Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.JournalofSurgicalResearch.com

Association for Academic Surgery

Design of vessel ligation simulator for deliberate practice

Justin L. Hsu, BS,[a] *James R. Korndorffer Jr., MD,*[b] *and Kimberly M. Brown, MD*[a,*]

[a] *Department of Surgery, University of Texas Medical Branch, Galveston, Texas*
[b] *Department of Surgery, Tulane University School of Medicine, New Orleans, Los Angeles*

ARTICLE INFO

Article history:
Received 3 January 2015
Received in revised form
16 February 2015
Accepted 27 February 2015
Available online 6 March 2015

Keywords:
Vessel ligation
Knot-tying
Surgical education
Surgical simulation
Surgical skills assessment
Force sensor

ABSTRACT

Background: Surgical residents develop technical skills at variable rates, often based on random chance of cases encountered. One such skill is tying secure knots without exerting excessive force. This study describes the design of a simulator using a force sensor to measure instantaneous forces exerted on a blood vessel analog during vessel ligation and the development of expert-derived performance goals.

Materials and methods: Vessel ligations were performed on Silastic tubing at an offset from a Vernier Force Sensor. Nine experts (surgical faculty and senior residents) and 10 novices (junior residents) were recruited to each perform 10 vessel ligations (two square knots each) with two-handed and one-handed techniques. Internal consistency for the series of vessel ligations was tested with Cronbach alpha. Maximum forces exerted by novices and experts were compared using Student *t*-test.

Results: Internal consistency across the 10 ligations on the simulator was excellent (Cronbach alpha = 0.91). The expert group on average exerted a significantly lower maximum force when compared with novices while performing two-handed (0.76 ± 0.39 N *versus* 1.12 ± 0.49 N, $P < 0.01$) and one-handed (0.84 ± 0.32 N *versus* 1.36 ± 0.44 N, $P < 0.01$) vessel ligations.

Conclusions: Although the expert group performed vessel ligations with significantly lower peak force than the novice group, there were novices who performed at the expert level. This is consistent with the conceptual framework of milestones and suggests that the skill of gentle knot-tying can be measured and develops at different chronologic levels of training in different individuals. This simulator can be used as part of a deliberate practice curriculum with instantaneous visual feedback.

1. Introduction

Surgical knot-tying is a complex skill requiring precise and delicate motions, which includes the awareness of the force being exerted on fragile tissues. Several studies have reported the necessity of recognizing this force in robotic and laparoscopic surgeries, where the tactile and haptic feedback can be absent or distorted [1–4]. Accordingly, teaching residents to acquire these implicit motor skills before stressful encounters during open surgery may prevent unnecessary complications

* *Corresponding author.* Department of Surgery, University of Texas Medical Branch, 301 University Blvd, Galveston, TX 77555 0737. Tel.: +1 409 772 1846; fax: +1 409 747 2253.
E-mail address: kim.brown@utmb.edu (K.M. Brown).
0022-4804/$ – see front matter
http://dx.doi.org/10.1016/j.jss.2015.02.068

[5,6]. There are fewer opportunities for residents to learn and practice this skill in the clinical environment because of increased use of laparoscopy and energy devices. This study focuses on building a vessel ligation simulator designed to reproduce an open-surgery environment for the development of performance metrics and deliberate practice of surgical residents.

Most surgical residents typically train via the "see one, do one, teach one" skills development model, which can result in variable levels of skills acquisition [7–9]. Although proficiency-based laboratory training and deliberate practice have proven effective in supplementing resident training and increasing skill retention, there are no widely used methods to provide immediate feedback on force exerted as part of deliberate practice toward proficiency [10,11]. The force exerted during knot-tying as an assessment tool can also potentially benefit preexisting skills evaluations. The most commonly cited evaluation method of surgical skills, the Objective Structured Assessment of Technical Skills, although highly reliable, is limited by cost, faculty availability, and administrative challenges [12–14]. Other evaluation methods using hand motion analysis, knot-tying speed, and final knot analysis produced promising results in discriminating experts and novices but are limited by the lack of real-time feedback for deliberate practice and lack of ability to quantify the force exerted [13–16].

