Force and torque feedback in endoscopic vessel harvesting

Julia Wiercigroch[1], Keyvan Hashtrudi-Zaad[2], Tamas Ungi[1], Gianluigi Bisleri[3], Gabor Fichtinger[1]

1. Laboratory for Percutaneous Surgery, Queen’s University, Kingston, Canada
2. Department of Electrical and Computer Engineering, Queen’s University, Kingston, Canada
3. Department of Surgery, Division of Cardiac Surgery, Queen’s University, Kingston, Canada

ABSTRACT

PURPOSE: Endoscopic vessel harvesting is the preferred minimally invasive approach to obtain grafts for coronary bypass surgeries, however it requires extensive practice to minimize vessel damage. We propose to create a surgical training simulation with visual and haptic feedback. In this study, we focus on analyzing the force and torque peaks on the surgical retractor during the procedure.

METHODS: The original retractor handle was 3D scanned and modified to attach an ATI Mini40 force-torque transducer. The forces and torques in two radial artery and two saphenous vein procedures in human cadavers were recorded. The measurements, endoscopic video and surgical surface video were collected. The median and interquartile range of the force and torque peaks were calculated for the artery and vein harvesting procedures.

RESULTS: The median and interquartile range for saphenous vein harvests was larger than radial artery harvests. The largest median force and torque generated in the vein was 11.654 N [posterior] and 0.661 Nm [- frontal], whereas in the artery was 6.163 N [anterior] and 0.381 Nm [+ frontal], respectively.

CONCLUSION: The distribution of force and torque peaks in the retractor was found for endoscopic vessel harvests. This data can be used to design a haptic user interface, and to establish expert benchmarks for learning curve evaluation.

KEYWORDS: Endoscopic vessel harvesting, force-torque analysis

1. PURPOSE

Patients with severe coronary heart disease undergo cardiac artery bypass grafting (CABG) to improve blood flow to the heart muscles. A healthy blood vessel is harvested from the leg or arm and is used to redirect blood around a blocked or partially blocked artery in the heart. CABG is the most common cardiac surgery performed worldwide. There were 200,000 isolated annual cases of CABG in the US [1] and the average incidence rate in western European countries is 62 per 100,000 inhabitants [2]. For a successful CABG, the surgeons must construct quality anastomoses with durable conduits, conventionally using the radial artery or great saphenous vein [3]. However, a significant number of patients suffer early graft failure after CABG. In a previous study, it was found that in the overall population, there was a 25.0 ± 0.2% chance of early graft failure for the radial artery, and 55.0 ± 0.2% chance for the saphenous vein 20 years after the procedure [4].

Vessels are conventionally harvested in a highly invasive open surgery that inflicts lasting damage to the surrounding tissue. Endoscopic vessel harvesting is a newer, minimally invasive approach that has become the preferred method to harvest grafts for CABG [5]. During this approach, a surgical retractor, sealer and endoscope are inserted through a small incision on the arm or leg. Using the video supplied by the endoscope, the surgeon must coordinate the tools underneath the skin to separate the graft from surrounding tissues and branching vessels. This technique is preferred instead of the open technique due to reduced wound complications, better cosmetic appearance and increased patient satisfaction [6].

Graft failure is dependent on operator’s experience and confidence in the harvesting technique. Endoscopic vessel harvesting is associated with a learning curve period, during which the probability of vessel damage is high [7]. Application of unnecessary forces and torques on the surgical retractor can lead to increased vessel stress, leading to early graft failure or making the graft unusable in CABG. Endoscopic training opportunities vary from hospital to hospital and are typically performed on human cadavers or phantom models resembling the leg or arm. Inconsistent training methods can lead to poor surgical technique, increased surgeon anxiety and decreased vessel quality.

Computer-assisted training facilitates skill acquisition by providing continuous quantitative feedback during deliberate and focused practice [8]. Virtual reality simulators for laparoscopic surgeries have been shown to improve the surgical performance on real patients [9]. However, in endoscopic vessel harvesting, considerable forces and torques must be applied to the retractor to lift the tissue away from the graft. Pure virtual simulators would not provide a comprehensive training experience for novice trainees, who must learn to apply adequate forces and torques to minimize graft stress and tissue damage. It is particularly important to combine haptic feedback with visual training simulators during the early phase of skill acquisition [10].

We propose to create a simulation system with visual and haptic feedback to train surgeons in the endoscopic vessel harvesting approach for both the radial artery (ERAH) and the saphenous vein (EVH). Trainees would receive visual feedback from the endoscope and would feel resistance on the surgical retractor as they practice the endoscopic technique.

