CONTRIBUTION OF AUGMENTED REALITY TO MINIMALLY INVASIVE COMPUTER-ASSISTED CRANIAL BASE SURGERY

CIS2 SEMINAR PRESENTATION

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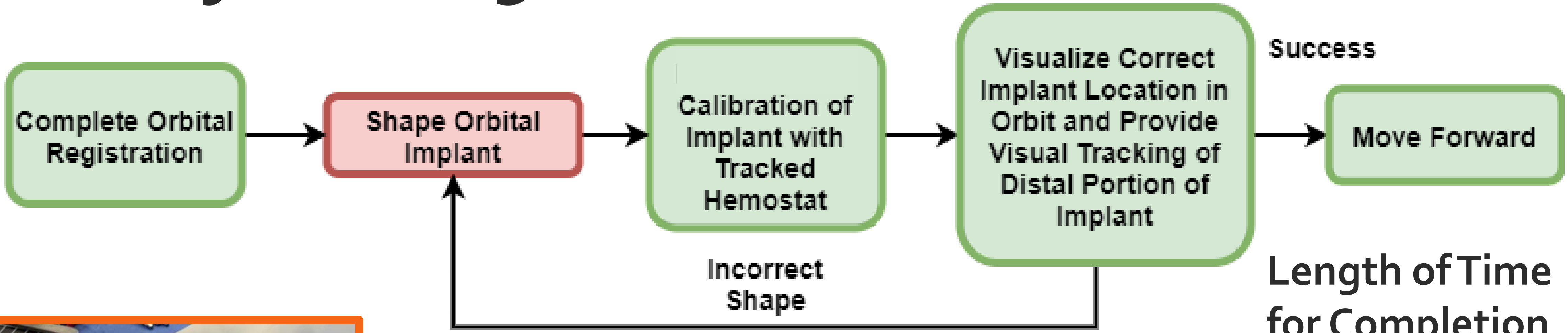
CIS2 Project Background



Orbital Floor Fracture:

- Due to pressure on the eye from blunt trauma, the medial wall and orbital floor can fracture.
- Fracture repair requires manipulation of delicate and complex structures in a tight, compact space.
- Surgeons struggle with visibility in the confined region.

Length of Time for Completion Gradient:

GREEN ~ Standard

BLUE ~ Slow Step

RED ~ Time Limiting Step

Contribution of Augmented Reality to Minimally Invasive Computer-Assisted Cranial Base Surgery:

- Cranial base procedures involve the manipulation of structures in the fields of *otology, rhinology, neurosurgery and maxillofacial surgery*. **COMPRENSIVE!**

- **Paper is review of recent studies of Augmented Reality in the Cranial Base Domain!**
- 45 different studies included in review.

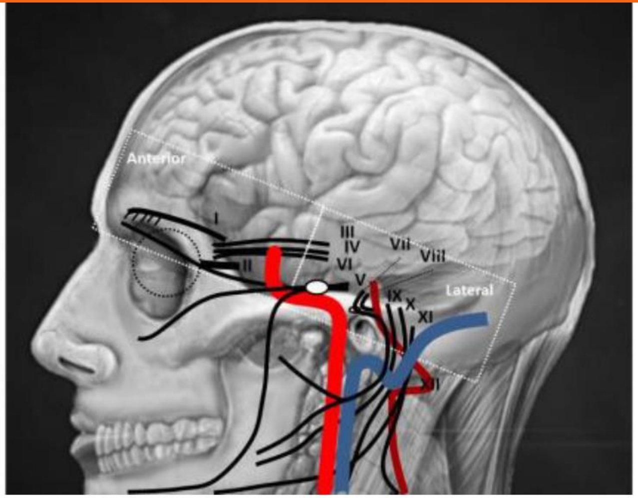


Fig. 1. Schematics of the cranial base region with the projection of cranial nerves (I to XII), and the major vessels: the carotid artery (light red), the sigmoid sinus (blue), the vertebral and basilar arteries (dark red).

