Visual Force Feedback Improves Knot-Tying Security

Tim Horeman, MSc,*,† Mathijs D. Blikkendaal, MSc,† Daisy Feng, MSc,†
Arjan van Dijke, BSc,* FrankWillem Jansen, PhD,*,† Jenny Dankelman, PhD,*
and John J. van den Dobbelsteen, PhD*

*Department of BioMechanical Engineering, Technical University Delft, Delft, The Netherlands; and
†Department of Gynaecology, Leiden University Medical Centre, Leiden, The Netherlands

BACKGROUND: Residents in surgical specialties suture multiple wounds in their daily routine and are expected to be able to perform simple sutures without supervision of experienced surgeons. To learn basic suture skills such as needle insertion and knot tying, applying an appropriate magnitude of force in the desired direction is essential. To investigate if training with real-time visual force feedback improves the suture skills of novices, a study was conducted using a training platform that measures all forces exerted on a skin pad, i.e., the ForceTRAP.

METHOD: Two groups of novices were trained on this training platform during a suture task. One group (nov-c) received no visual force feedback during training, whereas the test group (nov-t) trained with visual feedback. The posttest and follow-up test were performed without visual force feedback.

RESULTS: A significant difference in reaction force, (nov-c: mean 2.47 N standard deviation [SD] ± 0.62, nov-t: mean 1.79 N SD ± 0.37), suture strength (nov-c: median 25 N interquartile range (IQR) 15, nov-t: median 50 N interquartile range 25), and task time (nov-c: mean 109 s SD ± 22, nov-t: mean 134 s SD ± 31) was found between the control and training group of the posttest.

CONCLUSION: Participants that are trained with visual force feedback produce the most secure knots in the posttest and their suturing results in lower applied forces. Therefore, the results of this study indicate that visual force feedback supports students while learning to insert the needle smoothly, to effectively align the suture threads and to balance the force between instruments during knot tying. However, for long-term learning effects, probably more than 1 training session is required. (J Surg 71:133-141. © 2014 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: medical education, interrupted sutures, visual force feedback, training

COMPETENCIES: Practice-Based Learning and Improvement, Medical Knowledge

INTRODUCTION

Suturing is one of the most common methods for wound closure, and surgeons suture multiple wounds in their daily routine. Suturing of superficial and deep skin lacerations is considered as one of the most important procedural skills that all surgical residents ought to possess at the start of their medical career.[1] After graduation, doctors are expected to be able to perform simple sutures without supervision of experts.[2] However, because of the lack of opportunities to practice while in their medical education program, most residents acquire these basic surgical skills when starting to treat patients in practice.

Courses dedicated to practising surgical skills would help novices to gain surgical experience before their first contact before they treat patients in practice. Such courses will increase confidence, improve performance, and reduce the number of beginner's errors.[3] When a suture fails to perform its function, the consequences may be disastrous.[4-6] A bleeding may occur when the suture loop that surrounds a vessel is disrupted. When a suture in an abdominal wound unties or breaks, wound dehiscence and even evisceration may follow.[7] Because of the importance of setting knots of good quality, there is a continuing need to improve techniques to teach basic suture skills.[8] The most important criteria for proper wound closure are known: proficiency in speed, precision of hand movements, and the firmness of the body of the suture.[9]

In a suture, tightness of the loop of the thread determines the pressure on the tissue nearby the wound, and therefore the blood supply and drainage of the wound area. As a

Correspondence: Inquiries to Tim Horeman, MSc, Faculty of Mechanical, Maritime and Materials Engineering (3mE), Department of BioMechanical Engineering, Technical University Delft, Mekelweg 2, 2628 CD Delft, The Netherlands; e-mail: t.horeman@tudelft.nl

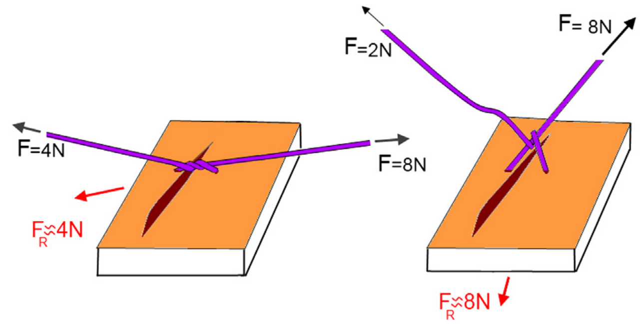

FIGURE 1. Two commonly seen errors at the start of a surgical knot. Left: poor balance of 8 N to 4 N = 4 N causes a reaction force inside the tissue of 4 N. Right: poor force imbalance in combination with bad thread alignment increases the reaction force even further creating a perfect scenario for dangerous knots.

result, the healing process of the wound is related to the suture itself.[10] A good suture is not too tight to prevent infections and necrosis and not too loose to be unable to press the wound edges together. Furthermore it will not unravel during the recovery of the wound by natural skin movements or accidental manipulation.

