Ergonomic Aspects of Clinical and Surgical Procedures

Discussion Panel Proposal

**Panelist:** T. Armstrong¹, C. Cao², S. Hallbeck³, R. Radwin⁴, D. Rempel⁵

¹ University of Michigan, ² Wright State University, ³ Mayo Clinic, ⁴ University of Wisconsin-Madison, ⁵ University of California at San Francisco, *moderator & contact

58th Annual Meeting of the Human Factors and Ergonomics Society
Hyatt Regency Chicago, Chicago, Illinois
October 27-31, 2014

This discussion panel aims to identify ergonomic concerns, solutions and research needs, physical stresses, and outcomes related to clinical and surgical procedures. This session will begin with formal presentations to demonstrate current ergonomic concerns and research initiatives associated with clinical and surgical procedures to frame the panel discussion for the second part of the session. Discussion of different procedures will help to identify solutions and research needs that relate to a broad range of ergonomic problems. Questions will be collected from the attendees and speakers and organized so as to guide the panel discussion and to engage all of the speakers in the discussion to achieve the symposium aims.

**INTRODUCTION**

Clinicians are often exposed to high physical stresses for prolonged periods that can adversely affect their comfort, health and performance (Kohn et al. 2002; Park et al 2010; Sari et al. 2010). This panel aims to identify common ergonomic concepts and practices that can be a) applied immediately, b) can be adapted, or c) can be developed to improve outcomes and the health and safety workers who perform clinical and surgical procedures.

**METHODS**

Presentations of examples of investigations of ergonomic issues for various clinical and surgical procedures will be used to generate questions for a structured panel discussion and to engage all of the speakers in the discussion to achieve the aims of the symposium.

Presentation topics include: 1) a taxonomy for describing and identifying differences among surgical procedures; 2) new non-invasive tools for studying postures during clinical procedures; 3) a new method using marker-less video capture for quantifying a surgeon’s hand activities during open surgical procedures; 4) an investigation of posture stresses and discomfort among surgeons; and 5) an ergonomic evaluation of tools used for dental procedures.

**PANEL SUMMARY**

Standardization of Surgical Procedures for Identifying Best Practices and Training
Armstrong, T., Mathur, A., Yu, D., Kasten, S., Minter, R.
University of Michigan

**Introduction:** Previous studies show that standardization of surgical procedures can improve outcomes – even if it is not clear that they are the best procedures (Kawanaka et al. 2009; Shrikhande, Barreto, & Shukla 2007). Standardized work helps to prevent skipping or adding steps, and with unintended consequences. It provides important benchmarks by which abnormal conditions can be identified and fixed.

**Methods:** We previously described a hierarchical taxonomy for describing microvascular anastomoses that are performed to establish blood flow to a host to donor tissue during surgical reconstruction. (Yu, Minter, et al. 2014). This work focused on the “join vessel” subtask, but framework can be used to explore sources of variation for other important aspects tissue transfers. Before vessels can be joined it is necessary isolate and prepare the vessels – these steps are divided into subtasks and elements as previously described and shown in Table 1. In addition, a time-based analysis was performed using video recordings through the dissecting microscope used by the surgeons for seven cases and the amount of time accounted for by each element was determined.

Table 1: Subtasks, elements and observed times for vessel preparation (n=7).

