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Review

Building a framework for ergonomic research on laparoscopic instrument handles

Zheng Li [a], Guohui Wang [a], Juan Tan [a], Xulong Sun [a], Hao Lin [b], Shaihong Zhu [a,*]

[a] Department of General Surgery, Third Xiangya Hospital, Central South University, 138 Tongzipo Lu, Yuelu Qu, Changsha, Hunan 410000, China
[b] Department of Equipment, Third Xiangya Hospital, Central South University, 138 Tongzipo Lu, Yuelu Qu, Changsha, Hunan 410000, China

HIGHLIGHTS

- Laparoscopic instrument handles need ergonomic design for comfortable.
- The methodology in ergonomic study on laparoscopic instrument handles is elaborated.
- A guideline is feasible for ergonomic evaluation of laparoscopic instrument handles.

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ABSTRACT

Laparoscopic surgery carries the advantage of minimal invasiveness, but ergonomic design of the instruments used has progressed slowly. Previous studies have demonstrated that the handle of laparoscopic instruments is vital for both surgical performance and surgeon's health. This review provides an overview of the sub-discipline of handle ergonomics, including an evaluation framework, objective and subjective assessment systems, data collection and statistical analyses. Furthermore, a framework for ergonomic research on laparoscopic instrument handles is proposed to standardize work on instrument design.

1. Introduction

Laparoscopic surgery has become a mainstay of modern surgery, especially in general surgery, urology, gynecology and cardiothoracic surgery [1,2]. Laparoscopic surgery brings the advantages of improved cosmesis, reduced postoperative pain and shortened hospitalization. However, along with its rapid development and general acceptance, surgeons have reported physical injuries, mental fatigue and stress during and following laparoscopic procedures [3]. Certain postures during laparoscopic surgery are known to be more physically demanding and stressful [4,5]. Reports of discomfort or aches in their shoulders, wrists, palms and fingers, and nerve function impairment have been well documented [6,7].

Many of these problems are attributable to shortcomings in the design of instruments used for laparoscopic surgery [8–13]. The handle of laparoscopic instruments is an indispensable part of the instruments, inappropriate design of which can have a deleterious effect on surgeons' efficiency and well-being. Ergonomics refers to the science relating the human being and his work environment including the anatomical, physiological, psychological, and mechanical considerations that may affect general well-being, efficiency and health in occupational settings.

Ergonomics research is relatively new in its application to modern surgery. Most surgeons are unaware or tend to ignore its importance and essence. Moreover, the ability and methodological framework for making an ergonomic assessment of an instrument handle may be entirely lacking. In order to accurately describe the relationship between the surgeons' comfort and the instrument's design, ergonomic research has been introduced into laparoscopic surgery. Indeed, a close cooperation between the surgeon and the ergonomist can lead to improved surgical performance and decreased injuries. Therefore, constructing a framework for

* Corresponding author.
E-mail address: zshxy3@163.com (S. Zhu).

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ergonomic studies of laparoscopic instrument handles calls for more attention.

To facilitate the practical application of surgical ergonomics, we focus on the methodology of ergonomic research on instrument handles in this narrative review. The evaluation platform, objective and subjective assessment tools, data collection and statistical analyses are discussed. To demonstrate the depth and breadth of the discipline, we describe tasks, models, motion analysis, EMG, questionnaires and methods of data analysis. Finally, we summarize and construct a framework for future ergonomic research on laparoscopic instrument handles.

2. Principles of ergonomic research on laparoscopic instrument handles

To evaluate the ergonomic aspects and compare the design of different types of laparoscopic instrument handles, a reliable and credible evaluation system needs to be instituted based on ergonomic criteria.

In 1999 Matern described 14 principles for an ergonomically satisfactory handle for laparoscopic instruments [14] (Table 1). He used these principles to evaluate four different available handles and designed a new handle that fulfilled most of these principles. An additional 8 principles were added by Matern in 2001 [2] (Table 1). However, only 5 of them can be quantified. Though ergonomic principles for evaluating handles are now clear, and the criteria for designing a new handle have been described in detail [15], a series of quantifiable measurements combined into a framework would be more practical and useful.

