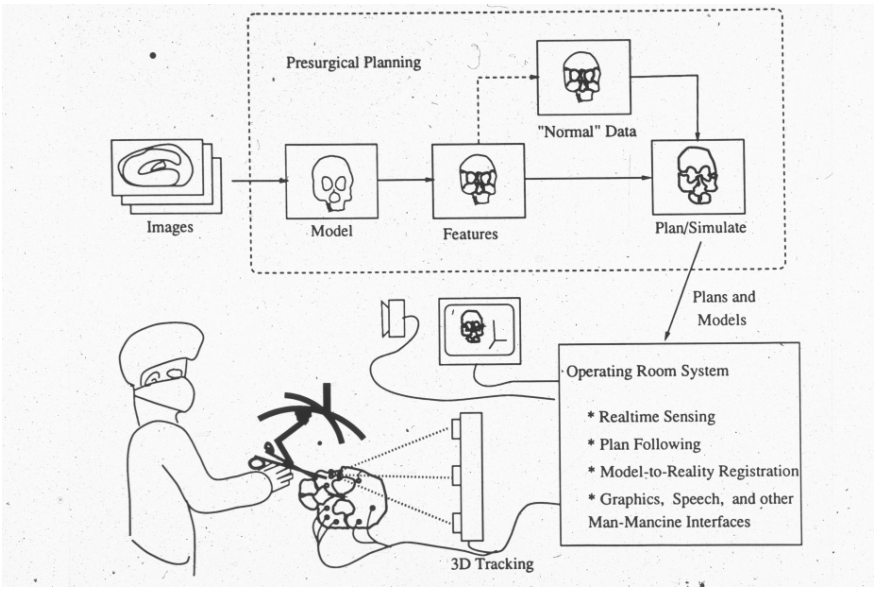
- Surgeon **did not** want help in making the cuts.
- Surgeon **did** want help in positioning and holding the bone fragments
- Robots can do this





## But there were some minor concerns …

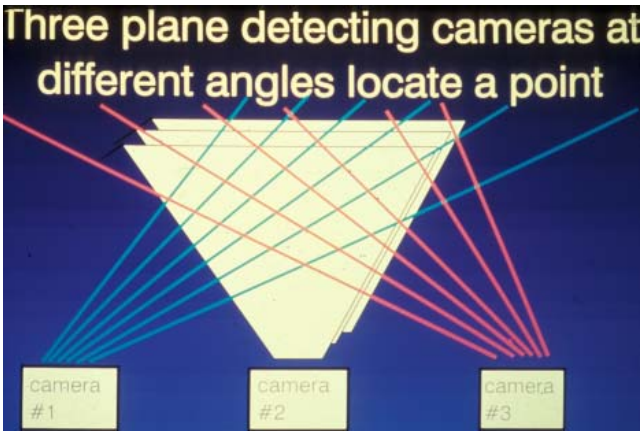
## Our approach: navigation + passive manipulation aid