<table>
<thead>
<tr>
<th>Subtask</th>
<th>Element</th>
<th>% Tot</th>
<th>Min-Max (s)</th>
<th>Av±SD (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prep Vessel</td>
<td>Dissect vessels</td>
<td>30%</td>
<td>172-392</td>
<td>298±83</td>
</tr>
<tr>
<td></td>
<td>Control side branches</td>
<td>3%</td>
<td>0-75</td>
<td>32±29</td>
</tr>
<tr>
<td></td>
<td>Control inflow - Clamp</td>
<td>4%</td>
<td>0-85</td>
<td>37±30</td>
</tr>
<tr>
<td></td>
<td>Open recipient vessel</td>
<td>1%</td>
<td>0-25</td>
<td>7±49</td>
</tr>
<tr>
<td></td>
<td>Cut vessels to size</td>
<td>2%</td>
<td>5-42</td>
<td>20±14</td>
</tr>
<tr>
<td></td>
<td>Check art inflow press</td>
<td>2%</td>
<td>0-55</td>
<td>18±17</td>
</tr>
<tr>
<td></td>
<td>Strip adventitia</td>
<td>16%</td>
<td>8-509</td>
<td>156±172</td>
</tr>
<tr>
<td></td>
<td>Dilate vessels</td>
<td>5%</td>
<td>0-116</td>
<td>47±37</td>
</tr>
<tr>
<td></td>
<td>Place background</td>
<td>2%</td>
<td>0-41</td>
<td>15±19</td>
</tr>
<tr>
<td></td>
<td>Position Vessel</td>
<td>18%</td>
<td>39-286</td>
<td>175±86</td>
</tr>
<tr>
<td>Maintain field/vessel</td>
<td>Irrigate</td>
<td>8%</td>
<td>8-17</td>
<td>74±67</td>
</tr>
<tr>
<td></td>
<td>Evacuate</td>
<td>10%</td>
<td>0-280</td>
<td>102±93</td>
</tr>
</tbody>
</table>

**Results and Future Work:** The time to prepare a vessel ranged from 489 to 527s. During that time surgeon must bend his or her neck and back to view the work through a microscope while performing precise manipulations using a sustained pinch grip. It can be seen that “dissect vessel” in which...
the surgeon cuts away tissue to expose the donor and host arteries accounts for the greatest amount of time (30%). Positioning the vessels account for the second greatest amount of time (18%). The donor tissue must be positioned so that there are not any kinks in the vessel that might impede blood flow. While dissecting and positioning vessels accounts for the most amount of time, they are the least variable. The coefficients of variation for dissection and positioning are 28% and 49% respectively. The steps required to expose the vessel are similar for most cases, but the positioning of the vessel varies due to the size and shape of the host site, the location of host vessels, the size and shape of the donor tissue and the location of donor vessels -- which may vary significantly from case-to-case.

Stripping adventitia, in which connective tissue is removed from the outside of the vessel, accounts for the third largest amount of time. It also is one of the most variable elements (coefficient of variation = 104%). Surgeons do not all agree about how much tissue needs to be removed for a successful outcome. Further study is needed to determine the trade-off between removing connective tissue, surgeon fatigue and patient outcome.

This work illustrates how surgical tasks can be decomposed to identify possible causes of task variations and to study their effects on surgeon fatigue and patient outcomes. Further studies are needed to test these hypotheses to determine best practices for microsurgery, for other types of surgery and for other medical procedures.

**ETrack: Posture Assessment in Surgical Settings**

Coles\(^1\), T.R., Dumas\(^1\), C., Cao\(^2\), C.G.L.

\(^1\)The Australian eHealth Research Center, CSIRO
\(^2\)Biomedical, Industrial and Human Factors Engineering, Wright State University

**Introduction:** Increasingly, medical simulation is being recognized as enablers for more productive and safer clinical practice. However, many current simulators limit the scope of training to tool-directed learning, focusing training around simulated tool tips. Performance training and assessment that is trainee-centered, such as the ergonomics of postures and movement of the surgeon, is needed to complement current approaches. For example, in a task analysis of bronchoscopy, it was observed that several key learning objectives involve ergonomic hand/arm postures on instrument handling and surgeon positioning around the patient. A tool-centered simulation approach to training would exclude these learning objectives, thereby necessitating additional training beyond the simulator. To capture trainee-centered information for inclusion in simulation training, ergonomic analysis must be performed to identify the key trainee-centered learning objectives. Ergonomic analysis for surgeons is often based on data collected whilst the clinicians interact with their patients in the clinical environment, using observation techniques that require pen-and-paper notation. Motion tracking technology offers a more objective and precise method of collecting data to perform ergonomic assessment of postures, efficiency of movements, physical spatial layout of the clinical environment, etc. However, advanced motion tracking platforms such as those used in the film industry are often expensive, require an expert to operate, and require the clinician to be covered in precisely-placed reflective markers or electronic sensors, which can interfere or prove hazardous with the aseptic environment. We present here the ETrack, a motion tracking solution that requires no markers, uses low cost hardware, is simple to set up and compact to transport.

