The effects of muscle-strengthening and endurance-building exercises on suturing performance among novices: An engineering evaluation of the hands, wrists, fingers, and forearms

by

Kristina Schaffhausen

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Industrial Engineering

Program of Study Committee:
Dr. Richard Stone, Major Professor
Dr. Stephen Gilbert,
Dr. Susan Hallbeck

Iowa State University

Ames, Iowa

2023

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

MVC	Maximum Voluntary Contraction
SLO	Simulated Long Operation

ACKNOWLEDGMENTS

I want to thank my committee chair, Dr. Richard T. Stone, and my committee members, Dr. Stephen Gilbert and Dr. Susan Hallbeck, for taking the time to serve on my committee throughout the course of this research. Further, I would also like to thank my friends, colleagues, coworkers, bosses, and the IMSE department faculty and staff for making my time at Iowa State University an unforgettable experience. I also offer my appreciation to those willing to participate in my study, without whom this thesis would not have been possible. More specifically, I thank all of Dr. Stone's ATHENA Lab members for your help and guidance over the years. I owe you all big time, and I will never forget how profoundly you impacted my undergraduate and graduate school experiences. Thank you to Allison Hubbell, Mohammed Ameen, and Braden Westby for your contributions to this study. I sincerely appreciate all of the time and effort you put in to help me out.

ABSTRACT

The following thesis investigates the impact of muscular endurance-building and strengthening exercises on the suturing performance among novices (n = 16). This study focuses on simple interrupted and simple continuous suturing techniques and involves exercises targeting the hands, wrists, fingers, and forearms. To reduce the amount of muscular pain and fatigue medical professionals experience while suturing, researchers augmented novices over a nine-week-long study through ergonomic intervention. Here, experimental participants performed many exercises using an adjustable hand gripper in conjunction with regular suturing practice. During Weeks 4 and 9, all participants completed a 60-minute simulated long operation (SLO), and their discomfort was assessed in the aforementioned areas. This study aimed to assess whether ergonomic interventions could reduce the perceived level of muscular pain and/or fatigue after a four-week duration.

Ultimately, researchers found no statistical significance; however, after being exposed to consistent resistance training, experimental participants experienced the following: a) a 45% (n = 5) decrease in distance between the final two complete sutures, b) a 45% (n = 5) increase in their pinch MVC on both their dominant and non-dominant hand, c) a 72% (n = 8) increase in their grip MVC on both their dominant and non-dominant hand, and d) a reduction in pain in the webbing of the hand, fingers, and forearm after undergoing an ergonomic intervention. These findings suggest that consistent resistance training may benefit medical professionals in reducing feelings of perceived pain and fatigue in the hands, wrists, fingers, and forearms during operations. Further examination is necessary to identify the exact muscles impacted, and certain limitations must be addressed beforehand to accomplish this.

CHAPTER 1. GENERAL INTRODUCTION

Background

The healthcare industry is one of the most demanding and challenging fields of work. Healthcare professionals, particularly surgeons, work in high-pressure environments where precision and accuracy are vital. However, the demanding nature of the job often leads to physical and mental exhaustion, which can lead to surgeon's fatigue and occupational burnout. These issues can result in medical errors, which can be catastrophic for patients, leading to injuries or even death. Surgeon's fatigue is a phenomenon that can result in medical errors during surgery, which can have serious downstream consequences for patients and physicians. It is a state of physical or mental exhaustion that can impair a surgeon's performance in the operating room (Janhofer et al., 2019). Suturing is a standard procedure performed in surgery and involves fine motor skills to close a wound or incision. The technique requires surgeons to use repetitive pinching and gripping motions with their hands, wrists, fingers, and forearms, which can lead to muscle soreness and fatigue over time. The repetitive pinching and gripping can lead to the development of muscle fatigue, which can cause a decrease in the precision and control of the surgeon's movements, leading to potential errors and accidents in the operating room. Medical personnel (e.g., students or licensed professionals) may experience hand tremors and prolonged discomfort, ultimately affecting the speed at which they learn to suture. Imprecise suturing can result in noticeable scarring, tissue damage, and possible longer healing periods for patients (Abdelall et al., 2021). Similarly, current medical instruments come with their own set of ergonomic shortcomings that can lead to discomfort and poor surgical performance. These poorly designed instruments, coupled with repetitive motions, can cause musculoskeletal disorders among medical personnel (González et al., 2020).