In this paper, we focus on the physical aspect of the training simulator, measuring the force and torque peaks on the surgical retractor during a cadaver lab. By measuring the magnitude of forces and torques generated, a haptic device can be chosen or designed to replicate the surgical procedure. Furthermore, the distribution and amplitude of peaks can be used as a metric to compare the performance of novice trainees to experts. Novices are known to exert excessive forces when learning new medical procedures, while experts perform more efficient motions during the same procedure [7].

2. METHODS

2.1 Modification and Instrumentation of the Surgical Retractor

An ATI Mini40 force-torque (FT) transducer with SI-20-1 metric calibration was selected to measure the forces and torques throughout the endoscopic vessel harvesting procedures. The maximum sensed values were expected to stay within the sensing ranges and below the single-axis overload parameters (www.ati-ia.com).

The handle and metal blade from the surgical retractor were separated. A CAD model of the surgical retractor handle was created by scanning the tool using the Artec Eva 3D scanner (https://www.artec3d.com). Two adapter models were created to mount the FT sensor to the blade and the handle (Figure 1). The overall height of the handle was shortened to account for the height added by the sensor and additional mounting adapters. To reduce the compliance of the 3D printed handle and adapters, the infill was set to 40%.

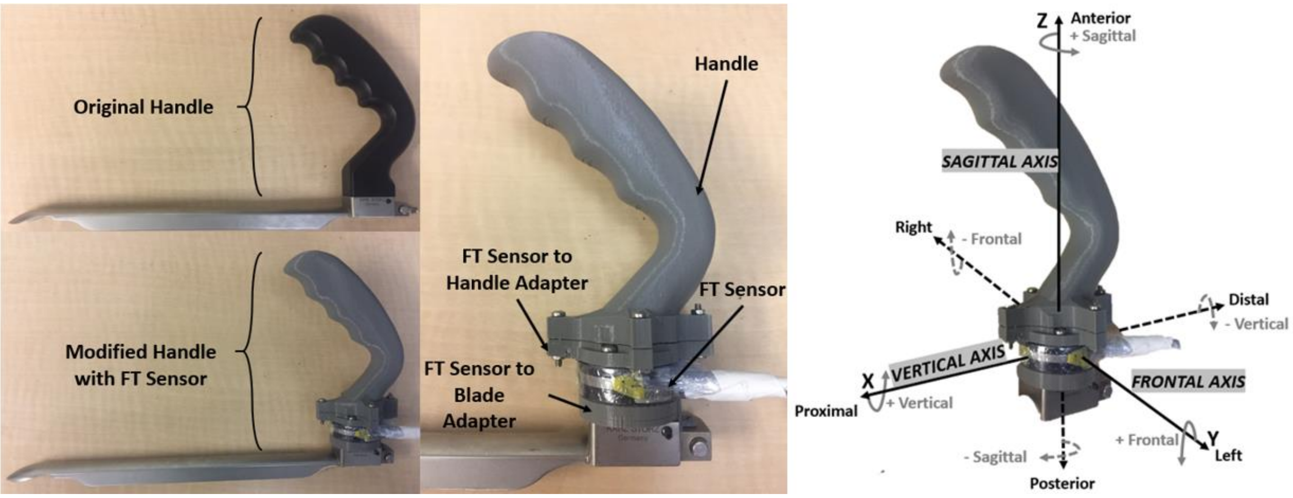


Figure 1. *Left:* Original and modified handle comparison
Center: Labeled 3D printed modifications and FT sensor
Right: Labeled directions for forces and torques (solid = positive, dotted = negative)

2.2 Cadaver Data Collection Set Up

The data acquisition system (DAQ) consisted of the data acquisition card (NI PCI-6034E), DAQ FT interface and power supply and the FT transducer. A MATLAB and Simulink program with the QUARC^{TM} extension (www.quanser.com) was created to communicate with the transducer in real-time and record the forces and torques acting on the device. To remove sensor bias, a QUARC^{TM} bias removal block was used for the first two seconds of the simulation. Data was sampled at 200 Hz and was passed through default Simulink lowpass and moving average filter blocks with bandwidths 8 Hz and 23 Hz, respectively. The resulting forces and torques were displayed in real-time.

2.3 Human Cadaver Study

The surgeon performed the endoscopic harvesting approach for all four vessels harvested. The FT sensor was covered for sanitation purposes throughout the study. Once the surgical retractor was required, the surgeon used the modified retractor with the FT sensor. Force and torque measurements, surgical surface video and endoscopic video were recorded until the surgeon completed the endoscopic harvest (Figure 2). The surgical surface video recorded the surgeon's hands throughout the procedure whereas the endoscope displayed the positioning of the tool tip under the skin.

