Robotic surgery and training: electromyographic correlates of robotic laparoscopic training

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Abstract

Background: Robotic laparoscopic surgery has been shown to decrease task completion time, reduce errors, and decrease training time, as compared with manual laparoscopic surgery. However, current literature has not addressed the physiologic effects, in particular muscle responses, to training with a robotic surgical system. The authors seek to determine the frequency response of electromyographic (EMG) signals of specific arm and hand muscles with training using the da Vinci Surgical System.

Methods: Seven right-handed medical students were trained in three tasks with the da Vinci Surgical System over 4 weeks. These subjects, along with eight control subjects, were tested before and after training. Electromyographic (EMG) signals were collected from four arm and hand muscles during the testing sessions, and the median EMG frequency and bandwidth were computed.

Results: The median frequency and frequency bandwidth both were increased after training for two of the three tasks.

Conclusion: The results suggest that training reduces muscle fatigue as a result of faster and more deliberate movements. These changes occurred predominantly in muscles that were the dominant muscles for each task, whereas the more demanding task recruited more diverse motor units. An evaluation of the physiologic demands of robotic laparoscopic surgery using electromyography can provide us with a meaningful quantitative way to examine performance and skill acquisition.

Key words: da Vinci — Electromyography — Frequency analysis — Laparoscopy — Robotic surgery — Training

Laparoscopy, a form of minimally invasive surgery, has revolutionized the treatment of abdominal pathologies. The benefits for patients include shorter recovery time with less pain [23], fewer adhesions [10], and better postoperative quality of life [14] than experienced with traditional open procedures. However, manual laparoscopy also has shown several limitations during surgery. These limitations include lack of depth perception, poor camera control, limited degrees of freedom at the instrument tips, and inverted hand–instrument movements [2, 3, 15]. Furthermore, these limitations lead to unnatural and painful surgical postures that result in fatigue for the surgeon [2, 3, 15].

The advent of robotic surgical systems, such as the da Vinci Surgical System (DVSS; Intuitive Surgical, Inc., Sunnyvale, CA, USA), have overcome some of the limitations associated with manual laparoscopy. The addition of three-dimensional visualization has provided depth perception [6] and increased dexterity [16, 17]. Wristlike articulations of the instruments also have been shown to improve surgeons’ dexterity [16]. Coordinated hand–instrument movements have reduced the training time for robotic systems versus manual laparoscopy [5]. In addition, tremor abolition and motion scaling have been shown to enhance dexterity with the use of robotic systems, as compared with manual techniques [16].

Studies comparing robotic surgical systems with manual laparoscopy have examined the effectiveness of robotic procedures. Researchers have found that with the use of robotic systems, surgeons improve in dexterity [16] and residents can be trained more quickly [5, 7, 12]. In addition, there are fewer errors, and the time required for task completion is reduced [11, 13, 16, 20, 22]. However, the current means of evaluating surgical performance and skill acquisition during training are limited to measurement of task completion time and the number of errors [11, 13, 16, 20, 22], or to subjective evaluation by an expert.
To our knowledge, no studies have examined physiologic measures of surgeons during the performance of robotic surgical techniques. In manual laparoscopy, physiologic evaluations have been limited mainly to ergonomic measures [2, 3, 15]. These studies have found increased stress and fatigue associated with manual laparoscopy because of the surgeons’ postures. Additionally, Quick et al. [21] investigated electromyography during manual laparoscopy and found that both the task and the type of grasper used contributed to muscle fatigue. This type of analysis has not yet been conducted for robotic surgery.

Thus, it is not known whether robotic surgery leads to increased fatigue. Most importantly, it is not known whether training has an effect on fatigue. Electromyography can assist in the evaluation of physiologic muscular fatigue [1]. Specifically, frequency analysis of the electromyographic signals from the muscles involved has proved to be an effective method for measuring muscle fatigue and motor unit recruitment during static force exertion [1]. Specifically, increased muscle fatigue is associated with a decreased median frequency of the power spectrum [1, 4]. In addition, increases in the frequency bandwidth of the power spectrum imply additional recruitment of motor units with varying conduction velocities [8, 9].

More recently, it has been shown that frequency analysis also can be applied to cyclic dynamic tasks to evaluate muscular fatigue [4]. Hypothetically, training should decrease muscular exertion (i.e., median frequency) during surgery and thus improve the ability of the surgeon to operate. Therefore, this study sought to determine how muscle responses change during training with the dVSS.

Fig. 1. Experimental tasks. A Bimanual carrying. B Needle passing. C Suture tying.