In addition to surgeons, other medical team members may also experience fatigue, such as nurses or anesthesiologists, due to holding static and/or awkward postures for extended periods. After speaking with a licensed orthopedic surgeon from Canada, researchers learned that for this surgeon in particular, muscle fatigue began in the forearms during long operations. Over time, this pain gradually worked its way to different parts of the body, such as the fingers, neck, and lower back (A. Many personal communication, 2021). Research has shown that human factors contribute to surgical errors that happen annually, as well as inadequate communication among surgical teams, ineffective or unreliable protocols put into place, and time pressures to complete cases (Rodziewicz et al., 2021). Johns Hopkins University's experts estimated that 250,000 deaths occur each year due to medical errors, and this number may be higher depending on one's exact definition of the term 'medical error' (McMains, 2015). Medical personnel may experience cumulative trauma disorders from highly repetitive movements, such as suturing, which can be career-ending. Or, they may require personnel to take a temporary leave of absence (Fagarasanu et al., 2004).

Surgeons' fatigue can result from various factors, including long work hours, sleep deprivation, elevated stress levels, and physical fatigue from holding static, awkward postures for long periods. In a review of 444 surgical malpractice claims, surgeon reviewers suggested an improvement in routine performance during operations because most technical errors occurred with experienced surgeons under complicated circumstances. Further, 49% of these technical errors resulted in an irreparable patient disability. This finding emphasizes the importance of routine tasks and how the physical act of suturing requires steady hands, controlled fine motor movements, and uninhibited muscle use. (Regenbogen et al., 2007).

Muscle fatigue is another type of fatigue that can impact healthcare professionals, particularly those who perform physical tasks as part of their job. Muscles can become fatigued when overworked, leading to weakness and reduced performance, which can be particularly dangerous for surgeons and other healthcare professionals who need to maintain a high level of precision and control during procedures. Occupational burnout is another type of fatigue characterized by emotional exhaustion, depersonalization, and a reduced sense of personal accomplishment (Mayo Clinic, 2021). Burnout can occur in any profession but is particularly common in healthcare due to the high-stress levels and long work hours. Burnout can lead to various adverse outcomes, including reduced job performance, increased medical errors, and potential loss of life in the operating room. Additionally, muscle fatigue can result in decreased job satisfaction and increased levels of occupational burnout among surgeons, affecting their mental and physical well-being and quality of life (Galaiya et al., 2020).

To prevent muscle soreness and fatigue, surgeons must have good posture and proper ergonomics while suturing. For instance, using a comfortable grip and maintaining a neutral wrist position can help reduce muscle strain and soreness. Surgeons may also benefit from practicing exercises and stretches that help strengthen the muscles used during suturing, such as handgrip strengthening exercises and finger stretching. Additionally, taking microbreaks and switching to different tasks during surgeries can help prevent muscle fatigue, aiding in physical performance and mental focus (Hallbeck et al., 2017).

Fatigue is a serious issue in the healthcare industry, particularly for surgeons and other medical professionals who work long hours and perform physically and mentally demanding tasks with minimal breaks. It can contribute to medical errors, which can have severe consequences for patients. Ultimately, it is important for healthcare organizations to take steps to mitigate fatigue and burnout among their employees to ensure that patients receive the highest quality care possible.