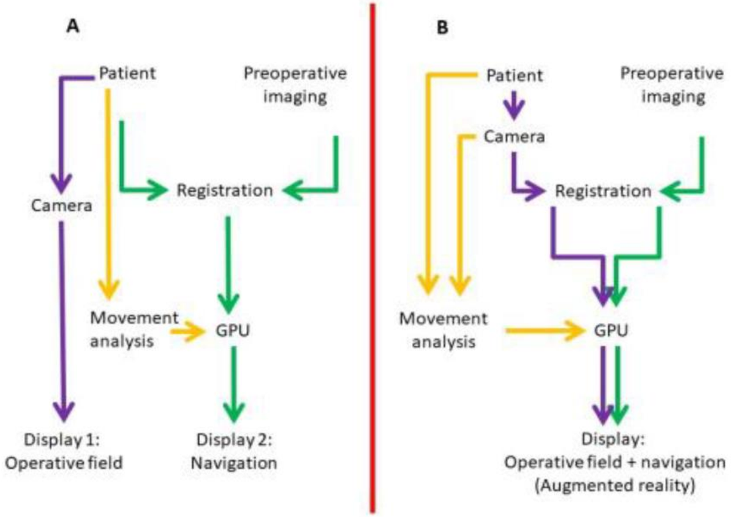


Fig. 2. Comparison between the structures of conventional navigation system (A) and a navigation system integrating augmented reality (B). GPU: Graphic processing unit.

Figures From: R. Hussain, A. Lalande, C. Guigou and A. Bozorg Grayeli. (2019) Contribution of Augmented Reality to Minimally Invasive Computer-Assisted Cranial Base Surgery, *IEEE Journal of Biomedical and Health Informatics*.

Study	Application	Test Subjects	Hardware	Registration	Motion Tracking	Instrument Tracking	Display	Specifications
Murugesan et al. [7]	*Maxilla*	*8R*	*CT, stereocamera, translucent mirror*	*Enhanced ICP algorithm*	*TLD on bounded boxes followed by ICP*	*NS*	*IVD*	*OR: 0.2-0.6 mm FR: 13 fps*
Citardi et al. [4]	*Endoscopic sinus dissection*	*4C*	*CT, EM surgical navigation system*	*Contour based*	*Image based*	*EM*	*Monitor*	*TRE: 1.5 mm*
Wang et al. [59]	*Maxilla*	*1H, 1R, 1P*	*CT, camera,OTS*	*Enhanced ICP algorithm*	*Optical flow based TLD on bounded boxes followed by ICP*	*NS*	*NS*	*OR: 1 mm FR: 5 fps*
Cabrillo et al. [48]	*Inferior clivus chordoma*	*1H*	*CT, MRI, microscope*	*Surface matching*	*NS*	*NS*	*Ocular*	*NS*
Cho et al. [47]	*Middle and inner ear*	*5A*	*OCT, stereomicroscope, beam splitter*	*Beam splitter optics*	*Beam splitter optics*	*NS*	*Ocular*	*NS*
Dixon et al. [75]	*Transphenoi-dal skull base surgery*	*1C*	*CT, endoscope, OTS*	*Marker based*	*Optical*	*Optical*	*Monitor*	*TRE: 2.6 mm*
Inoue et al. [43]	*Brain tumour*	*3H*	*MRI, camera, OTS*	*Point matching (fiducial markers)*	*Optical*	*Optical*	*Monitor*	*FRE: 1.7 mm OR: 2-3 mm*
Essig et al. [60]	*Head and neck tumours*	*1H*	*CT, OTS*	*Point matching (fiducial markers)*	*Optical*	*Optical*	*Monitor*	*FRE: 1.3 mm*
Birkfellner et al. [66]	*Skull base surgery*	*1P*	*CT, binocular HMD, OTS, VISIT surgical*	*Point matching (fiducial markers)*	*Optical*	*NS*	*HMD*	*FRE: 0.9 mm FR: 40 fps*
Freysinger et al. [61]	*Paranasal and frontal skull base surgery*	*79H*	*(US, ISG viewing wand) OR (CT/MRI, ARTMA virtual*	*Point matching*	*Mechanical or EM*	*EM*	*Monitor*	*FRE: < 2 mm FRE: 3 mm*

Figure From: R. Hussain, A. Lalande, C. Guigou and A. Bozorg Grayeli. (2019) Contribution of Augmented Reality to Minimally Invasive Computer-Assisted Cranial Base Surgery, *IEEE Journal of Biomedical and Health Informatics*.

