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An ergonomic comparison of in-line vs pistol-grip handle configuration in a laparoscopic grasper

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Abstract

Background: Laparoscopic instruments incorporate both in-line and pistol-grip handle configurations, yet it is unclear which design is most advantageous for surgeons, particularly when operating at angles perpendicular to the surgeon's position. We present a detailed electromyographic (EMG) comparison of these handle configurations under different force and angle conditions.
Methods: Nine general surgeons used a Microsurge grasper with the handle in an in-line (MS-IL) and pistol (MS-PS) configuration, as well as a standard hemostat (HE), to grasp and close two spring-loaded metal plates. The task was performed randomly by each subject with the three instrument configurations at two forces levels (0.7 N, 4.2 N) and at three angles to the surgeons' body (0, 45, and 90°). Surface EMG was measured from the flexor carpi ulnaris (FCU), flexor digitorum profundus (FDP), flexor digitorum superficialis (FDS), extensor carpi ulnaris (ECU), extensor digitorum comunis (EDC), and thenar compartment (TH). The peak root mean squared (RMS) EMG voltage was calculated for each instrument, force, and angle condition. Statistical comparison was carried out by ANOVA.
Results: Both laparoscopic handle configurations required significantly higher contractions of all muscle groups compared to the hemostat at the high force level. TH was not affected by laparoscopic handle configuration. MS-IL required higher FCU, ECU, and EDC contractions at 45° compared to MS-PS. However, MS-IL decreased the flexor compartment muscle contractions (FDP, FDS, FCU) at 90° compared to MS-PS.
Conclusions: Laparoscopic grasping requires higher forearm and thumb muscle contractions compared to the use of a hemostat. The in-line handle configuration is no better than the pistol configuration except when grasping at 90° to the surgeon, where rotation of the handle and wrist back toward the surgeon significantly decreases forearm flexor compartment muscle contractions.

Key words: Laparoscopy — Ergonomics — Electromyography

The technical difficulties encountered by laparoscopic surgeons stem from the numerous sensory and motor limitations caused by indirect access to and viewing of the operative field [15]. One of the main biomechanical limitations of laparoscopic surgery is the fixed point of entry of each instrument through a trocar which may cause the surgeon to employ awkward wrist positions during manipulation in different areas of the abdomen [15]. This limitation is further compounded by the inferior handle-to-tip force transmission ratio in laparoscopic instruments [18]. Therefore, during laparoscopic surgery, surgeons could be expected to experience a less efficient transmission of hand force through the instrument with resultant muscular fatigue and possible discomfort. Indeed, we have recently reported that surgeons do report increased forearm discomfort immediately following laparoscopic operations compared to open operations [3], and we correlated this subjective data with a significant increase in the amplitude of the forearm flexor compartment EMG signals during use of laparoscopic instruments.

The present study is a more detailed EMG investigation of six forearm and hand muscles with two goals: first, to compare forearm and hand muscle contractions during the use of laparoscopic and open instruments under different grasping loads and at different wrist angles relative to the user; and second, to evaluate whether there is any benefit to the use of an in-line handle configuration in contrast to the more usual pistol-grip handle in laparoscopic instruments.

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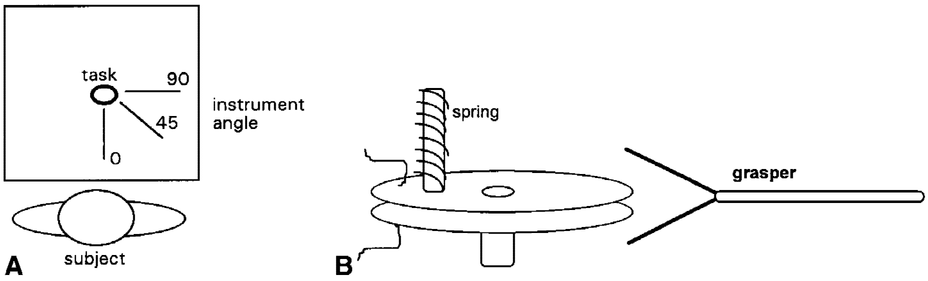

Fig. 1. **A** Diagram of surgeon-subject relative to task indicating the three angles of grasping relative to the surgeon's body. **B** Diagram of the plate assembly used for the grasping task. Two copper plates are separated by a smaller insulating spacer and held together by an off-center spring mechanism. Instrument tip contact with the top plate initiates the electrical timing signal, and when the two plates come together the electrical signal stops. The electrical timing signal precisely brackets the duration of grasping and eliminates measurement of force ''overshoot'' after plate closure.