Suturing Precision & Scarring

The process of healing after a surgical procedure involves a complex series of events, and one important aspect is scar formation, which consists of the deposition of collagen. This fibrous protein gives strength and support to the skin. However, the formation of scars can also lead to complications such as contractures, hypertrophic scars, and keloids (Marshall et al., 2018). The precise placement of sutures is essential to achieve optimal healing and minimize the risk of complications and scarring. Slight differences in the sutures' placement can significantly impact the healing process. For example, if sutures are placed too far apart, the wound may not close properly, leading to delayed healing, increased risk of infection, and potentially unsightly scars. On the other hand, if sutures are placed too close together, the wound edges may be pulled too tightly, leading to tension and poor healing (Oxford Medical Education, 2015).

Precise suturing is essential to ensure proper wound closure and minimize physical complications and visible scarring risk. Suturing requires a surgeon to use fine motor skills, including precise pinching and gripping motions. These movements require a significant amount of physical effort and repetitive motions. As a result, surgeons can experience muscle soreness and fatigue in muscle groups responsible for these pinching and gripping motions and other areas in the body. Thus, precise suturing can help ensure the wound is closed properly, leading to better healing and less unsightly scarring. Ultimately, improper placement of sutures can directly affect how visible or invisible a scar is; therefore, small deviations in placement can have a rather large impact on scar visibility.

Motivation & Research Objectives

Assessing perceived muscular pain and fatigue in the hands, wrists, fingers, and forearms aids in comprehending the effects of surgical training on the musculoskeletal well-being of medical professionals. Attempts at reducing pain in the aforementioned areas are critical for surgeons and other medical personnel so they can focus on the operation in front of them and not the pain they may be experiencing while operating. Chapter 2 outlines a longitudinal study motivated by the fact that surgical procedures involving suturing require prolonged and repetitive manual work that can be physically demanding. These repetitive motions can cause musculoskeletal disorders, resulting in pain, discomfort, and reduced work efficiency for medical professionals.

This study has three main research objectives, including assessing the level of perceived muscular pain and fatigue, investigating the frequency and intensity of suturing activities, and evaluating the effectiveness of ergonomic interventions. The first research objective of this longitudinal study was to assess the level of perceived muscular pain and fatigue among novice suturing participants, which involved obtaining data through questionnaires and interviews to understand how the participants felt during and after the suturing process. The second research objective was to investigate the frequency and intensity of suturing activities that most likely caused muscle pain and fatigue. The third research objective was to evaluate the effectiveness of ergonomic interventions in reducing muscular pain and fatigue during suturing. This objective involved implementing ergonomic interventions, particularly muscle-strengthening and endurance-building exercises, and assessing their impact on the participants' perceived pain. By addressing these research objectives, this study aimed to provide insights into developing and preventing surgeon's fatigue among medical professionals.

References

Abdelall, E.S., Stone, R.T., Rajana Nedved, L. and Fales, C. (2020). Bend the Tool, Not the Wrist: An Ergonomic Investigation of Medical Suturing Needle Holder Design and Medical Engineering Solution. *Surgical Innovation*, 28(1), pp.62–70. doi:https://doi.org/10.1177/1553350620950896.

Bann, S.D., Khan, M.S. and Darzi, A.W. (2003). Measurement of Surgical Dexterity Using Motion Analysis of Simple Bench Tasks. *World Journal of Surgery*, 27(4), pp.390–394. doi:https://doi.org/10.1007/s00268-002-6769-7.

Berguer, R., Forkey, D.L. and Smith, W.D. (1999). Ergonomic problems associated with laparoscopic surgery. *Surgical Endoscopy*, 13(5), pp.466–468. doi:https://doi.org/10.1007/pl00009635.

Ching, S.S., Mok, C.W., Koh, Y.X., Tan, S.-M. and Tan, Y.K. (2013). Assessment of Surgical Trainees' Quality of Knot-Tying. *Journal of Surgical Education*, 70(1), pp.48–54. doi:https://doi.org/10.1016/j.jsurg.2012.07.002.