Why AR? What's the buzz about?

- Advantage: is the significant improvement in ergonomics.
  - All information is available on a single view: no need for surgeon to go back and forth.
  - Access hidden information without interfering with the surgical process.
- However, paper states:
  - AR has not been successfully applied as of yet in CBS. Why?
    - Limitations in workspace and maneuverability
    - High precision (typically 1-2 mm)
    - **ROOM FOR IMPOVEMENT!**

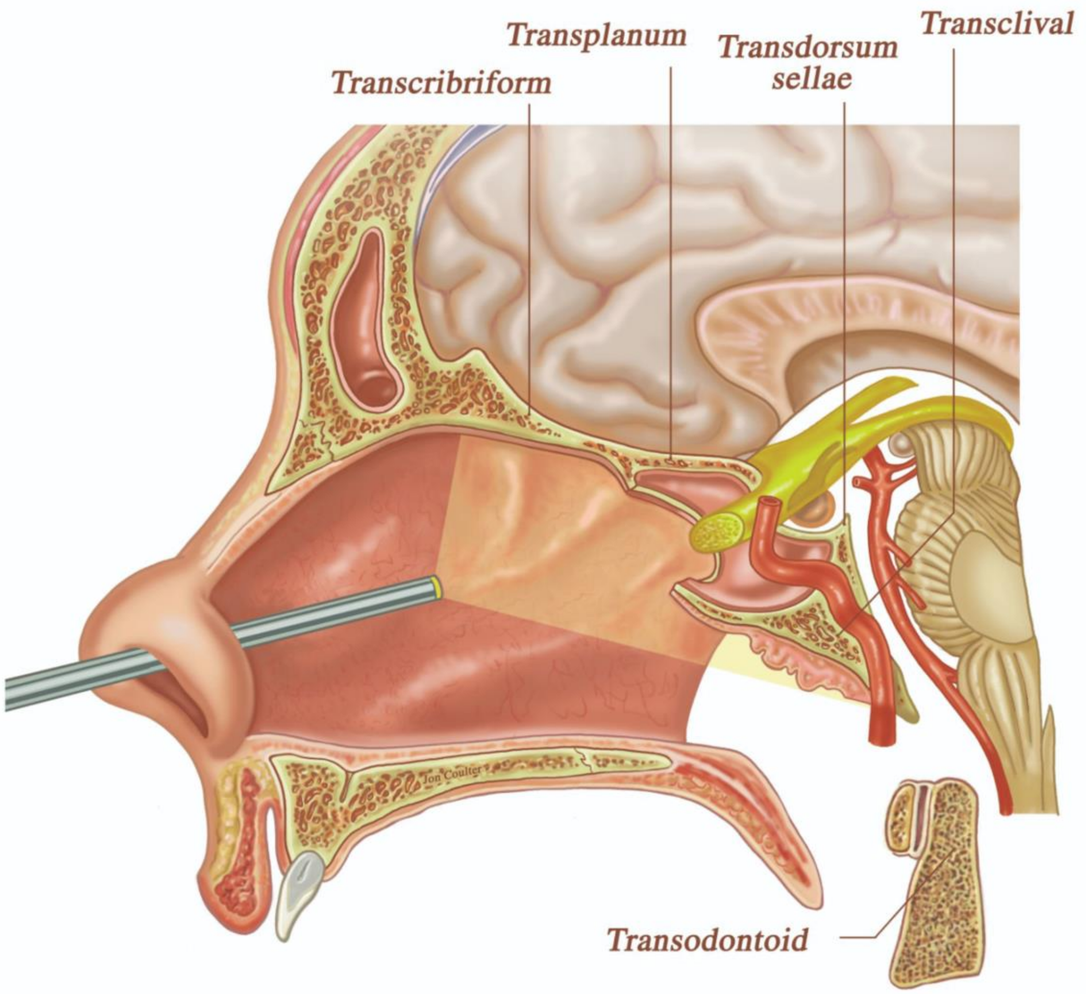


Image From: https://neurosurgerycns.wordpress.com/2011/06/28/ahead-of-print-somatosensory-evoked-potential-monitoring-during-endoscopic-endonasal-approach-to-skull-base-surgery/

Steps to Success: Calibration

- Techniques used in early AR systems.
  - Relied on fiducial registration procedure.
- Most popular method is photometric calibration.
  - Observe calibration object and determine camera parameters.
- Marker frame techniques >> good accuracy
  - external equipment can introduce complications in surgery.
  - Limits instrument maneuverability.
  - Hard to use in procedures that require microscope.

