Paper review

SURGICAL INSTRUMENTS FOR ROBOTIC OPEN MICROSURGERY

Radhika Rajaram

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Selected papers:

1) Patkin, M. (1977), Ergonomics Applied to the Practice of Microsurgery. *Australian and New Zealand Journal of Surgery*, 47: 320–329.
2) Lee, G., Lee, T., Dexter, D., Klein, R., & Park, A. (2007). Methodological Infrastructure in Surgical Ergonomics: A Review of Tasks, Models, and Measurement Systems. *Surgical Innovation, 14*(3), 153-167.
3) Hignett, S., & Mcatamney, L. (2000). Rapid Entire Body Assessment (REBA). *Applied Ergonomics, 31*(2), 201-205.

1. Introduction

The aim of our project is to develop microvascular needle driver and or forceps that can be integrated with the Galen Robot. In the interest of ergonomics and workspace optimization, it is required that the instruments be held by the robot at the middle and by the surgeon at the top. Other design considerations include rotatability and design for manufacturability and sterilizability. Towards this end, we have selected the above literature to give us guidelines on more microsurgery-specific design requirements and methods of measuring and evaluating the success of our design.

2. Ergonomics Applied to The Practice of Microsurgery

This paper describes in detail, five main areas of ergonomic importance in a microsurgical environment:

(i)Visual feedback; (ii) accuracy of hand movement and control of tremor; (iii)the acquisition of skill; (iv) hand grip used for precise work (v) design and care of microsurgical instruments

(i) Visual feedback:
This section examines factors such as microscope magnification, lighting intensity, glare, color contrast and eye fatigue. These factors are outside the scope of our project's control, so they are not discussed here.

(ii) Accuracy of hand-movement and motor control:
Many useful design considerations are explained in this section, but in our case, the robot will cancel out the hand tremor. Therefore, this section is also not discussed in this review.

(iii) Acquisition of skill:

Three levels of phases of skill acquisition are coding, temporal and hierarchical organization.

Coding involves muscle memory or linkage of specific movements to specific outcomes. Temporal organization is the grouping of coded actions in a sequence, such as in suturing.

Hierarchical organization refers to making a choice of strategies based on the sensory information available and previous experience. This section, while not providing any direct design guidelines for instruments, is useful when considering the arrangement of tools in the workplace to allow for faster skill acquisition.

(iv) Hand posture and finger movements:

This section is the most relevant part of the paper. It provides the following dimensional recommendations based on biomechanical analysis of the "microvascular grip":

1) The length of the handle from where it is gripped to the top end must be around 10 cm for proper balance. The distance from the fingertips to the instrument jaws is dependent on the access to the tissues at the operation. For conventional ontological procedures, one can expect this value to be around 2 cm. As our tool is also held at the middle by the robot, this design recommendation can be ignored.

2) The handle cross-section must be circular to allow of rotatability. The handle should be milled for friction to achieve better gripping.

3) The diameter of handle must be between 5-10 mm so that instrument can be small enough to rest in the thumb cleft and large enough to avoid excessive rotation.

4) The force required for opening or closing the instrument should be between 40 – 100 gm. Above this limit, the surgeon may experience fatigue and below this limit the surgeon will not be able to hold the instrument without actuating it.

5) A 6:1 mechanical advantage will guarantee the least fatigue to the surgeon.

(v) Instrument care and maintenance:

This part comments on corrosion, cleaning methods, stiffness testing and sharpness testing for surgical instruments. As manufacturing methods have greatly improved over the last three decades, this section may not be very useful as it was published in 1977.

Summary and review:

This paper provides very good and actionable suggestions for tool and workplace design. As it is an outdated paper, some of the information regarding instrument care and visual feedback is no longer relevant.

3. Methodological Infrastructure in Surgical Ergonomics: A Review of Tasks, Models, and Measurement Systems

This article classifies different surgical tasks and models and describes various ergonomic measurement systems with respect to laparoscopy. However, most of the concepts and tools can be applied to microsurgery with little or no modification.

(i) Tasks:

Surgical tasks can be classified into three categories:
a)   Static tasks, that require no major motion, but simply the actuation of the tool
        Eg: opening and closing of scissors
b)   Simple navigation tasks, that do involve joint movement and manipulation
        Eg: navigation around an electrified wire course
c)   Manipulation tasks, that involves a lot of skill
        Eg: - pushing small object into small aperture, instrument-instrument rope passing, cable passing, shape cutting, suturing, tying

By measuring the success rate and speed of completion, we can compare the ergonomics of different instrument designs.