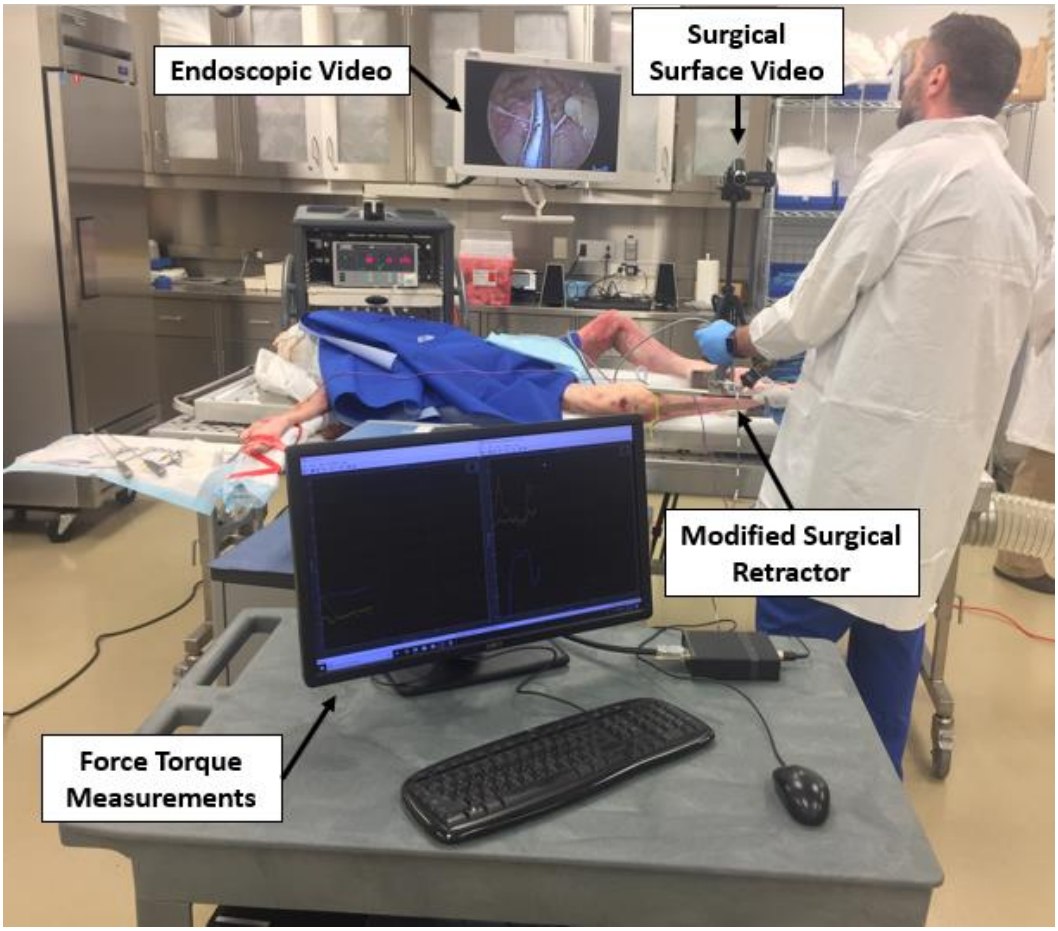


Figure 2. Surgeon completing an endoscopic saphenous vein harvest using the modified surgical retractor with endoscopic video, surgical surface video and FT measurements.

Queen's University Human Body Donor Program
Anatomy Learning Center
Department of Biomedical and Molecular Science

Peak forces and torques from the radial artery harvests were analysed separately from the great saphenous vein harvests. Peaks meeting the time separation and minimum prominence criteria were classified as surgical actions. Through observation of the surgical surface video, it was determined that deliberate procedural actions were separated by approximately 2.5 seconds. The minimum prominence was selected by doubling the average total force or torque experienced in a specified direction during the procedure. Positive and negative directions were treated separately. The minimum, maximum, median and interquartile range (IQR) of the force and torque peaks was calculated and presented using a box-and-whisker plot. Results are presented as median (IQR) [direction].

3. RESULTS

The largest median force and torque generated in EVH was 11.654 (18.158) N [posterior] and 0.661 (0.764) Nm [-frontal]. This was greater than the largest median forces and torques generated in ERAH, which were 6.163 (7.310) N anterior] and 0.381 (0.412) Nm [+ frontal], respectively (Figure 3).

.