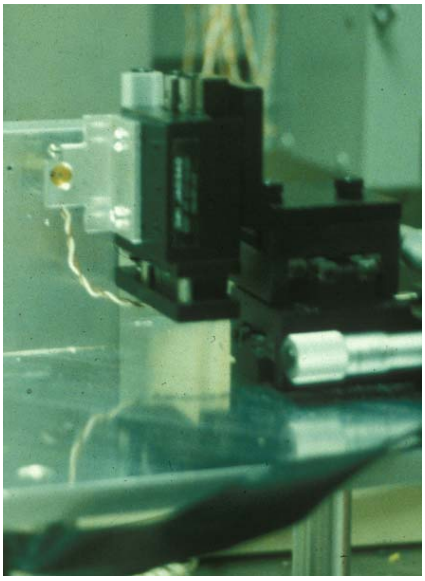


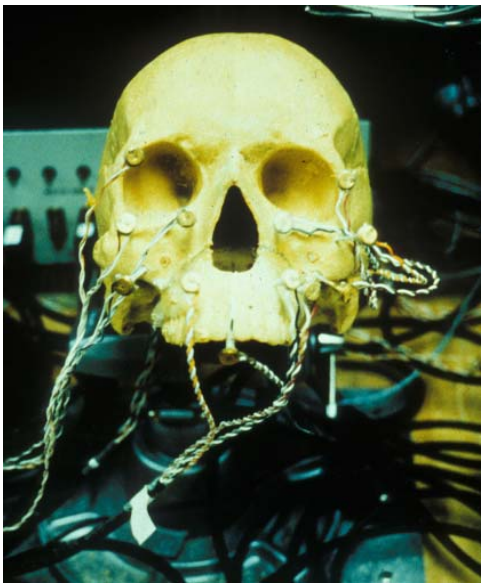



## Optical tracking: NDI Optotrak




Accurate (±0.1 mm) tracking of infrared LED markers over approx 1 $m^3$ workspace



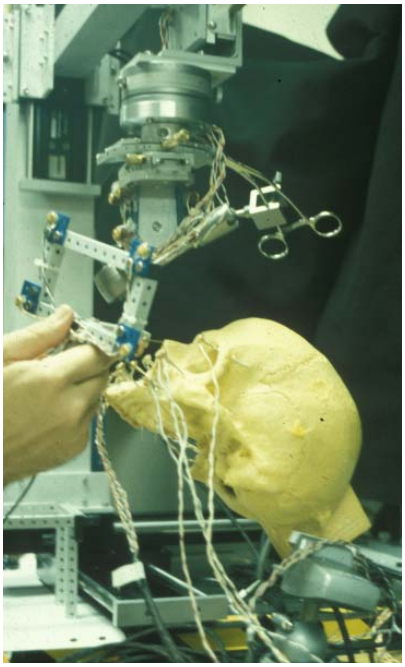






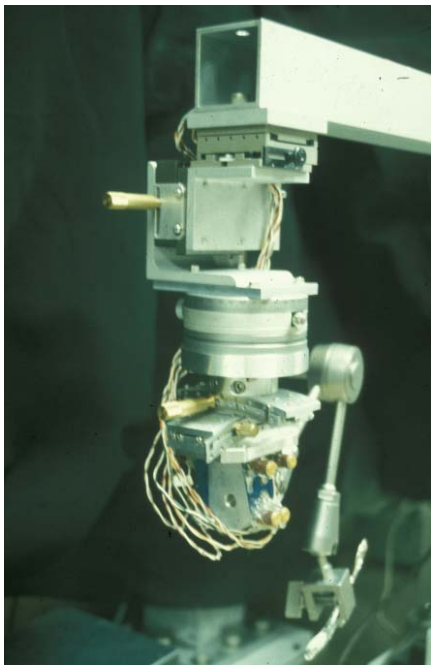
## Passive Manipulation Aid

- LED markers on adjustable manipulation aid, pointer, and patient skull



## Passive Manipulation Aid

- Adjustable surgical clamp holds bone forceps
- Six DOF motion with hand-set brakes
- Remote center-of-motion with iso-center in bone



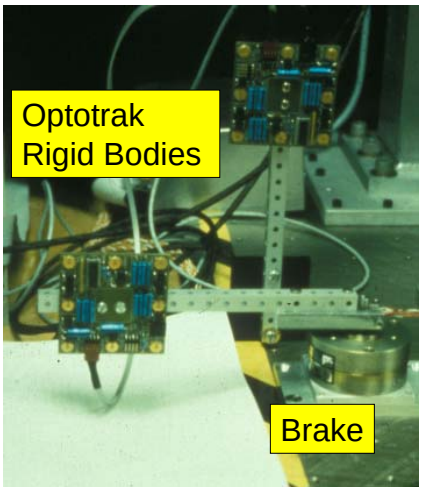




## Assembled system

## Possible refinement: computer set brakes with audible feedback cue

- Computer tracked position of tool optically
- Electric particle brake set when reached target
- Computer played tone to give audible feedback when got close to alignment