Methods

General study design

Control studies were performed with each subject squeezing a hand dynamometer at a force ranging from 0 to 32 lb in increments of 4 lb to study the linearity of the EMG signal with muscle force exerted. The experiment consisted of each subject performing a specified mechanical grasping task with each of the following three independent variables in random order: (1) Instrument type (Crile hemostat, Microsurge grasper-pistol configuration, and Microsurge grasper-in-line configuration); (2) Angle of task relative to subject (0°, 45°, and 90°); and (3) Level of grasping/spreading force (low = 0.7 N and high = 4.2 N). Each task consisted of five repetitions of the grasping motion to obtain a reliable average. A total of 18 grasping tasks (3 instruments × 3 angles × 2 forces) were performed by each subject in random order. Subjects' posture was standardized such that the handle of the instrument used was at elbow height, forearm distance, and directly in front of the subject when the instrument was placed in the 0° position. A videotape was made combining simultaneous views of the subject and the raw EMG signal for review if needed.

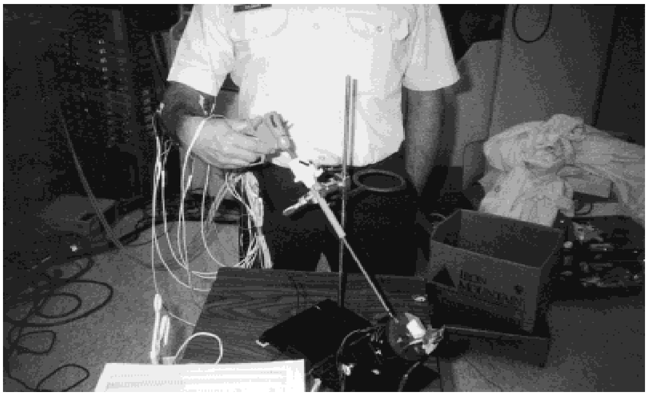

Fig. 2. Photograph of subject with EMG electrodes placed on right forearm and thumb, grasping the plate assembly with a laparoscopic grasper at 45° to his body. Note the standard position of the instrument handle at elbow height for comfort.

Construction of the grasping/spreading plates and the operating environment

Grasping forces were measured by an assembly of two closely spaced copper plates separated by a nonconductive wafer and held together by an off-center spring mechanism. The grasping force for each task was changed from low to high by rotating the plate assembly 180° on its axis, thus changing the point on the perimeter where the instrument actuated the plates from nearest to farthest from the off-center spring. (The high force level was set during a pilot study by adjusting the spring tension to accommodate the lowest of the maximum grasping forces among the three instruments studied.) A simple electrical circuit permitted the initial contact by the instrument jaw with the upper plate to provide a 1.5-V timing signal to the EMG acquisition software via a dedicated timing channel. When the plates closed by the action of the grasping instrument, the input voltage was short-circuited across the plates and the timing signal returned to zero. Thus a quasi–square wave input timing signal was obtained during each task that exactly bracketed the time when the subject was closing the plates and allowed us to exclude from the analysis any ''overshoot'' forces applied after plate closure. The grasping plate assembly was placed on a variable-height table in front of the surgeon and could be rotated 0°, 45°, and 90° away from the surgeon (Figs. 1, 2).

EMG recording and data reduction

The surface EMG signals from six muscles in the right hand and forearm (flexor carpi ulnaris [FCU], flexor digitorum profundus [FDP], flexor digitorum superficialis [FDS], extensor carpi ulnaris [ECU], extensor digitorum comunis [EDC], and thumb [TH]) were simultaneously recorded via shielded bipolar electrodes placed 0.5 cm apart over the individual muscle bellies according published recommendations [4]. The maximum voluntary contraction (MVC) from each muscle was obtained by contracting the muscle against fixed resistance three times and the average was used for normalizing individual EMG data. The raw EMG and timing signals were sampled digitally at 508.13 Hz using MS-DOS DATAPAC II Ver. 4.0 software and stored on a hard disk. The software used the timing signal to eliminate all EMG data not occurring within the grasping interval. From the digitized raw EMG signal from each grasping motion the peak root mean square (RMS) amplitude was extracted to measure the maximum muscle contraction during a particular grasping task repetition. The data was transferred to a spreadsheet where the five repetitions for each task were averaged and the data was expressed as a percent of MVC for each muscle.

