The American Journal of Surgery (2016) 211, 411-415

The American Journal of Surgery®

Association for Surgical Education

Force feedback vessel ligation simulator in knot-tying proficiency training

Justin L. Hsu, B.S.[a], James R. Korndorffer, Jr, M.D., M.H.P.E., F.A.C.S.[b], Kimberly M. Brown, M.D., F.A.C.S.[a,*]

[a]*Department of Surgery, University of Texas Medical Branch, 301 University Blvd, Galveston, TX 77555-0737, USA;* [b]*Department of Surgery, Tulane University School of Medicine, Tulane University, New Orleans, LA, USA*

KEYWORDS:
Vessel ligation;
Simulation;
Surgical training;
Knot-tying;
Force feedback;
Curriculum

Abstract

BACKGROUND: Tying gentle secure knots is an important skill. We have developed a force feedback simulator that measures force exerted during knot tying. This pilot study examines the benefits of this simulator in a deliberate practice curriculum.

METHODS: The simulator consists of silastic tubing with a force sensor. Knot quality was assessed using digital caliper measurement. Participants performed 10 vessel ligations as a pretest, then were shown force readings and tied knots until reaching proficiency targets. Average peak forces precurriculum and postcurriculum were compared using Student *t* test.

RESULTS: Participants exerted significantly less force after completing the curriculum (.61 N ± .22 vs 1.42 N ± .53, $P < .001$), and had fewer air knots (10% vs 27%). The curriculum was completed in an average of 19.4 ± 6.27 minutes and required an average of 11.7 ± 4.03 knots to reach proficiency.

CONCLUSIONS: This study demonstrates the feasibility of real-time feedback in learning to tie delicate knots. The curriculum can be completed in a reasonable amount of time, and may also work as a warm-up exercise before a surgical case.

Tying secure knots in open surgery is an important skill, particularly in high-stakes contexts such as deep in the abdomen or retroperitoneum, where rough tissue handling or insecure knots can result in bleeding that may be difficult to control. The skill of tying delicate knots is developed over the course of a resident's training, and opportunities to practice this skill have become fewer, due to increasing use of minimally invasive approaches, and widespread use of energy devices.

Learning the mechanics of knot tying is well suited to simulation-based training (SBT), and several curricula have been developed and studied for effectiveness in teaching students and residents how to tie surgical knots.[1–3] Assessment tools include measures of time, knot integrity, hand motion efficiency, and checklist or global ratings. SBT has also been leveraged for improving or refining the basic skill of knot tying.[4–7]

Tying delicate knots requires proficiency in the fundamentals of forming and cinching down a surgical knot, as well as the ability to gauge the strength of the tissues and suture material, to avoid avulsing the tissue being ligated or breaking the suture. In the clinical context, this skill

The authors declare no conflicts of interest.

* Corresponding author. Tel.: +1-409-772-1846; fax: +1-409-747-2253.

E-mail address: kim.brown@utmb.edu

Manuscript received June 11, 2015; revised manuscript August 11, 2015

0002-9610/$ - see front matter © 2016 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.amjsurg.2015.09.009

is learned through "trial and error," with the feedback consisting of either causing bleeding or breaking the suture. Using a simulator that records force exerted on a vessel analog during suture ligation, we demonstrated that we can accurately and reliably provide immediate visual feedback to a trainee on the amount of force exerted and at which point in the knot formation the peak force occurred.[8]

The purpose of this study is to examine the use of our force feedback simulator in the context of a deliberate practice curriculum. We hypothesize that trainees given immediate feedback on their force exertion will reach proficiency using our curriculum in a single session.

Participants and Methods

Study participants

This study was approved by the University of Texas Medical Branch Institutional Review Board. Study participants were volunteers recruited from the 4th year medical school class and 1st and 2nd year general surgery categorical resident classes using institutional review board approved fliers. Medical student participants were required to demonstrate proficiency at 2-handed knot tying using the University of Texas Southwestern Open Surgical Skills Curriculum before enrollment. Nine 4th year medical students comprised our study cohort.