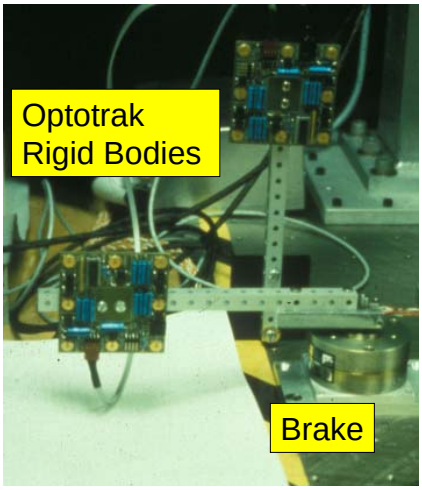





## Possible refinement: computer set brakes with audible feedback cue

**Results**

- Were able to achieve very good alignments (sub-mm)
- Very tedious to use
  - Brake was too slow
  - No “d-tent” effect



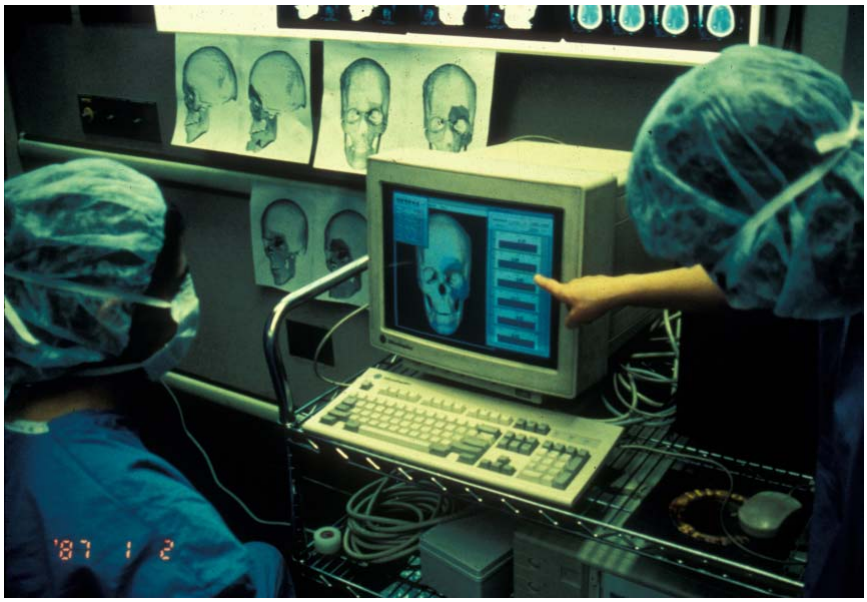
# On to clinical use …

- For legal reasons, the IBM hardware was not used clinically.
- Dr. Cutting was able to re-implement the tracking system using a PIXSYS optical tracker
- First case encountered equipment difficulties and was completed manually