Statistical analysis

The final data was transferred to STATISTICA software for statistical analysis. A three-way repeated measures ANOVA was performed for each muscle to evaluate the effect of instrument type, wrist angle, and force on muscle contraction. Tukey's Honest Significant Different test was used for specific post hoc comparisons and a $p < 0.05$ was chosen to indicate statistical significance.

Results

Linear regression analysis of the dynamometer squeezing revealed a linear relationship between peak EMG RMS voltage and muscle force ($0.8 < r < 0.98$) in all muscles. The three-way analyses of instrument type, wrist angle, and grasping force for each muscle studied are demonstrated in Fig. 3. In all cases there was a statistically significant interaction between instrument type and grasping force such that only laparoscopic instruments exhibited a significant

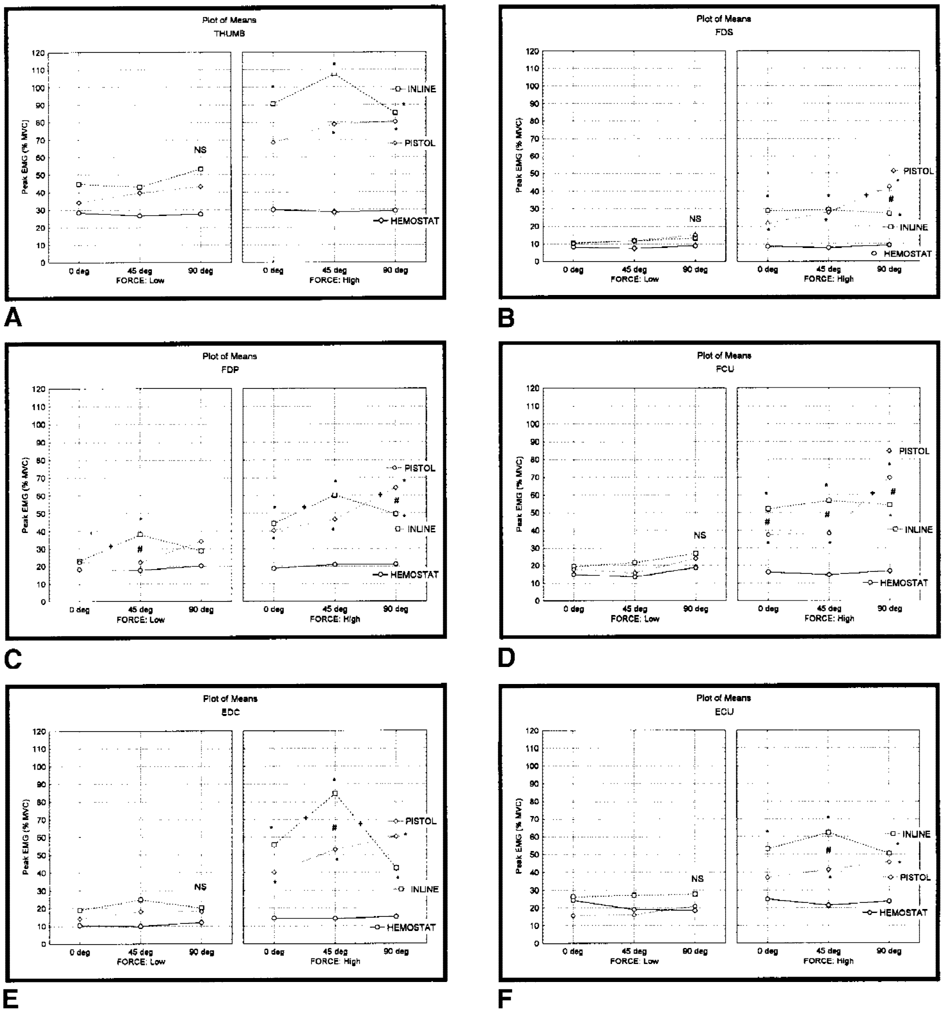

Fig. 3. Normalized (% of maximum voluntary contraction) peak root mean square electromyographic voltages for **A** thumb, **B** flexor digitorum superficialis (FDS), **C** flexor digitorum profundus (FDP), **D** flexor carpi ulnaris (FCU), **E** extensor digitorum comunis (EDC), and **F** extensor carpi ulnaris (ECU). Each data point represents the average of nine surgeon-subjects performing a standardized grasping task at low (0.7 N) and high (4.2 N) forces and at 0°, 45°, and 90° to his/her body. *$p < 0.05$ vs hemostat, #$p < 0.05$ in-line vs pistol, †$p < 0.05$ single instrument angle n vs angle $n-1$.