Dalager, T., Jensen, P.T., Eriksen, J.R., Jakobsen, H.L., Mogensen, O. and Søgaard, K. (2020). Surgeons' posture and muscle strain during laparoscopic and robotic surgery. *British Journal of Surgery*, 107(6), pp.756–766. doi:https://doi.org/10.1002/bjs.11394.

Fagarasanu, M., Kumar, S. and Narayan, Y. (2004). Measurement of angular wrist neutral zone and forearm muscle activity. Clinical Biomechanics, [online] 19(7), pp.671–677. doi:https://doi.org/10.1016/j.clinbiomech.2004.05.004.

Figueiredo, S., Machado, L., Lousada, A.D.P., Castelo, L.S., Fardilha, M.L. and Sa, A. (2016). Physicians versus surgeons. A pilot study on hand dexterity within a controlled population. Acta Orthopaedica Belgica, [online] 82(3), pp.456–461. Available at: https://pubmed.ncbi.nlm.nih.gov/29119884/ [Accessed 23 Apr. 2023].

Galaiya, R., Kinross, J. and Arulampalam, T. (2020). Factors associated with burnout syndrome in surgeons: a systematic review. *The Annals of The Royal College of Surgeons of England*, 102(6), pp.401–407. doi:https://doi.org/10.1308/rcsann.2020.0040.

González, A.G., Barrios-Muriel, J., Romero-Sánchez, F., Salgado, D.R. and Alonso, F.J. (2020). Ergonomic assessment of a new hand tool design for laparoscopic surgery based on surgeons' muscular activity. Applied Ergonomics, 88, p.103161. doi:https://doi.org/10.1016/j.apergo.2020.103161.

Gonzalez-Navarro, A.R., Quiroga-Garza, A., Acosta-Luna, A.S., Salinas-Alvarez, Y., Martinez-Garza, J.H., de la Garza-Castro, O., Gutierrez-de la O, J., de la Fuente-Villarreal, D., Elizondo-Omaña, R.E. and Guzman-Lopez, S. (2021). Comparison of suturing models: the effect on perception of basic surgical skills. BMC Medical Education, 21(1). doi:https://doi.org/10.1186/s12909-021-02692-x.

Hallbeck, M.S., Lowndes, B.R., Bingener, J., Abdelrahman, A.M., Yu, D., Bartley, A. and Park, A.E. (2017). The impact of intraoperative microbreaks with exercises on surgeons: A multi-center cohort study. *Applied Ergonomics*, 60, pp.334–341. doi:https://doi.org/10.1016/j.apergo.2016.12.006.

Hughes, D.T., Forest, S.J., Foitl, R. and Chao, E. (2014). Influence of medical students' past experiences and innate dexterity on suturing performance. The American Journal of Surgery, 208(2), pp.302–306. doi:https://doi.org/10.1016/j.amjsurg.2013.12.040.

Janhofer, D.E., Lakhiani, C. and Song, D.H. (2019). Addressing Surgeon Fatigue. Plastic and Reconstructive Surgery, 144(4), pp.693e699e. doi:https://doi.org/10.1097/prs.0000000000006075.

Khan, W.F., Krishna, A., Roy, A., Prakash, O., Jaryal, A.K., Deepak, K.K., Bhattacharjee, H., Sreenivas, V. and Bansal, V.K. (2020). Effect of structured training in improving the ergonomic stress in laparoscopic surgery among general surgery residents. Surgical Endoscopy, 35(8), pp.4825–4833. doi:https://doi.org/10.1007/s00464-020-07945-2.

Lowndes, B.R. and Hallbeck, M.S. (2012). Overview of Human Factors and Ergonomics in the OR, with an Emphasis on Minimally Invasive Surgeries. Human Factors and Ergonomics in Manufacturing & Service Industries, 24(3), pp.308–317. doi:https://doi.org/10.1002/hfm.20383.

Marshall, C.D., Hu, M.S., Leavitt, T., Barnes, L.A., Lorenz, H.P. and Longaker, M.T. (2018). Cutaneous Scarring: Basic Science, Current Treatments, and Future Directions. *Advances in Wound Care*, 7(2), pp.29–45. doi:https://doi.org/10.1089/wound.2016.0696.

