Artificial Intelligence Driven Surgical Skill Optimization

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Disclosures

- IP protection filed by Johns Hopkins

8 Big Questions About AI

Interest in artificial intelligence has exploded over the past six months.

Meet our team

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Objectives

- Review methods of surgical skill assessment
- Discuss AI technology for assessment of skill

Are all surgeons created equally?
AI will not replace the surgeon. However the surgeon who understands HOW to leverage AI will replace the one who doesn’t.

-SHAMEEMA SIKDER, MD

What makes a good surgeon?

There are many qualities that make a good surgeon. Some of the most important include:

• Technical skills: Surgeons must have excellent hand-eye coordination and manual dexterity. They must be able to make precise movements with their hands and fingers, even under pressure.

• Knowledge: Surgeons must have a deep understanding of anatomy, physiology, and pathology. They must be able to identify and treat a wide range of surgical conditions.

• Decision-making skills: Surgeons must be able to make quick and accurate decisions under pressure. They must be able to weigh the risks and benefits of different treatment options and choose the best one for each patient.

• Communication skills: Surgeons must be able to communicate effectively with patients, their families, and other healthcare professionals. They must be able to explain complex medical concepts in a way that is easy to understand.

• Empathy: Surgeons must be able to empathize with their patients and understand their fears and concerns. They must be able to provide compassionate care and support during a difficult time.

• Resilience: Surgeons must be able to handle the stress and emotional demands of their job. They must be able to bounce back from setbacks and continue to provide high-quality care.

In addition to these qualities, good surgeons are also typically hard-working, dedicated, and passionate about their work. They are committed to providing their patients with the best possible care.

Dreyfus Model of Skill Acquisition

Novice

Learn

Do

Advanced Beginner

Competent

Expert

The Dreyfus model describes the stages of skill acquisition in five stages:

1. Novice: Beginner stage where the learner is just starting to acquire the skill.
2. Advanced Beginner: The learner is becoming more proficient and can perform tasks with some degree of competence.
3. Competent: The learner is able to perform tasks with accuracy and consistency.
4. Proficient: The learner can perform tasks with high accuracy and speed.
5. Expert: The learner can perform tasks with ease and can handle complex situations.
How does one become a good surgeon?

• TRADITIONAL APPRENTICE MODEL:
  - Natural skill
  - Opportunity to observe

• CURRENT MODEL:
  - Variable baseline skill
  - Structured training program
  - Assessment and Feedback

Assessment and Feedback

How can skill be assessed intraoperatively?

Human-Driven Surgical Skill Optimization
ASSESSMENT & FEEDBACK

STRUCTURED KNOWLEDGE

UNSTRUCTURED NARRATIVE

UNSTRUCTURED VIDEO

ASSESSMENT & FEEDBACK

SIMULATION - VIRTUAL - WETLAB

Better Surgery

RUBRICS

MULTIPLE RUBRICS AVAILABLE FOR ASSESSMENT OF SURGICAL TECHNICAL SKILL
• OASIS & ICO-OSCAR:PHACO

ADVANTAGES
• QUICK
• VALIDATED
• AFFORDABLE ($4000 IN ANNUAL COSTS)

DISADVANTAGES
• TIME-INTENSIVE
• RESOURCE-INTENSIVE
• SOME ELEMENT OF SUBJECTIVITY

Better Surgery

What about AI?

Will AI replace surgeons?
It is unlikely that AI will completely replace surgeons in the near future. However, AI is likely to play an increasingly important role in surgery in the coming years. For example, AI can be used to:

• Assist surgeons during surgery: AI-powered surgical robots can help surgeons make more precise incisions and reduce the risk of complications.
• Diagnose diseases: AI can be used to analyze medical images and data to help surgeons diagnose diseases more accurately.
• Personalize care: AI can be used to analyze a patient’s medical history and other data to personalize their care.

Overall, AI has the potential to improve the quality of care that surgeons can provide. However, it is important to remember that AI is a tool, and it is still under development. Surgeons will still be needed to make critical decisions and provide compassionate care to their patients.

WILL SURGICAL EDUCATORS BE REPLACED BY AI?
MAYBE A LITTLE BIT??