- **Ideally no calibration!**
- **No such calibration techniques comply with CBS requirements, (ergonomics, security, reliability).**

Image From: https://hospitalnews.com/canadian-first-robotics-enter-the-world-of-orthopedic-surgery/

Steps to Success: Registration

- Most common approach is to use methods that are point based and/or contour based.
- Anatomical landmarks?
  - Difficult to track
- Combination of point and surface >> best in performance.
- Contours in face can be used.
  - Methods rely on matching algorithm >> ICP
    - Accurate but slow. Ideally needs to be 5 min to 10min.
- Specifically for AR
  - Dental casts have been proposed for holding ref frame.

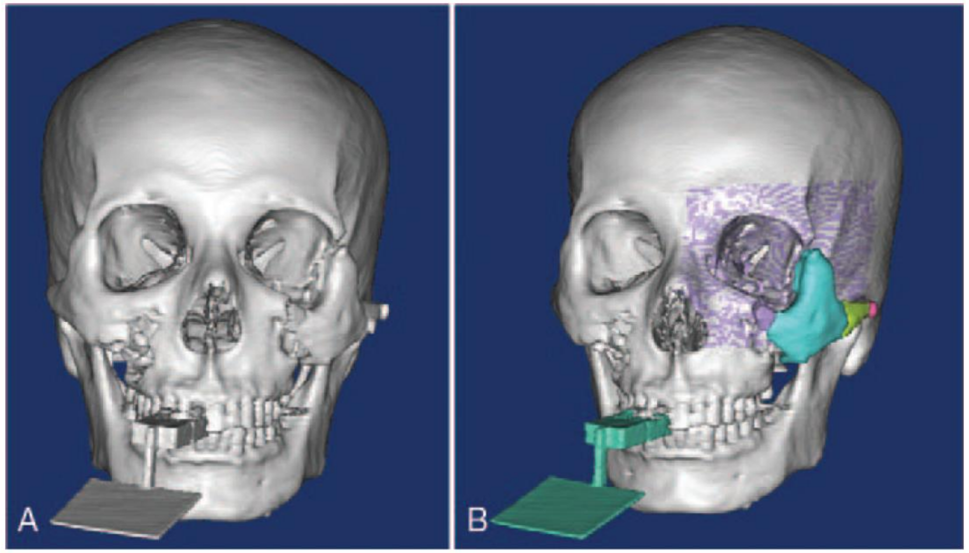


FIGURE 9. A: Reconstructed 3D model through original CT data; B: Segmenting fracture ends and visual identification marks in the injured area