Mayo Clinic (2021). Know the signs of job burnout. [online] Mayo Clinic. Available at: https://www.mayoclinic.org/healthy-lifestyle/adult-health/in-depth/burnout/art-20046642#:~:text=Job%20burnout%20is%20a%20special.

McMains, V. (2015). Study Suggests Medical Errors Now Third Leading Cause of Death in the U.S. - 05/03/2016. [online] Hopkinsmedicine.org. Available at: https://www.hopkinsmedicine.org/news/media/releases/study_suggests_medical_errors_now_third_leading_cause_of_death_in_the_us.

Ohu, I.P.N. 2015, Analysis of ergonomics and highly non-linear dynamics of surgical motions and muscle activations in minimally invasive surgery, Southern Illinois University at Carbondale

Oxford Medical Education. (2015). *How to suture*. [online] Available at: https://oxfordmedicaleducation.com/clinical-skills/procedures/how-to-suture/.

Pérez-Duarte, F.J., Sánchez-Margallo, F.M., Martín-Portugués, I.D.-G., Sánchez-Hurtado, M.A., Lucas-Hernández, M., Sánchez-Margallo, J.A. and Usón-Gargallo, J. (2013). Ergonomic Analysis of Muscle Activity in the Forearm and Back Muscles During Laparoscopic Surgery. Surgical Laparoscopy, Endoscopy & Percutaneous Techniques, 23(2), pp.203–207. doi:https://doi.org/10.1097/sle.0b013e3182827f30.

Regenbogen, S.E., Greenberg, C.C., Studdert, D.M., Lipsitz, S.R., Zinner, M.J. and Gawande, A.A. (2007). Patterns of Technical Error Among Surgical Malpractice Claims. Annals of Surgery, 246(5), pp.705–711. doi:https://doi.org/10.1097/sla.0b013e31815865f8.

Rodziewicz, T.L., Houseman, B. and Hipskind, J.E. (2021). Medical Error Reduction and Prevention. [online] PubMed. Available at: https://www.ncbi.nlm.nih.gov/books/NBK499956/#:~:text=At%20least%204000%20surgical%20errors.

Şahin, F., Atalay, N.Ş., Akkaya, N. and Aksoy, S. (2017). Factors affecting the results of the functional dexterity test. *Journal of Hand Therapy*, 30(1), pp.74–79. doi:https://doi.org/10.1016/j.jht.2016.04.005.

Slack, P., Coulson, C., Ma, X., Webster, K. and Proops, D. (2008). The Effect of Operating Time on Surgeons' Muscular Fatigue. The Annals of The Royal College of Surgeons of England, 90(8), pp.651–657. doi:https://doi.org/10.1308/003588408x321710.

Verrelli, D.I., Qian, Y., Wilson, M.K., Wood, J. and Savage, C. (2016). Intraoperative tremor in surgeons and trainees. Interactive CardioVascular and Thoracic Surgery, [online] 23(3), pp.410–415. doi:https://doi.org/10.1093/icvts/ivw150.

Relevant Definitions

- **Muscular endurance**: The ability of a muscle or group of muscles to sustain repeated contractions over a period of time without experiencing fatigue.
- **Suturing**: The act of closing a wound or incision using a needle and thread to bring edges of a wound together, promoting healing and preventing infection.
- **Muscular strength**: The maximal force a muscle or group of muscles can generate during a single contraction.
- **Simple interrupted suturing**: A suturing technique where each stitch is made separately and tied off before the next stitch is made.
- **Simple continuous suturing**: A suturing technique where a continuous suture is made along the length of the wound, with each stitch tied off at the end of the suture.
- **Maximum voluntary contraction**: the maximum amount of force that a muscle or group of muscles can produce during a voluntary effort. It is usually measured by having the individual contract their muscles as hard as possible against an external resistance, such as a dynamometer.