AI-Driven Surgical Skill Optimization

Input (SURGICAL PERFORMANCE)

Direct Observation
Video
Instrument motion
Hand motion
Eye tracking
Other e.g. photoplethysmography, machine data

Data Processing

Expert Ratings
Machine Learning
Deep Learning
Crowdsourcing
Performance Metrics

Output

Feedback
Data
Clinical Outcomes

WILL SURGEONS BE REPLACED BY ROBOTS?
Dr. Terminator
Changing the Paradigm of Surgical Training

AI assisted feedback:
Surgical Video

Assessment of Performance

Customized feedback: Fast track to master surgeon

Can we use a crowd to annotate instrument labels on surgical videos?

How do we get started?

Crowdsourcing Annotation of Surgical Instruments in Videos of Cataract Surgery

Demonstrate reliability and validity of crowdsourced annotations for information on surgical instruments.
Data Collection

Defined six tools to annotate:
• Keratome Blade
• Cystatome
• Irridie
• Irrigation/Aspiration Cannula
• Anterior Chamber Cannula
• Phaco Probe

Consistency in Crowd Annotations

Collected 200 images from 2 procedures, 9 annotations per image, under 48 hours.

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<thead>
<tr>
<th>Overall consistency</th>
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<tr>
<td>Average</td>
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Per-tool consistency

<table>
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<th>Tool</th>
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<tr>
<td>Keratome</td>
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<td>Cystatome</td>
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<td>AC Cannula</td>
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Overall accuracy

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Key Points: Crowd can localize tool tips very consistently and accurately

Summary

We can harness human intelligence reliably and accurately at scale to analyze surgical videos. Applications include automated objective surgical skill assessment, directed feedback, and coaching.
Conclusions

- Tool identification: Inter-rater agreement of 0.63 (Fleiss' kappa)
- Accuracy of 0.88 for identification of instruments compared against an expert annotation.
- Crowdsourcing can be effectively used to identify instruments in a surgical video

Now what?

- We can get a crowd to annotate instrument labels on surgical videos
- How much granular detail can we gather within a step using instrument motion?

Now what?

- We can get a crowd to annotate instrument labels and tips on surgical videos
- What step should we next focus?
Can We Efficiently Use Structured Rating Scales to Objectively Assess Global Technical Skill in Cataract Surgery?

Kapil Mishra, Sidra Zafer, S Swaroop Vedula, Shameema Sidler
PMID: 31706522 DOI: 10.1016/j.jvs.2019.07.030

IS TIME A VALID MEASURE OF SKILL?

PROCEDURE SPEED IS OFTEN USED AS A PROXY FOR EXCELLENCE
FASTER SURGEONS ARE REGARDED AS BETTER SURGEONS
TIME HAS BEEN USED FOR QUANTIFYING SKILL IN JUNIOR AND EXPERIENCED SURGEONS

Operative Time predicts appointment status & is not of much utility to assess surgical technical skill in cataract surgery

OBJECTIVE ASSESSMENT OF TECHNICAL SKILL TARGETED TO TIME IN CATARACT SURGERY

Next?

• We can get a crowd to annotate instrument labels on surgical videos
• Capsulorhexis is a good step on which to focus.
• Can we automate phase detection?

DEMONSTRATE MACHINE LEARNING AND DEEP LEARNING TECHNIQUES CAN HELP TOOLS THAT EFFICIENTLY SEGMENT VIDEOS OF CATARACT SURGERY INTO CONSTITUENT PHASES FOR SUBSEQUENT AUTOMATED SKILL ASSESSMENT AND FEEDBACK.
Conclusions

• Modeling time series of labels of instruments in use appeared to yield greater accuracy in classifying phases of cataract operations than modeling cross-sectional data on instrument labels, spatial video image features, spatiotemporal video image features, or spatiotemporal video image features with appended instrument labels.

• Time series models of instruments in use may serve to automate the identification of phases in cataract surgery, helping to develop efficient and effective surgical skill training tools in ophthalmology.

Making progress....