increase in EMG amplitude between low force (no difference between instruments except for FDP at 45°) and high force (significant differences between laparoscopic and open instruments under all conditions). Three-way statistically significant interactions between instrument type, grasping force, *and* wrist angle occurred in FDS, FCU, and EDC and indicated that there was a significant change in EMG amplitude in these muscles between 45° and 90° wrist flexion with the in-line handle becoming lower than the pistol-grip handle. Similarly, a two-way interaction between instrument type and wrist angle in FDP also demonstrated a lower EMG amplitude for the in-line handle vs the pistol-grip handle at 90° wrist flexion. In all cases where wrist angle caused a significant interaction, the data demonstrated a similar pattern reflecting a decrease in EMG amplitude with the in-line handle between 45° and 90°, while the pistol grip demonstrated no change or and increase in EMG amplitude between these angles.

It is important to note that the in-line handle also demonstrated a higher EMG amplitude at 0° in FCU and at 45° in FCU, ECU, and EDC compared to the pistol grip. The EMG amplitude of the thumb appeared to be unaffected by wrist angle.

Discussion

Ergonomic research has been applied to workplace and tool design in industry, the office, and the dental workplace with the goals of reducing musculoskeletal injury and increasing work efficiency and comfort [5, 16, 17]. Recent publications [2, 3, 15] and letters [9, 11] indicate that there are substantial biomechanical and cognitive obstacles to overcome in video-endoscopic surgery and that the application of standard ergonomic analyses to this surgical activity may be of benefit. Surface EMG has been used to study upper-extremity muscle activity during typing [5], carpentry work [6], welding [8], and upper-extremity rehabilitation [12, 13]. Our control studies confirm that the relationship between the normalized RMS voltage and the force generated by a contracting muscle is linear when the exerted forces remain below 80% of MVC [1], thus allowing EMG signals to be used as an indirect measure of muscle contraction.

The first important fact demonstrated by the present study is that laparoscopic graspers require the surgeon to exert substantially higher muscle forces than open instruments to accomplish the same task. This force appears to increase dramatically when the surgeon is working at 90° to him/herself (with the wrist substantially flexed). The overall difference in performance between open and laparoscopic instruments is due to differences in the efficiency of force transmission from handle to tip. In laparoscopic instruments, the handle-force-to-tip-force ratio is significantly inferior to open instruments [18; Gerber, S and Berguer, R. Unpublished data].

The effect of wrist angle on grasping force is more complex. Our results demonstrate that the in-line handle requires equal or greater muscle force than the pistol grip handle at 0° and 45°. In contrast, at 90° we see a significant advantage with the inline handle, permitting the surgeon to rotate the wrist back toward him/herself and significantly decrease the flexor muscle strain. It is important the note that we studied the laparoscopic grasper manufactured by Microsurge because the same instrument can be used with the handle either in a pistol or in-line configuration. With the handle in the in-line configuration, the instrument can be rotated back toward the surgeon when working near 90° perpendicular to the body, thus avoiding the extreme flexion and ulnar deviation of the wrist seen with the pistol grip. Extrapolating from our data, we believe that if the in-line handle is used at 90° *without* backward rotation of the wrist, it would likely result in higher muscle contractions than the pistol grip. Our results are consistent with published biomechanical studies demonstrating that ulnar deviation and flexion of the wrist decrease maximum grip force [7]. Another explanation is that the handle configuration of laparoscopic instruments requires the operator to use the opposing muscles of the thenar and hypothenar compartments for gripping, rather than the more powerful grasping grip that uses the deep forearm flexors [10, 14]. It is likely that both of these factors contribute to the need for increased muscle contraction when using a laparoscopic instrument. In studying the influence of handle design in laparoscopic instruments, we conclude that the inline configuration does not appear to confer any advantages except at extreme working angles with rotation of the surgeon's wrist back toward him/herself.

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Discussion

Dr. Forde: Do you know to what extent industry utilizes any studies or information of this sort in the design of instruments?

Dr. Berguer: I'm not aware that they do use information of this sort in the design of instruments, but the closed nature of corporate America doesn't allow me to make a final statement on that.