CHAPTER 2. AUGMENTATION OF NOVICES AT SUTURING

Abstract

The following thesis investigates the impact of muscular endurance-building and strengthening exercises on the suturing performance among novices (n = 16). This study focuses on simple interrupted and simple continuous suturing techniques and involves exercises targeting the hands, wrists, fingers, and forearms. To reduce the amount of muscular pain and fatigue medical professionals experience while suturing, researchers augmented novices over a nine-week-long study through ergonomic intervention. Here, experimental participants performed many exercises using an adjustable hand gripper in conjunction with regular suturing practice. During Weeks 4 and 9, all participants completed a 60-minute simulated long operation (SLO), and their discomfort was assessed in the aforementioned areas. This study aimed to assess whether ergonomic interventions could reduce the perceived level of muscular pain and/or fatigue after a four-week duration.

Researchers found no statistical significance; however, consistent resistance training resulted in the following among experimental participants: a) a 45% (n = 5) decrease in distance between the final two complete sutures, b) a 45% (n = 5) increase in their pinch MVC on both their dominant and non-dominant hand, c) a 72% (n = 8) increase in their grip MVC on both their dominant and non-dominant hand, and d) a reduction in pain in the webbing of the hand, fingers, and forearm after undergoing an ergonomic intervention. These findings suggest that consistent resistance training may benefit medical professionals in reducing feelings of perceived pain and fatigue in the hands, wrists, fingers, and forearms during operations.

Introduction

Disclaimer: The following chapter received IRB approval (see Appendix A).

Researchers augmented novices through ergonomic intervention over a nine-week-long study in an attempt to reduce the amount of muscular pain and fatigue participants experience while suturing. For a period of four weeks, two experimental groups engaged in daily muscle-strengthening and endurance-building exercises using an adjustable hand gripper, while also practicing two suturing techniques (simple interrupted and simple continuous). The control group continued practicing the two techniques for the time being without any ergonomic intervention. Researchers chose simple interrupted and simple continuous suturing techniques to familiarize participants with knot tying and how to thread the sutures symmetrically.

Simple interrupted suturing is defined as "a single, roughly circular (i.e., simple) loop of suture material, individually tied. This technique permits individual tensioning of each suture, and if one suture should later fail, the others remain unaffected" (Streitz, 2021). A depiction of the simple interrupted suturing technique is shown in Figure 1 (Veeraraghavan, 2021).