The purpose of this study was to establish a reliable measurement of safe, proficient knot-tying in a simulated model of open vessel ligation and to develop performance metrics for skills training. The first objective consists of the development of a low-cost vessel ligation simulator capable of measuring the force exerted during ligations while also offering training capability. The second objective consists of the study on the differences between the force exerted by experts and novices during vessel ligations with the development of expert-derived performance goals for deliberate practice.

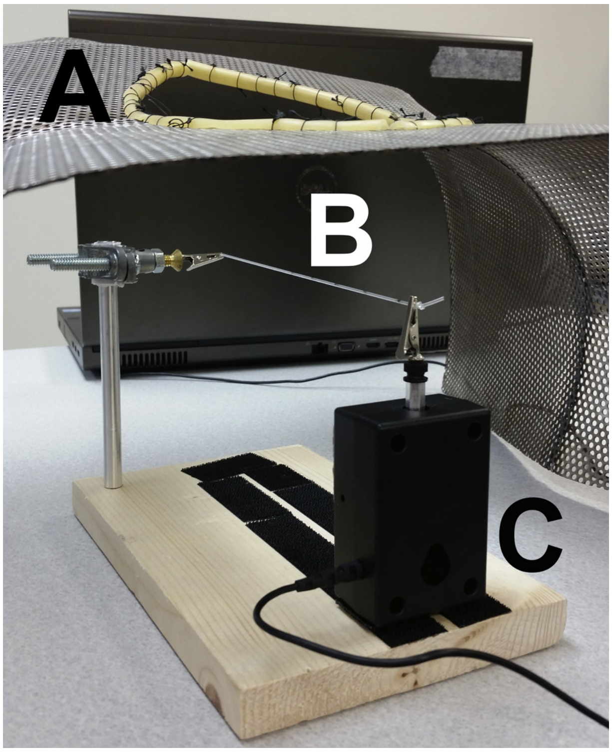

Fig. 1 – Picture of vessel ligation simulator prototype. "A" is situated next to the stainless steel abdomen opening wrapped with a layer of rubber tubing. "B" indicates the Silastic tubing where vessel ligations were performed. "C" is the vertically mounted force sensor, which was moved via Velcro attachment toward the fixed anchor after each successive vessel ligation. (Color version of the figure is available online.)

2. Methods

The simulator was constructed with a replaceable Silastic tubing vessel analog (0.025 inch I.D. × 0.047 O.D., Dow Corning, Midland, MI) suspended horizontally at a fixed height inside a stainless steel abdomen model that simulated tying deep inside the abdomen with limited access (Fig. 1).One end of the tubing was clamped to a vertically mounted Dual-Range Force Sensor (Vernier Software & Technology, Beaverton, OR), whereas the other end was attached, without tension, at a fixed anchor. Vessel ligations were performed on the tubing by tying two square knots with 3-0 Silk sutures <0.5 cm from a marked sensor location, while participants wore their usual surgical gloves. 3-0 Silk sutures were chosen based on the actual task of ligating a vessel of similar diameter and its low elasticity, which maximized force transition to the vessel analog. The ligation created in close proximity to the sensor clamp mimicked a vessel ligation next to a vascular clamp. The sensor itself was shifted down the tubing 1 cm at a time to accommodate successive vessel ligations on the same tubing. This method allowed for a low-cost, high throughput capability for translating into repetitive training session as one segment of tubing allowed for at least 10 vessel ligations.

Since the ligation locations on the tubing were at an offset (<1 cm) from the force sensor, the data collected would naturally be reduced depending on the offset distance from the sensor attachment. Therefore, a spring scale was used to produce a known amount of force (1 and 2 N) at progressively higher offsets (0, 2, 4, 6, and 8 mm) to study the relation between offset distance and force reduction. The study data were then normalized by compensating with the interpolated offset-force relationship.

To prevent participants from tying loose and inferior ligations to achieve softer force readings, knot integrity was evaluated by measuring ligated vessel diameter with a digital caliper. The measurement was made only to encompass the loop of suture around the tubing while avoiding the bulk of the square knot itself. Because the diameter of a vessel ligation on an artificial vessel was different than on a biological vessel depending on elasticity, suture thickness, and initial vessel diameter, this threshold for "tight" ligation was determined by a water patency test with a digital caliper to allow more objectivity over plain visual inspection. Random vessel ligations were tied by faculty on segments of Silastic tubing to create a wide selection of vessel ligations tightness. A 1-mL needle syringe was used to inject water freely