**Methods:** The ETrack (www.aehrc.com/ETrack) posture capture tool uses Microsoft’s Kinect Infra Red tracking hardware for posture capture. This technology was designed primarily for computer games and is a low cost (RRP $249 USD) markerless tracking solution.

ETrack (Figure 1), a Microsoft Widows 7 program enables the researcher to visualize the surgeon being tracked, in real-time, as an animated two-dimensional distance map. Prior to recording posture data, the researcher can select points of interest on the tracked “stick figure” to be recorded. During recording, the xml data file is populated with position data and a time stamp at a rate of 30 samples per second. The software tool provides pre-programmed flag buttons and a free text option to highlight or note positions of interest in real-time for post analysis. In addition to real time posture and position capture, retrospective analysis of scenes captured using the Kinect Studio recording platform (a free Microsoft tool) can be performed.

**Results and Future Work:** ETrack has been successfully used in a posture analysis in performing bronchoscopy (Coles et al. 2014). The software is free and a simple interface makes the tool easy to use for those without advanced computer programming skills. The exchangeable xml data format can be simply loaded into most analysis software. An xml loading package for R is also provided. Future work is needed to integrate the tool-centered training component with the trainee-centered component in a training system to allow self-directed training.

![Figure 1: ETrack. Posture and position capture software. (top left) Visualization of captured depth map. (top middle) A 3D skeletal view of a practitioner’s movements. Shown visualiz-](http://example.com/image.png)
ing upper limbs only. (top right) A camera view of the practitioners interactions. (bottom right) A 2D distance view of the practitioners head (white) right hand (green) and left hand (red) from the motion sensor (top black bar). (bottom center) A set of buttons to flag particular poses during a procedure. (bottom left) Users can select points of the tracked skeleton they wish to record.

A marker-less video tracking approach for quantifying open surgical skill

Introduction: This paper describes use of video to capture and analyze a surgeon’s hand activities during complex open surgical procedures. Videos of surgeons of varying experience level were recorded performing selected operations that require a high level of specialized technical skill. An industrial engineering methods analysis was conducted of videos from actual operations and simulations of surgical procedures in order to breakdown surgical tasks into specific technical elements and movements/exertions. Automated marker-less video analysis was used to objectively quantify the motion and kinematic characteristics of the surgeon hand movements. Differences in kinematic measures between tasks, surgeons, and experience level were explored. The ultimate goal is to identify kinematic characteristics that may be used for quantifying surgical skill.

The ability to objectively quantify technical skill is critical to ensuring that all surgeons achieve and maintain an adequate level of competency. We currently lack a conceptual model for technical skill and have no empirical measure to quantitatively describe technical skill. Previous attempts to objectively assess surgical technical skills include global rating scales, procedure-specific checklists, and dexterity analysis systems (Moorthy et al. 2003). While these systems have been employed in situ, the majority of our understanding about psychomotor and other properties of technical skill is based on simulation studies.

Methods: We have developed novel video processing software for automatically tracking hand motion to quantify repetitive hand activity and motion kinematics using a video feature extraction method to indirectly quantify upper limb activity using marker-less video motion analysis (Chen et al. 2013). A cross correlation-based template-matching algorithm was programmed to track the motion and simple load transfer task was implemented in order to simulate repetitive motion activities. The algorithms tracked the motion of a general region of interest on the upper extremities selected by an analyst, and statistically estimated its velocity and acceleration. Differences in hand motion kinematics for suturing, cutting and tying tasks were measured.

Videos of the surgeon’s hands were made during actual open surgeries and simulated surgical procedures. Videos in the OR were made by cameras installed in the operating room light. Cases included bowel anastomosis, vascular anastomosis, pancreatico-jejunostomy, and colostomy operations. Simulated surgeries were also videotaped during resident exit examinations.