(ii)   Models:

a)   Traditional training boxes which comprise a confined space with access ports and a CCD camera for recording have been developed for many surgical training programs. These boxes may not be sophisticated enough for detailed assessment of skills.
b)   Virtual reality simulators with haptic and graphic feedback allow for detailed analysis of skill and comfort assessment. However, many of them can be unrealistic for experienced surgeons. Furthermore, they are expensive and not generalizable for different surgical procedures.
c)   Intraoperative models refer to cadavers or special phantoms that can be worked on in an actual Operating Room. Many operating rooms may not be able to accommodate ergonomic measurement systems and this is the major drawback of this model.

(iii) Measurement systems:

This portion of the paper elaborates on the objective measurement instruments that can be used to quantify ergonomic factors such as posture and stress.

a)   Motion capture systems:
There are many varieties of motion capture systems. They can be broadly classified into orientation, electromagnetic (EM), optical, and video-based motion analysis systems.

Orientation sensor systems return the angular movements (yaw, pitch and roll). This can be useful for head tracking. EM systems can provide both orientation and location data.
However, they are subject to interference. Optical motion tracking utilizes retroreflector markers to return joint and segmental landmark locations. Movement at each joint can be calculated in 3 directions (flexion/extension, abduction/adduction, and internal/external rotation). CoP (centre of Pressure) can also be determined. The drawback of this system is that reflective surgical instruments can confuse the system. Video analysis is the simplest system which involves manual recording of position and orientation. However, computer vision techniques can be used to automate the analysis.

b)   Electromyography:

Muscle exertion causes change of the action potentials which can be measured just above the skin using surface or needle electrodes. EMG data analysis relates muscle activation to outcome (force, torque, movement, fatigue level). Both hand and posture ergonomics can be evaluated with this method.

Three types of analysis can be carried out:
1) *Amplitude of EMG signal averaged over time:*
   This only provides the overall strain of the task and does not provide intuitive numbers
2) *Percentage of Maximum Voluntary Contraction (% MVC):*
   This is a better analysis as the strength of the muscle is taken into consideration
3) *Frequency analysis:*
   This can be used to understand task induced fatigue

c)   Force-plate systems:
These systems measure Ground Reaction Force (GRF) exerted by the body through piezoelectric transducers or strain gauges. Complex force-plate systems can provide:

1) 3D resolution of force
2) 2D coordinates of Centre of Pressure
3) rotational moments about x, y and z axes

However, this system is good only for overall posture measurement and not for handheld instrument ergonomics.

Summary and review:
This paper contains excellent information regarding all aspects of ergonomic evaluation. However, it does not explain what numbers constitute good or bad ergonomics. It would be very useful to have some metrics that can help us decide when a redesign is necessary.

4)   Rapid Entire Body Assessment (REBA)

This paper describes a popular postural analysis tool developed specifically for healthcare practitioners. REBa has the following features:

1) It is sensitive to musculoskeletal risks in a variety of tasks

2) It segments the body and codes the different segments

3) It provides a scoring system for muscle activity caused by static, dynamic, rapid changing or unstable postures

4) It takes into consideration factors like grip, loading, coupling and support

5) The scoring system gives an action level with indication of urgency

6) It does not require complicated measurement systems

REBA segments the limbs into two groups: Group A includes the legs, neck and trunk while Group B includes the wrist, upper arm and forearm. Group A has 60 postural combinations This reduces to nine possible scores to which a Load/Force score is added. Group B has 36 combinations which also reduces to 9 scores to which a 'Coupling' score is added. A and B scores are combined in a table to give 144 combinations to which an activity score can be added.

REBA scores correspond to action levels range from 0 to 4, with 0 indicating least risk and no action required, while 4 indicates high risk and immediate action.

Summary and review:

REBA is a fast and easy-to-use postural analysis tool and has been verified to be quite accurate. It has been used to evaluate robotic-assisted surgeries as well. It can be used for workplace ergonomics and tool positioning but it not possible to study fingertip forces.

Conclusion:

The three papers together make a comprehensive resource for ergonomic design rules, measurement and evaluation methods for microsurgical tools. Since our surgical instrument is integrated with a robot, we may face unique challenges while trying to implement safe and effective instrument design. Even though we do not aim to test the instruments with experienced surgeons, the knowledge of correct working posture can help in our self-evaluation.