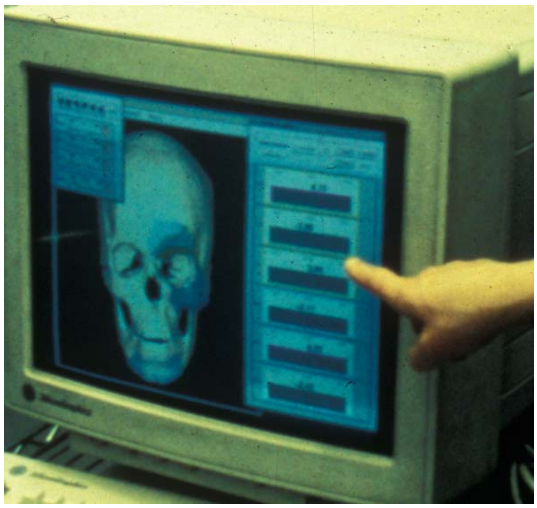



# 2nd Clinical Case



# 2nd Clinical Case

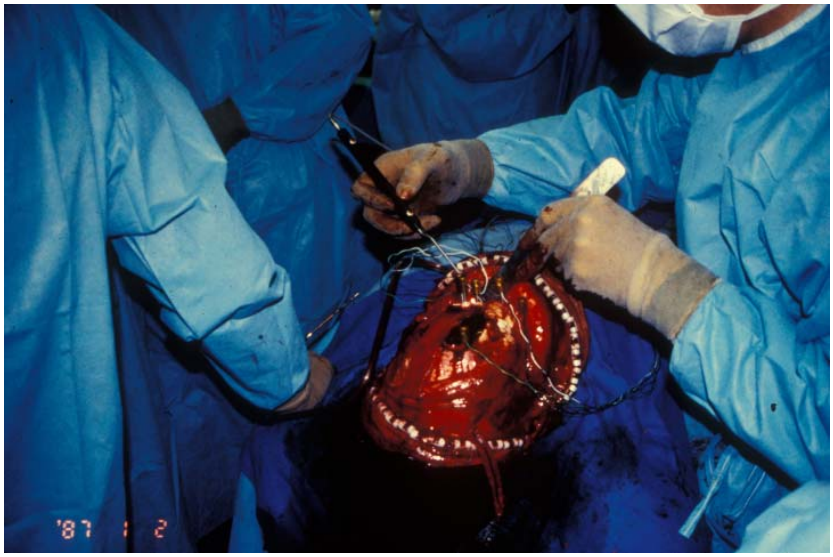
- Patient had radiation therapy at relatively early age
- As a result bone around one eye socket failed to grow properly
- Goal was to fix this defect







# 2nd Clinical Case



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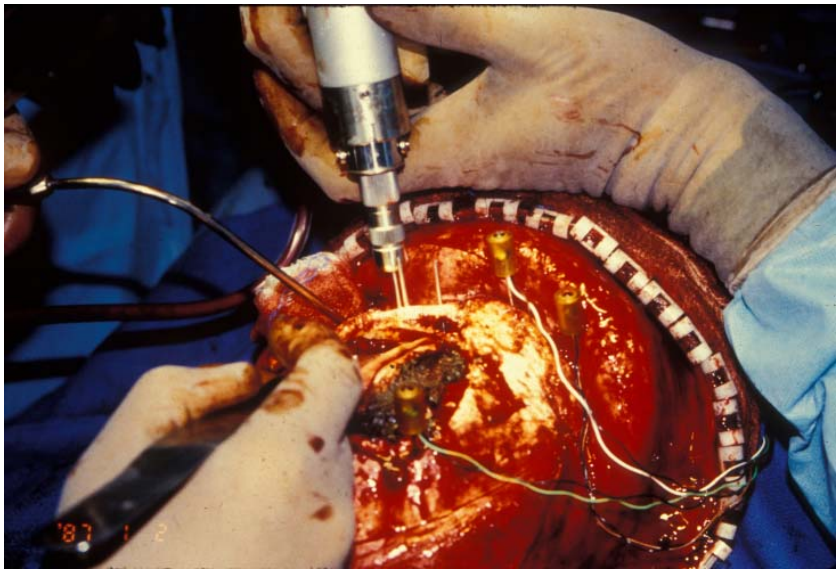