• We can get a crowd to annotate instrument labels on surgical videos
• We can get a machine to identify the correct phase of surgery with the labels
• What about assessing performance?
Deep neural networks effectively model surgical technical skill in capsulorhexis given structured representation of intraoperative data such as optical flow fields extracted from video or crowdsourced tool localization information.

**Conclusions**

What next??:
- Automate instrument labeling
- Automate chaptering
- Increase robustness of current automated analysis
- Facilitate data flow
Video Based Surgical Skill Assessment

Direct Observation Surgical Skill Assessment

Artificial Intelligence
Machine Learning
Deep Learning
Computer Vision

Computer Vision

DEEP LEARNING

WHERE'S WALDO?

RGB Video
Predict instrument tip positions as keypoints (KPs)
Skill

RGB Video
Deep learning with attention (ATT) modules
Skill

Attention Modules Method (ATT)
2D CNN RNN

Keypoints Method (KP)
TCN

Bag of Words (BoW)
Augmented Bag of Words (Aug BoW)
Discrete Fourier Transform (DFT)/Discrete Cosine Transform (DCT)
Sequential Motion Textures (SMT)
Approximate Entropy (ApEn)/Cross Approximate Entropy (XApEn)

Novel Methods for Skill Assessment

Novel Deep Learning (DL) Methods
Assess AI methods for objective, unbiased video-based assessment

Experimental Design

Previous Work

Current progress

- We can get a crowd to annotate instrument labels on surgical videos
- We can get a machine to identify the correct phase of surgery with the labels
- We can use machine learning to assess performance of the chapter CV < DL < DL with attention
DL methods susceptible to class differences
Assessment directly from RGB video
DEEP LEARNING USING ATTENTION MODULES CAN BE USEFUL TO ASSESS INTRAOPERATIVE SKILL DIRECTLY FROM VIDEO

DEEP LEARNING > INTEREST-POINT BASED METHODS TO ASSESS INTRAOPERATIVE SKILL

EXTERNAL VALIDATION AND EVALUATION OF DEEP LEARNING METHODS FOR INTENDED PURPOSES

Where do we go next?
How do we get there?
Can we use AI to help?

SAM - The Foundational Model from Meta

Segment Anything
Research by Meta AI

Data - What is it trained on?
- 11 Million images - high resolution, from photographers worldwide
- 1 Billion Masks - generated automatically by the SAM data engine (details coming up)
- Publicly available dataset - SA-1B

Results
Zero Shot Transfer Using SAM

Segment Anything is a strong segmentation model. But it needs prompts (like boxes/points) to generate masks.

Grounded DINO is a strong zero-shot detector which enables generating high-quality boxes and labels with free-form text.

The combination of the two models enables detecting and segmenting everything with text inputs.

Results of Grounded SAM on CATARACTS

Project By IDEA Research
LANGUAGE & VIDEO?

QuerYD
Audio + text narratives

Video Localized Narratives
Narratives are shallow but they are grounded to the video

LLAVA - A few Zero shot experiments

The image shows a person's eye with a foreign object, possibly a hook or a metal tool, lodged in the center of the eye. The eye appears to be red and irritated, possibly from the intrusion. Several medical instruments, including scissors and a hook, are present in the scene, suggesting that a surgical procedure is being performed or about to be performed. The person's eye is the main focus of the image, while the various medical instruments are scattered around the area.
Was the eye maintained in the center of the view?

Yes, the eye is in the central focus of the image, and it is maintained in the center of the view. This allows for a clear representation of the cataract surgery and the medical instruments being used during the procedure.

Which stage of the surgery is currently going on?

It is difficult to determine the exact stage of the surgery from the image. However, given the presence of the foreign object (such as a hook or a metal tool) and the medical instruments like scissors and a knife, it is likely that the surgery is in the middle of the procedure or approaching the removal of the cataract. The precise stage of the surgery cannot be confidently determined from the image alone.

What are the factors that the surgeon should be careful about during this part of the procedure?