The video segments were isolated based on the ability to view the hands between 30 s and 2 min, the light was not moved, and there were no obstructions. Contiguous clips of movements involved in the tasks were identified using Multimedia Video Task Analysis (MVTA) software. Hand motion for performing specific surgical tasks were tracked. These included suturing and tying.

A rectangular region of interest (ROI) was marked manually to identify the focal area where hand activities are to be tracked, such as a point on the hand or arm. A template matching tracking algorithm was implemented to track the ROI motion trajectory over successive video frames.

Results and Discussion:
A representative speed-time plot for suturing and tying is shown in Figure 1. Summary statistics for suturing and typing tasks are provided in Table 2.

We conclude that marker-less video tracking can be used for tracking a surgeon’s hands during operation procedures, it is possible to quantify hand motions from standard video recordings of surgical tasks and that it we observed distinct differences in kinematic motion patterns for various surgical

![Figure 2: Representative speed v. time plots for suturing and tying tasks.](image-url)
tasks. Future work will study these differences are associated with experience and surgical skills evaluations.

### Table 2: Comparison between suturing and tying tasks (N=5 surgeons)

<table>
<thead>
<tr>
<th>Suturing</th>
<th>Tying</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>Speed</td>
</tr>
<tr>
<td><strong>(mm/s)</strong></td>
<td><strong>(mm/s)</strong></td>
</tr>
<tr>
<td>41.78</td>
<td>61.46</td>
</tr>
</tbody>
</table>

**Physical Workload and Discomfort in the Operating Room**

**Introduction:** Recent publications demonstrate the physical impact of operative procedures on surgeons: “While patients benefit, surgeons suffer: An upcoming epidemic” (Park et al. 2010); “The operation room as a hostile environment for surgeons: Physical complaints during and after laparoscopy” (Sari et al. 2010); “The aching surgeon: a survey of physical discomfort and symptoms following open, laparoscopic and robotic surgery” (Plerhoples et al. 2012) and “Are your ORs Hurting your Docs” (Berguer 2013). There are several national self-reported studies reporting between 60% (Sari et al. 2010: Plerhoples et al. 2012) to nearly 90% (Park et al. 2010; Kim Fine et al. 2013) of respondents experiencing pain/discomfort during or after performing surgery for surgical specialties such as minimally invasive, gynecological and pediatric.

**Methods:** To compare these retrospective data to prospective data, a study of OR workload was undertaken with 33 surgeons (11 women, 22 men) who performed 118 operations that lasted an average of 152.4 (sd=111.2) minutes.

**Results and Future Work:** In a preliminary questionnaire, 30% of the respondents said they experienced body discomfort attributable to surgery at 60 minutes into the surgery and an additional 50% said they experienced it at 120 minutes (the remaining 20% felt it earlier than 60 minutes, including some reporting immediate discomfort). This discomfort affected their posture (41.2%), concentration (29.4%), mobility (20.6%), stamina (17.6%), reaching toward an object (8.8%), lost work days (5.9%) and balance (2.9%), but not visualization of the surgical field (0%) – note this question and the next asked them to check all that apply so these do not add to 100%. To minimize these problems, they mainly changed positions (47.1%), took a break (29.4%), ignored it (26.5%), used a step to change height (26.5%), and/or changed instruments (8.8%).

These 33 surgeons were asked to complete the Surg-TLX (Wilson et al. 2011) after each surgery. Surg-TLX provides a global assessment consisting of physical, mental and temporal demands, situational awareness, degree of distraction, and complexity of procedure rated from 0 to 100%. Data from these 118 procedures were added to an additional 46 procedures by a single surgeon (total of 164 surgical procedures). For these 164 procedures, the Surg-TLX subscale of physical demand averaged 39.6% (sd=24.7%) with a median of 35% and a range from 0-100%, depending on the type and length of surgery. As expected, the physical demand was highly correlated with the complexity of the surgery ($\rho=0.815$, $\alpha\leq0.001$).