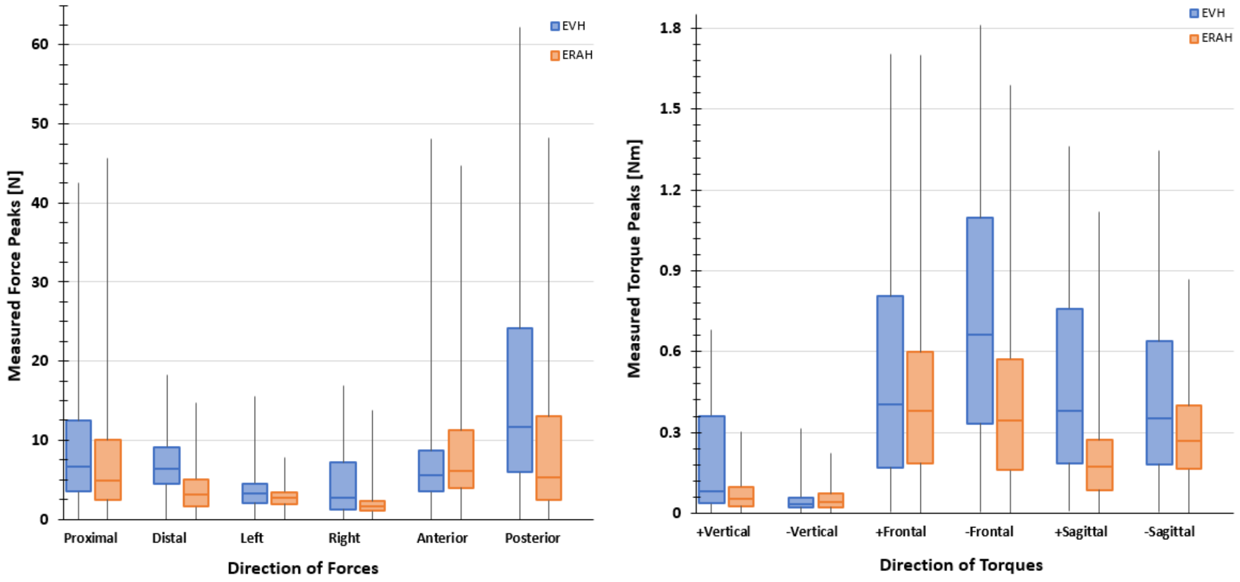
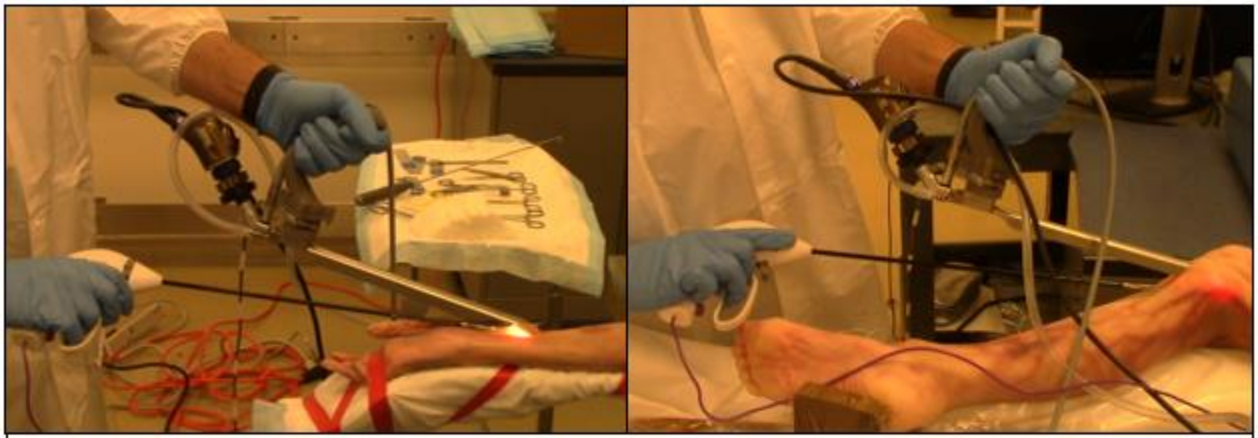


Figure 3. Box-and-whisker plot comparison of measured force *(right)* and torque *(left)* peaks in the EVH and ERAH procedures

4. DISCUSSION

A surgical retractor was modified and equipped with a transducer to collect force-torque measurements during non-sealed endoscopic vessel harvesting. The surgical surface video and sensor data revealed that forces and torques were primarily generated when the surgeon used the retractor to create space for the sealer and endoscope underneath the skin. The surgeon created noticeable sagittal torques and posterior forces when initially inserting the retractor, sealer and endoscope through the incision under the skin (Figure 4.1). Throughout the procedure, the surgeon generated frontal torques when lifting the retractor blade to physically separate the graft from the surrounding tissue (Figure 4.3). This allowed the surgeon to create enough space for the instruments while advancing the surgical instruments along the length of the graft to be harvested. Finally, the surgeon kept the retractor steady, creating no new force-torque peaks when using the sealer to cauterize the surrounding tissue or branching vessels (Figure 4.2). In general, the maximum, median and IQR for saphenous vein harvests was larger than radial artery harvests.