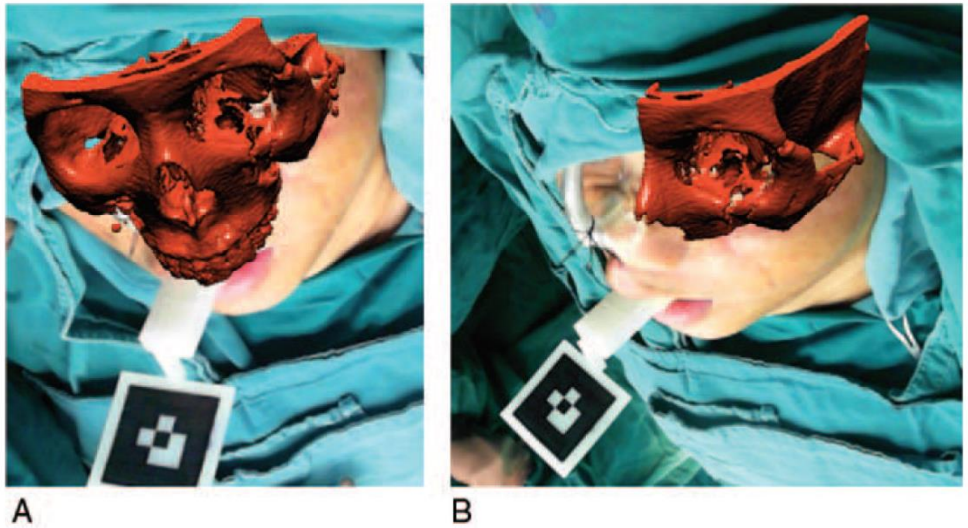


FIGURE 16. According to preoperative plan, respectively display the both sides of OZM (A) and original trauma appearance of the affected side (B) during the operation, and help the design of incision and exposure of the trauma area.

Figures from: Chen, Gang MD*; Zeng, Wei MD, PhD*; Yin, Huaqiang MD*; Yu, Yunbo MD†; Ju, Rui MD, PhD*; Tang, Wei MD, PhD* The Preliminary Application of Augmented Reality in Unilateral Orbitozygomatic Maxillary Complex Fractures Treatment, Journal of Craniofacial Surgery: March/April 2020 - Volume 31 - Issue 2 - p 542-548

Steps to Success: Visualization

- Lot's of options:
  - Monitors, wearables, projection devices…
- Most popular in CBS: Surgical monitor.
  - More then one surgeon can view.
  - Lot's of turning back n forth.
  - No depth cues.
- How about HMD?
  - NOT been popular among practitioners.
  - Out of focus images.
  - Latency between real and virtual info.
  - Not comfortable to wear.
  - Inattentional blindness.
- Pandora's box of possibilities in other developing visualization technology.

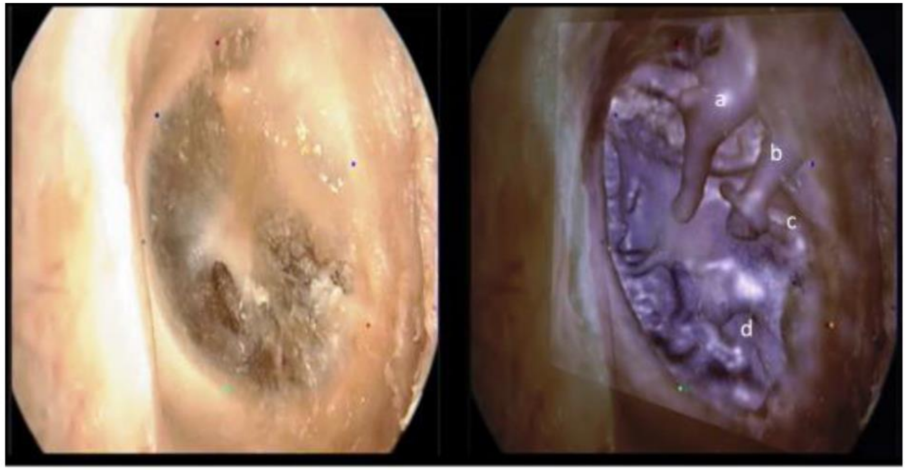


Fig. 4. An example of an AR display with image overlay. The image on the left is the endoscopic view of the tympanic