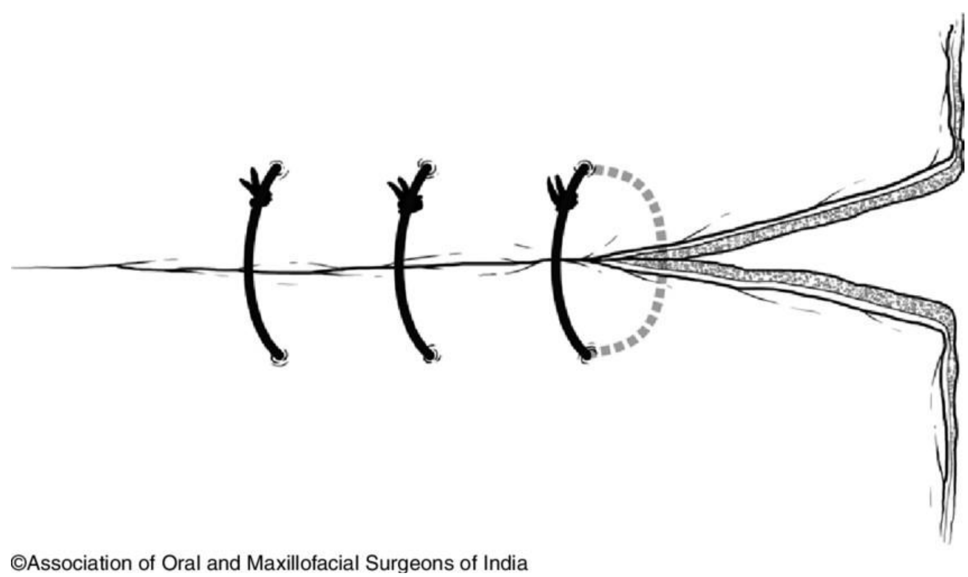


Figure 1. Depiction of Simple Interrupted Suturing Technique

Simple continuous suturing is an uninterrupted technique that uses a continuous strand of suture material with knots only at the beginning and end of the wound. However, if one piece of the suture material fails, then the suture's ability to close a wound is compromised (Li, 2021). A depiction of the simple continuous suturing technique is shown in Figure 2 (Veeraraghavan, 2021).

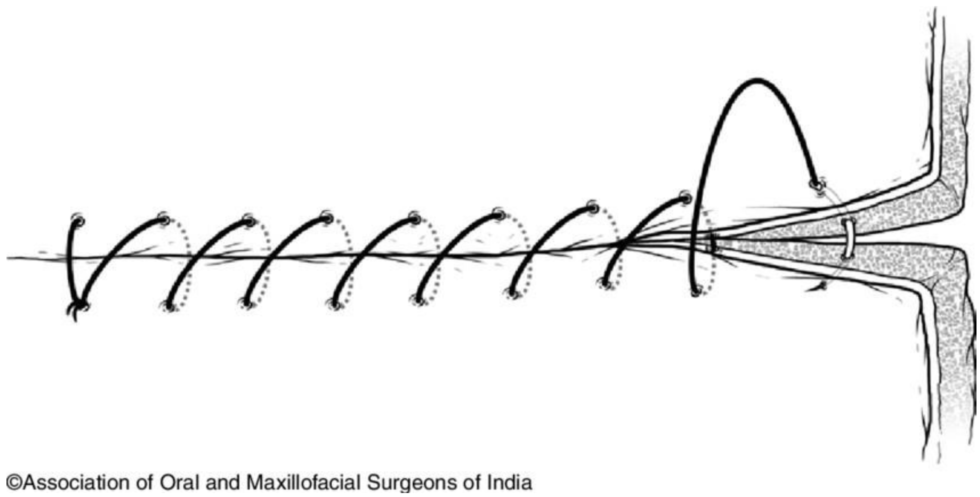


Figure 2. Depiction of Simple Continuous Suturing Technique

Before and after this ergonomic intervention of daily exercises with the experimental groups, all participants performed a 60-minute simulated long operation (SLO) in which they were to demonstrate their newly acquired suturing skills on a dummy mannequin using medical instruments. Researchers administered surveys about perceived muscular pain and fatigue in the hands, wrists, fingers, and forearms following the simulated long operations. Please note: Originally, participants were split into three groups; however, since there was no discernable difference between the two experimental groups, researchers statistically analyzed two groups: a control and a combined experimental group (experimented on vs. not experimented on). This research investigates the effect of muscular endurance and strengthening exercises on surgical suturing skills and perceived pain.

Researchers hypothesized the following:

Hypothesis 1: Engaging in consistent muscle-strengthening and endurance-building exercises (targeting the hands, wrists, fingers, and forearms) in conjunction with regular suturing practice will result in a reduction in perceived pain during simulated long operations after four weeks of ergonomic intervention.

Hypothesis 2: Changes in how often suturing is practiced among experimental groups will result in a discernible difference in suturing proficiency and/or perceived pain.

Hypothesis 3: Consistently engaging in muscle-strengthening and endurance-building exercises (targeting the hands, wrists, fingers, and forearms) will increase maximum voluntary contraction (MVC) readings on pinch and grip dynamometers.

Hypothesis 4: Consistently engaging in muscle-strengthening and endurance-building exercises (targeting the hands, wrists, fingers, and forearms) will result in more complete pinching and gripping contractions at 75% of pinching and gripping MVC readings on an adjustable hand gripper.