Force Balance and Thread Alignment

During needle insertion it is important that the curvature of the needle is followed. A well-controlled force in line with the tip of the needle should push the needle with minimal damage through the tissue. Inadequate needle insertion can result in excessive reaction forces that damage tissue from the inside. Reaction forces during knot tensioning occur owing to poor alignment of the threads or a force imbalance between instrument tips while tightening. If the force on the threads during knot tying is not in balance, a reaction force (FR) is generated in the tissue that can result in tissue damage (Fig. 1 [left]). A force imbalance between threads in combination with poor thread alignment indicates that a knot is not properly tensioned increasing the risk on dangerous and weak knots (Fig. 1 [right]). For proposed suture errors, a reaction force (FR) is generated in the tissue that can be measured by a force sensor. During needle insertion, a low reaction force is always present. In an ideal knot-tying scenario, the measured reaction force remains zero.

ForceTRAP With Visual Force Feedback

An increasing number of studies suggest that training with real-time visual feedback of instrument motion in virtual-reality and augmented-reality simulators has a positive effect on learning.[11,12] Moreover, a prior study in laparoscopic needle insertion showed that novices that were trained with augmented-reality feedback of the tissue manipulation force applied less force compared with the control group that received no visual feedback.[13] As a follow-up to this study, we developed a force sensor, the ForceTRAP, that incorporates colored LEDs to signal any imbalance in the forces exerted during tissue manipulation tasks.

In the current study, the ForceTRAP is used to provide feedback on 3 important suture errors that cause high reaction forces in (artificial) tissue. During needle insertion, the student is warned for high forces due to inefficient needle insertion with orange and red lights. During knot tying, the orange or red light warns for a force imbalance between the 2 tensioned threads or for poor alignment of the 2 tensioned threads.

The current study investigates the added value of real-time visual force feedback on suturing. The main research question is whether training with real-time visual force feedback improves the suture skills of novices.

MATERIALS AND METHODS

Hardware

The ForceTRAP is based on a previously developed force platform that was validated in 2 studies on intracorporal suturing in a box trainer.[14,15] In these studies, a force platform was used to validate the suture task with force parameters. The ForceTRAP uses distance sensors and a microcontroller to determine the deformations of 3 orthogonally placed parallelograms. Figure 2 displays such a parallelogram mechanism, which consists of 2 stiff bars and 2 spring blades. To measure deformation of the spring blades in a parallelogram mechanism, hall sensors (hall effect sensor linear, SS495A, HONEYWELL S&C) and magnets were used. If a parallelogram deforms, the spring blades bend which results in a change in distance between hall sensor and magnet. After calibration, the force applied on the parallelogram mechanism can be estimated from the sensor output. The microcontroller uses the sensor output to compute the absolute reaction force and to provide color feedback via

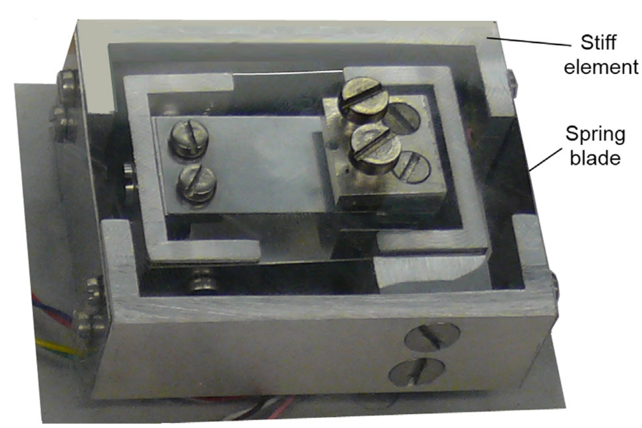

FIGURE 2. Picture of the 3D-force sensing unit of ForceTRAP. Three orthogonal-orientated sets of parallelogram mechanisms built from spring blades and stiff bars measure the force in X, Y, and Z direction.