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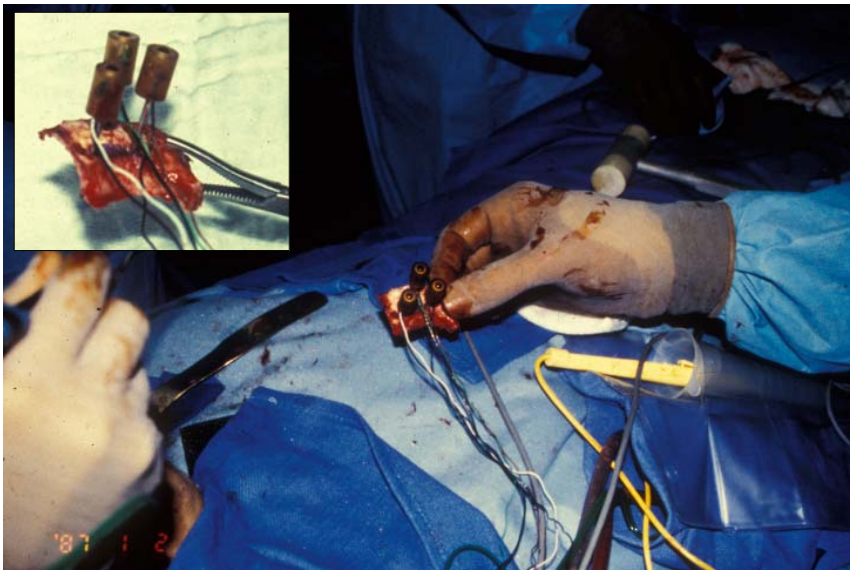

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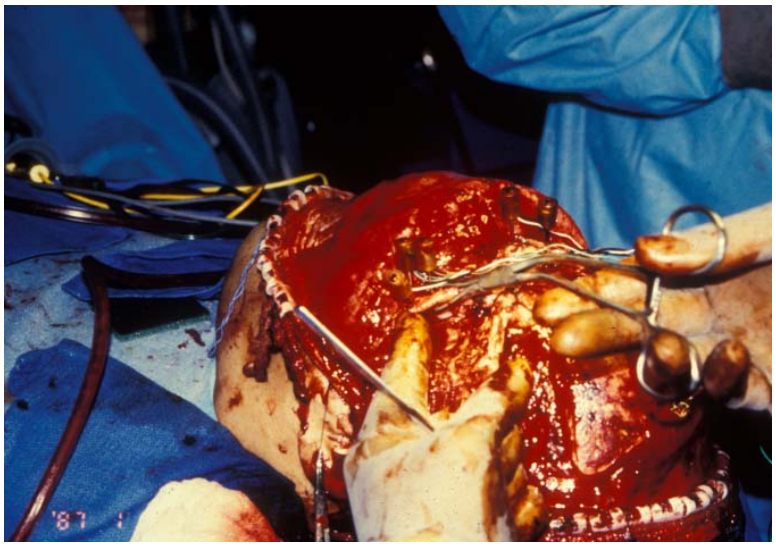
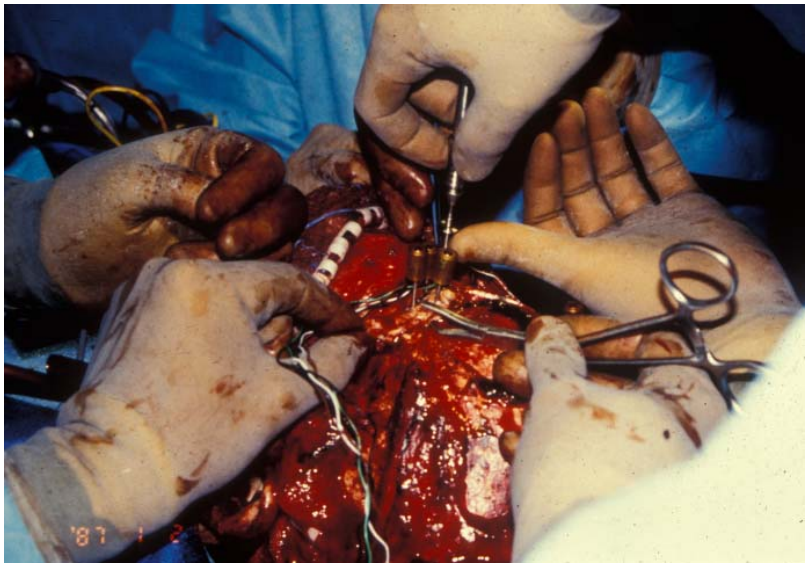