3. Methodology of ergonomics research on laparoscopic instrument handles

The methodological tools used in earlier studies for assessment of handles have belonged to 3 main categories. Tasks and models are vital components of an evaluation platform in surgical ergonomic research. Motion analysis and EMG are two objective tools for quantifying surgeons' physical workload and muscular discomfort, while questionnaire surveys are the most useful and direct methods for evaluation of subjective elements.

3.1. Models

The term "models" refers to the physical forms that simulate the surgical field and the operating room. Thus far the most frequently used models are open-up models, training box models, virtual reality models and operation room models [16](Table 2).

The open-up model is a basic model for ergonomic research. These systems are platforms that roughly simulate the abdominal cavity. The basic components include the walls, trocars and a restricted light source but no roof. The task object and one or two bracing structures are inserted. A multitude of different tasks, such as object transfer, circle cutting, and bowel suturing, can be conducted within this model. This model has many advantages: it is quick and cheap to construct, provides easily accessible data, the contents can be changed quickly and there is no requirement for a camera. Usually, open-up models are applied to novice trainees. Matern used an Ergo Box, a form of open-up model, with a trocar to perform three test courses: curve, helix and straddle [17], counting the trial time and errors of each trainee. These three courses performed in open-up model are useful to analyze the precise motion of the instrument in a closed state, to investigate rotational movements, and to analyze combinations of precise movement and opening/closing movements [17].

The training box model is the typical model chosen by most surgeons and ergonomists. It has a confined space, mimicking an abdominal cavity. Compared to the open-up model, a training box model provides a more realistic operating environment. Although it varies in exterior form, the basic components remain the same: trocar, laparoscope and light source. The trocars are deployed as a means of introduction for cameras and laparoscopic instruments, similar to that in open-up model. The light source is provided by a light source transmitting through an optical cable installed on the laparoscope. The training box model is considered as not only a recommended training program for novice laparoscopic surgeons, but also as an evaluation platform for laparoscopic instruments. For example, the commercial 'pelvi-trainer' model has been widely used in handle studies [18]. Special models such as the 'neonatal box' have been adopted according to task design [19]. However the light source and a laparoscope with a high definition monitor are unaffordable by most ergonomic research teams. Further, an assistant is required to manipulate the scope [20]. The recorded video of experiments also requires considerable work to convert the video into useful and comparable data.

Virtual reality (VR) models utilize a real-time simulated human body cavity generated by computer software. Used as a training machine, this model is able to provide surgeons with a life-like experience. This experience comes from realistic visual performance, tactile feedback and force feedback. By using this model, surgeons or trainers also benefit from standardized measurements

Table 1
Principles for ergonomic design of laparoscopic instrument handles.

Original 14 principles of ergonomic designing of laparoscopic handles in 1999	Additional 8 principles recommended in 2001
1. Adjustability to different hand sizes;	15. Instrument's shaft should be an extension of the forearm's rotation axis;
2. Multifunctionality of handle;	16. Axis of the instrument's shaft should be next to the axis of the forearm;
3. Avoidance of foot-switches;	17. Handle should allow for a neutral wrist position and the described "basic posture" of the surgeon;
4. As small a size as possible;	18. Low muscle activation should be necessary to manipulate the functional elements;
5. Provision for one-handed use;	19. The functional elements should allow force feedback, to allow for a feel of the tissue's consistency;
6. Handle identifiable from its design;	20. Anti-friction mechanics;
7. Prevents injury to hand pressure areas;	21. Non-reflective surface;
8. Operable by sensitive areas of the hand;	22. Handle should allow safe but not adhesive contact with the surgeon's gloved hand.
9. Convenient access to all functionalities;	
10. Size and dimensions should allow easy manipulation of functional elements;	
11. Any necessary springs should not hinder the use of instrument;	
12. Avoid indirect power transmission;	
13. Minimal autonomous dynamics;	
14. Avoids the need for cramped positioning and excessive shoulder movements.	