Vessel ligation simulator with force feedback

We have constructed and previously described a vessel ligation simulator representing the surgical task of ligating a vessel or tissue in the deep abdomen or retroperitoneum.[8] The vertically oriented force sensor records and displays force exerted during knot tying along the vertical axis, capturing the "pulling up" or "cinching down" that occurs when tying knots in that context (Fig. 1). Based on experienced faculty who perform open general or vascular surgery, we identified .6 N as the maximum peak force exerted when an expert ties a series of consecutive vessel ligations on the simulator.

Assessment of knot integrity

Knot integrity was assessed by measuring the diameter of the ligated silastic tubing vessel analog. Based on prior published work, knots with a diameter greater than 1.15 mm allowed water to pass through the silastic tubing; thus, 1.15 mm is the upper limit of a secure knot in this model, and any knot greater than this diameter was considered an "air knot."[8]

Precurriculum assessment

Participants performed a consecutive series of 10 simulated vessel ligations, consisting of 2 square knots, 4 throws, for each ligation, using 3-0 silk suture material and wearing appropriately sized surgical gloves. The absolute peak force was recorded for each ligation. Each knot was assessed, and the number of "air knots" was recorded.

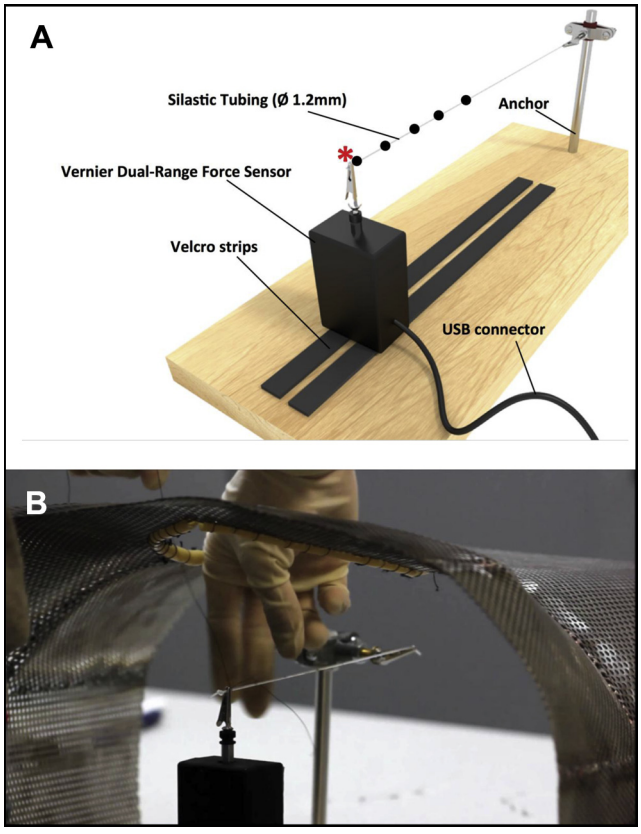

Figure 1 (A) Design of force feedback simulator. Asterisk marks the site of vessel ligation. Black dots indicate the sites of subsequent vessel ligations; sensor is mounted on Vel-cro, and is moved to the next black dot, toward the anchor, with each ligation, so that ligations are always done within 4 mm of the sensor. (B) Picture of the simulator within chassis, during vessel ligation.

Curriculum

After the pretest, participants were instructed to tie consecutive vessel ligations, which again consisted of 4 throws, 2 square knots each. During the curriculum, the force feedback display indicating real-time force readout and a maximum force indicator of .6 N was made available to the participant. Successful completion of the curriculum was defined as the participant completing 3 consecutive ligations with absolute peak force of less than .6 N, and no air knots, assessed after each ligation. The number of ligations performed and the time required to reach proficiency were recorded for each participant.

Postcurriculum assessment

After completing the curriculum, each participant repeated the 10 ligation assessment, during which the