# 2nd Clinical Case

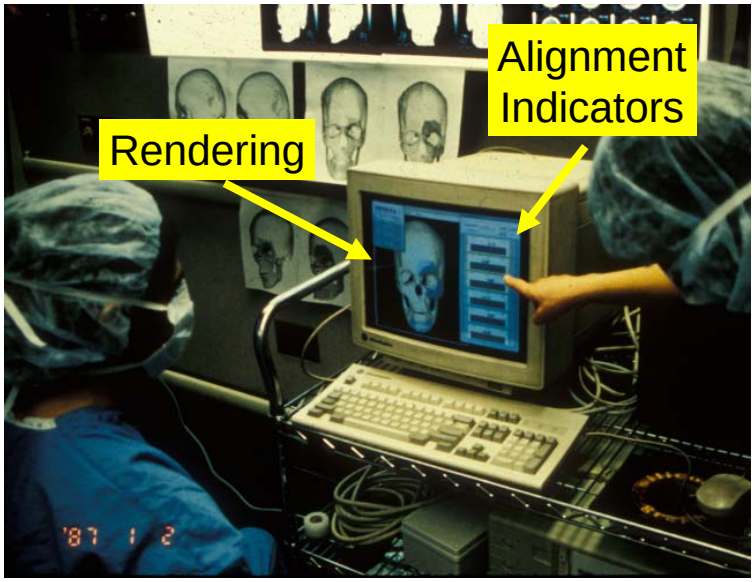


# 2nd Clinical Case: User Interface



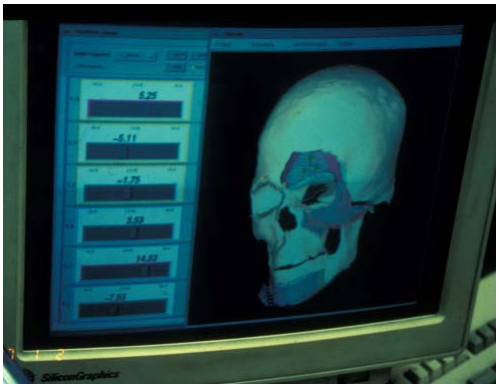



# 2nd Clinical Case: Display



# 2nd Clinical Case: Display

- **Full 3D display**

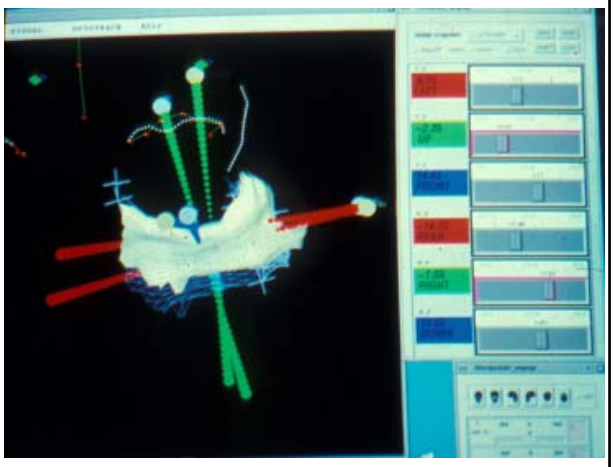






# 2nd Clinical Case: Display

- **Full 3D display**
- **Bone fragments + slider bars to show alignment**



# 2nd Clinical Case: Display

- Full 3D display
- Bone fragments + slider bars to show alignment
- **Axes + slider bars to show alignment**