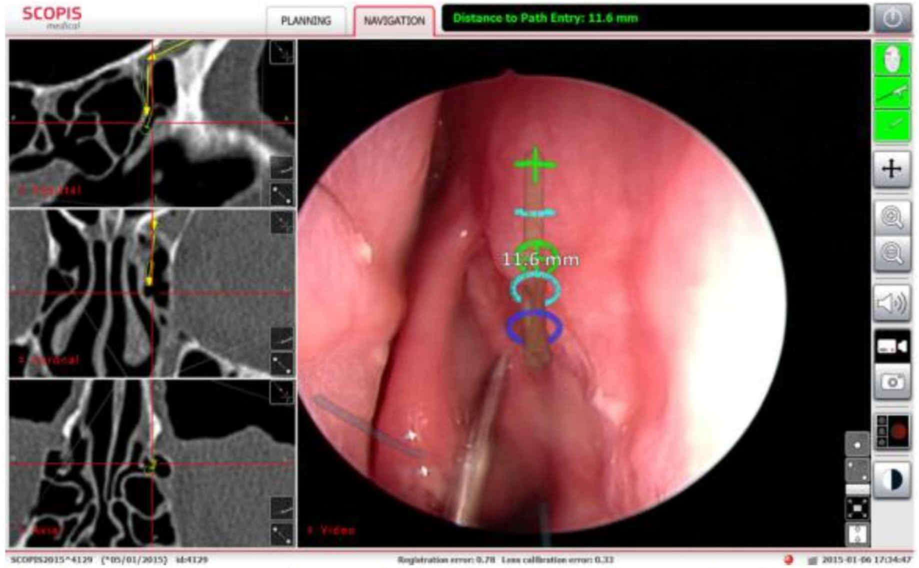


Fig. 5. An example of an AR display with navigational guidance depicting the frontal sinus outflow track [4].

Figures From: R. Hussain, A. Lalande, C. Guigou and A. Bozorg Grayeli. (2019) Contribution of Augmented Reality to Minimally Invasive Computer-Assisted Cranial Base Surgery, *IEEE Journal of Biomedical and Health Informatics*.

Steps to Success: Validation

- In surgical application, results can differ drastically from laboratory conditions.
  - From studies, 45% drop in accuracy when shifting to real OR.
- Factors involved in Accuracy
  - Fiducial registration error.
  - Fiducial localization error.
  - Target registration error.
  - Overlay error.
  - Tool error.
  - Display error.
- For AR to be successful
  - Errors sub-mm should be strived for in all above categories.

Image From: https://braintumorcenter.ucsf.edu/treatment/surgery/minimally-invasive-skull-base-surgery

Conclusions

- A list of requirements to be addressed for AR development is provided.

- AR reduces surgical time and mental workloads.
- Degree of improvement is associated with lack of surgeon experience.
- AR may benefit education.
- 81% of students preferred having AR integrated into their residences.
- 93% approved use in OR.

Considering these issues, a number of requirements can be defined for a functional AR surgical system:

(a) simple installation and setup before surgery.
(b) minimum calibration process.
(c) common focus for virtual objects and real-world images.
(d) high accuracy (submillimetric for otology).
(e) short registration time.
(f) unified integration of surgical instruments.
(g) low encumbrance.
(h) depth cues for both virtual objects and instruments.
(i) virtual objects superimposed only when necessary.
(j) high resolution and frame rate.
(k) low latency.
(l) adaptable adequate image-object contrast during projection.

Figures From: R. Hussain, A. Lalande, C. Guigou and A. Bozorg Grayeli. (2019) Contribution of Augmented Reality to Minimally Invasive Computer-Assisted Cranial Base Surgery, *IEEE Journal of Biomedical and Health Informatics*.

Paper Assessment

- **Paper is highly relevant to our work.**
  - We are attempting to create a novel AR system for craniofacial surgery.
- **What paper did well:**
  - Good range of studies examined.
  - Details on how to make a successful AR system (need proposal).
- **What paper did poorly:**
  - Lack of specific detail on any systems that are performing the best in the space currently.
  - No figures or real focus on HMDs.
- **Importance:**
  - Provides a streamlined view of the AR space regarding cranial base surgery.
  - Illustrates surgeon needs and shortcomings of previous attempts at AR system implementation.
  - Points out mistakes, so we don’t have to go down those routes.

Thank you!
Questions?

Citations:

Seminar paper:

R. Hussain, A. Lalande, C. Guigou and A. Bozorg Grayeli. (2019) Contribution of Augmented Reality to Minimally Invasive Computer-Assisted Cranial Base Surgery, *IEEE Journal of Biomedical and Health Informatics*.

Figures:

https://braintumorcenter.ucsf.edu/treatment/surgery/minimally-invasive-skull-base-surgery

https://hospitalnews.com/canadian-first-robotics-enter-the-world-of-orthopedic-surgery/

https://neurosurgerycns.wordpress.com/2011/06/28/ahead-of-print-somatosensory-evoked-potential-monitoring-during-endoscopic-endonasal-approach-to-skull-base-surgery/

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