These ratings demonstrate the physical work load in the OR, which should be assessed during surgery to create interventions to lower the physical stress in the OR. The subjective ratings show that as surgeries become more complex, the workload increases. The exact mechanism for this increase needs to be defined. Objective data will quantify specific physical activities to be targeted by an intervention to reduce the physical discomfort of surgeons during their workday.

**After using periodontal tools of different weight and diameter for 4 months in the dental practice: A follow-up study on pinch force**

Rempel, D., Lee, D. Division of Occupational and Environmental Medicine, Uni. of California, San Francisco, CA

**Introduction:** Dental practitioners (N=110) participated in a 4-month randomized controlled trial (RCT) to evaluate the effects of (1) a large diameter light weight periodontal tool vs. (2) a small diameter heavier tool, on right arm pain. Use of the lighter, larger diameter tool was associated with a greater improvement in arm pain scores than use of the heavier, narrow diameter tool (Rempel 2012). Previously, it had been demonstrated, in a laboratory setting, that less pinch force is applied during dental hygiene work with a large diameter, light scaling tool than a narrow diameter, heavy tool (Hui 2006). The purpose of this follow-up study was to evaluate the effect of the tool used during the 4 month RCT on applied pinch force during dental scaling.

**Methods:** At the end of the 4-month RCT study, ten dental practitioners from both treatment groups were randomly selected and participated in a follow-up laboratory study. They performed dental scaling on mannequin teeth (Hui 2006). They used both an instrumented small diameter, heavy periodontal tool and an instrumented large diameter, light tool while pinch force was measured. The order of testing was randomized.

**Results:** Median and APDF 90 pinch force values are summarized in Table 3. There were no significant differences between the two groups on pinch force applied to the small diameter tool. However, there was a trend for the pinch force applied to the large diameter tool to be lower among subjects who were assigned the larger lighter tool in the RCT (p=0.1).

This study suggests that over 4 months, subjects who were assigned the larger diameter, lighter dental tool, reduced their applied pinch force for dental scaling more than subjects who were assigned the smaller diameter, heavier tool in the RCT. The lower applied pinch force among those assigned the larger diameter, lighter tool may explain why they had a greater reduction in arm pain than the group assigned the smaller, heavier tool. This study provides some evidence that applied pinch force may be an intermediary factor in the arm pain that develops among dental workers.
Table 3. Mean pinch force (APDF50 and APDF90) measured during dental hygiene scaling on a mannequin in a laboratory setting by subjects who were part of a 4-month RCT in the dental office.

<table>
<thead>
<tr>
<th>Tool Assignment in the RCT</th>
<th>Larger, Lighter Tool (N=10)</th>
<th>Smaller, Heavier Tool (N=10)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy small tool</td>
<td>5.1 (2.6)</td>
<td>6.1 (3.5)</td>
<td>0.49</td>
</tr>
<tr>
<td>APDF 50 (N)</td>
<td>5.1 (2.6)</td>
<td>6.1 (3.5)</td>
<td>0.49</td>
</tr>
<tr>
<td>APDF 90 (N)</td>
<td>18.2 (5.6)</td>
<td>20.1 (7.7)</td>
<td>0.54</td>
</tr>
<tr>
<td>Light large tool</td>
<td>5.8 (3.1)</td>
<td>7.4 (3.7)</td>
<td>0.31</td>
</tr>
<tr>
<td>APDF 50 (N)</td>
<td>5.8 (3.1)</td>
<td>7.4 (3.7)</td>
<td>0.31</td>
</tr>
<tr>
<td>APDF 90 (N)</td>
<td>16.9 (5.5)</td>
<td>20.4 (4.1)</td>
<td>0.10</td>
</tr>
</tbody>
</table>

ACKNOWLEDGEMENTS

Standardization of Surgical Procedures for Identifying Best Practices and Training study was supported in part by a Graduate Medical Education Innovations Program Grant through the University of Michigan Health Systems.

After using periodontal tools of different weight and diameter for 4 months in the dental practice study was funded by the U.S. National Institute for Occupational Safety and Health (RO1-OH008892).

REFERENCES