During this part of the cataract surgery, the surgeon should be cautious about several factors to ensure a successful and safe procedure. Some of these factors include:

1. Maintaining proper positioning: The surgeon must ensure that the eye is appropriately positioned and aligned with the surgical instruments, which can be challenging given the small and delicate nature of the eye’s anatomy.
2. Managing the removal of the cataract: Carefully removing the cataract while minimizing the risk of damage to the surrounding eye structures, such as the cornea and lens, is crucial.
3. Handling the surgical instruments: Properly manipulate the scissors, knife, and other instruments to prevent injury to the eye without compromising the quality of the surgery.
4. Preventing complications: Surgeons must be vigilant about potential complications, such as bleeding, infection, or damage to the eye’s structures. Prompt action must be taken to address any issues that arise during the procedure.
5. Ensuring proper visualization: The surgeon must maintain a clear line of sight to the eye’s interior in order to perform the surgery accurately and efficiently.

By carefully considering these factors, the surgeon can successfully complete the cataract surgery while minimizing risks and ensuring the best possible outcomes for the patient.

Mini GPT-4

What stage of the surgery is a surgeon operating on right now?

Image shows a cataract surgery process. The surgeon is using ultrasonic aspiration machines to remove the lens from the eye. This machine uses ultrasonic energy to break up and aspirate the lens, which is then removed from the eye. The surgeon carefully removes the cataract while maintaining the integrity of the eye’s structures.

The next stage of the surgery involves the placement of an artificial lens (IOL) into the eye. The artificial lens helps to restore vision by replacing the natural lens that was removed during the cataract surgery. The surgeon carefully positions the IOL in the correct location, ensuring proper alignment and function.

Once the IOL is securely in place, the surgeon will close the incision to complete the cataract surgery. This final step is crucial for sealing the eye and preventing any complications. The surgery may be followed by a period of recovery and monitoring to ensure optimal outcomes.

Generic response

What stage of the surgery should the surgeon be in at this stage?

At this stage of the surgery, the surgeon should be finishing the removal of the cataract and preparing for the placement of an artificial lens (IOL) into the eye. The surgeon has already removed the cataract, and now the focus is on restoring vision through lens implantation.

Typically, after removing the cataract, the surgeon will cleanse the eye to remove any residual debris or debris from the incision. Then, the surgeon will place the IOL into the eye, ensuring proper alignment and function. The surgeon will carefully suture the incision to complete the surgery.

Postoperative care also includes administering medications, such as anti-inflammatory drops, to help reduce inflammation and promote healing. The patient will be monitored closely for any complications or side effects during the recovery period.
Was the eye maintained in the center of the view?

It is not possible for me to determine if the eye was maintained in the center of the view in the provided image, as the image does not show the entire surgical field. However, it is important for the surgeon to maintain the eye in the center of the view during the cataract surgery to ensure that the procedure is performed accurately and effectively.

To do this, the surgeon may use various techniques, such as using a fixation light or device to help the patient focus on a specific point, or manually adjusting the position of the patient's eye during the procedure. Additionally, the surgeon should use a well-functioning microscope and other visualization aids to ensure that the entire surgical field is visible and that the procedure can be performed safely and effectively.

But wait- there's more

Neuralangelo is an AI model for high-fidelity neural surface reconstruction.
ISSUES WITH AI
- What's the ground truth?
- Is there bias?
- What about hallucinations?

External Validity
- Video Quality
- Surgeon Population
- Institution

Approach for next phase
- Use data science to provide valid, objective, accessible feedback for surgeon technical skill
- Change current paradigms in
  - Resident and fellow education
  - Credentialing and licensing
  - Peer review in malpractice cases
  - Insurance reimbursements
  - Standardizing surgical clinical trials

DEVELOPMENT IS IMPORTANT - WHAT ABOUT DEPLOYMENT?
What's next?

Artificial Intelligence in Clinical Practice Is Here—Now What?

- EXPAND DATA SETS
- CONSIDER BIAS
- SCALE BIG DATA
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121 Questions?
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The Didache Hymn

You look into my eye,
You see the truth inside,
The things I can't deny,
The things I can't deny,
You see the pain
The fear, the doubt,
The sadness and the strain,
Of living every day.
With this disease that's in my way:
But you don't judge me,
You don't turn away,
You offer me your help,
And make my feet shine.
You tell me there is hope,
That I can see again,
That I can see life,
The way I used to do.

AI by BARD

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