1. Insertion of surgical instruments

2. Cauterization of tissue or branching vessels attached to graft

3. Advancement of surgical instruments along graft

Figure 4: Primary surgical actions involved in ERAH (left) and EVH (right)

Queen's University Human Body Donor Program
Anatomy Learning Center
Department of Biomedical and Molecular Science

The preliminary results show that an expert generates a maximum force of 62.247 N [posterior] and 1.810 N [- frontal]. The design of the haptic device should consider faithful transmission of tissue and tool dynamics to the trainee while having the capacity to output the maximum recorded forces and torques. Haptic devices with a greater output ranges should be considered since novices are known to exert larger forces than experts.

Since this is the first data set collected for the endoscopic vessel harvesting technique, more data should be collected to help understand how patient demographics as well as surgical experience of the operator influence the distribution of forces and torques generated in the procedure. This data will also enhance the simulation experience for novices where they will be able to test their ability to perform the procedure in patients with different age or gender, if applicable. Furthermore, the additional trials performed by surgeons will help determine an expert benchmark for forces and torques exerted during a simulated training session.

5. CONCLUSION

A surgical retractor was modified and equipped with a FT sensor to measure the forces and torques during endoscopic vessel harvesting procedures. The distribution of the force and torque peaks in the EVH and ERAH procedures was analysed to determine the variation of haptic feedback necessary in training simulators. The design of the haptic device should consider faithful transmission of tissue and tool dynamics to the trainee while having the capacity to output the maximum recorded forces and torques. The same data will also be used to establish expert benchmarks for force and torques exerted during simulated training sessions.

ACKNOWLEDGEMENTS

Julia Wiercigroch has been supported by the Undergraduate Student Research Award provided by the Natural Sciences and Engineering Research Council of Canada (NSERC). Gabor Fichtinger is supported as a Canada Research Chair in Computer-Integrated Surgery.

REFERENCES

[1] A. J. Weiss and A. Elixhauser, *Trends in Operating Room Procedures in U.S. Hospitals, 2001–2011: Statistical Brief #171*. 2006.

[2] L. Melly, *et al.*, "Fifty years of coronary artery bypass grafting.," *J. Thorac. Dis.*, vol. 10, no. 3, pp. 1960–1967, Mar. 2018.

[3] T. Turk, "Early graft failure after coronary artery bypass grafting: diagnosis and treatment," *Eur. Res. J.*, 2016.

[4] M. Gaudino *et al.*, "Radial Artery as a Coronary Artery Bypass Conduit," *J. Am. Coll. Cardiol.*, vol. 68, no. 6, pp. 603–610, Aug. 2016.

[5] M. Elbatarny, F. Rosati, and G. Bisleri, "Endoscopic Radial and Saphenous Vein Harvest Using Non-Sealed Tunnel Retractor and Advanced Vessel Sealing System," *Can. J. Cardiol.*, vol. 34, no. 10, p. S19, Oct. 2018.

[6] P. Nezafati, M. Kahrom, and M. H. Nezafati, "Endoscopic vein harvesting: the growing role in cardiac surgery.," *Arch. Med. Sci. Atheroscler. Dis.*, vol. 2, pp. e34–e36, 2017.

[7] B. Krishnamoorthy *et al.*, "A comprehensive review on learning curve associated problems in endoscopic vein harvesting and the requirement for a standardised training programme.," *J. Cardiothorac. Surg.*, vol. 11, p. 45, Apr. 2016.

[8] T. Ungi *et al.*, "Perk tutor: An open-source training platform for ultrasound-guided needle insertions," *IEEE Trans. Biomed. Eng.*, vol. 59, no. 12, pp. 3475–3481, 2012.

[9] N. E. Seymour *et al.*, "Virtual reality training improves operating room performance: results of a randomized, double-blinded study.," *Ann. Surg.*, vol. 236, no. 4, pp. 458–63; discussion 463-4, Oct. 2002.

[10] O. A. J. Van Der Meijden and M. P. Schijven, "The value of haptic feedback in conventional and robot-assisted minimal invasive surgery and virtual reality training: A current review," *Surgical Endoscopy*, vol. 23, no. 6. Springer New York LLC, pp. 1180–1190, 2009.