Hypothesis 5: Consistently engaging in muscle-strengthening and endurance-building exercises (targeting the hands, wrists, fingers, and forearms) will result in a reduction of perceived pain in the aforementioned areas after performing a 60-minute simulated long operation.

Hypothesis 6: Consistently engaging in muscle-strengthening and endurance-building exercises (targeting the hands, wrists, fingers, and forearms) will result in a reduction in the distance between the final two complete sutures at the end of a simulated long operation, which is when the most fatigue is experienced.

Participants

In total, 16 college-aged (either undergraduate, graduate, or recent graduate) participants completed the study, eleven males and five females (average age = 26.9 years, standard deviation = 6.6 years). Eligible participants were a) 18 years of age or older, b) had no limiting hard and/or arm abilities and/or related injuries, c) were capable of standing for 1-2 hours during two 60-minute simulated long operations, and d) had no previous suturing experience. Researchers obtained informed consent from all participants before beginning the study. It should be noted, researchers spent over one year trying to recruit participants. The study was intensive and longitudinal in nature, which resulted in 11 participants dropping out at various stages, posing a significant challenge for researchers to maintain participant retention. Due to time constraints, only a limited number of participants could fully complete the study, with the number further reduced by 11 dropouts, leaving a final count of 16 individuals.

Study Design

The study was conducted over a nine-week period, outlined in Table 1.

Table 1. Study Timeline

Week	**Instructions**
Week 1	***All participants*** (control and experimental) Informed Consent Form + Initial in-person meeting to gather initial MVC and endurance data + Receive all necessary materials & instructions
Weeks 2 - 3	***All participants*** (control and experimental) learn simple interrupted and simple continuous suturing techniques on their own time with provided materials & instructions (for a recommended 30 minutes per day, 5 days/week)
Week 4	***All participants*** complete their first simulated long operation (SLO) for 60 minutes
Weeks 5 - 8	***Control group*** continues suturing practice of both techniques with no ergonomic intervention ***Experimental Group #1*** completed daily exercises on both their dominant and non-dominant hands using an adjustable hand gripper in conjunction with 30 minutes of suturing practice 5 days/week ***Experimental Group #2*** completed daily exercises on both their dominant and non-dominant hands using an adjustable hand gripper in conjunction with 15 minutes of suturing practice 5 days/week
Week 9	***All participants*** (control and experimental) complete their final simulated long operation + Final MVC reads and endurance tests + Debrief

Independent variables include, a) whether participants engaged in exercises during Weeks 5-8, and b) how long participants were asked to practice suturing during Weeks 5-8. Dependent variables include, a) pinch and grip maximum voluntary contractions (MVCs), b) pinch and grip endurance tests at 75% of participants' MVCs, c) a pain scale survey administered after each 60-minute simulated long operation, and d) a precision metric measuring the distance between the final two complete sutures at the end of each simulated long operation.

Week 1:

During Week 1, all participants (control and experimental) met in person with researchers to gather maximum voluntary contraction (MVC) data on pinch and grip dynamometers. They also complete four endurance tests (two on each hand) at 75% of their pinch and grip MVC readings, requiring them to complete as many full contractions as possible until failure. Researchers demonstrated complete pinch and grip contractions to each participant before they completed each endurance test. The same maximum voluntary contraction readings and endurance tests were completed at the end of the study for comparison in Week 9. Researchers compared these values at the end of the augmentation period to identify any trends or improvements.

At this initial meeting, all participants received the proper materials and instructions for practicing simple interrupted and simple continuous suturing techniques at home. They were instructed to practice for 30 minutes per day, five days per week, for a recommended 2.5 hours per week. These instructions can be found in Appendix B. Material provided to all participants included the following a) a printed copy of the instructions, b) a silicone suture pad with pre-cut lacerations for practice, c) an assortment of medical-grade sutures to practice with, d) nitrile gloves, e) a 5-inch stainless steel needle driver, f) a 5.5-inch stainless steel forceps, and g) a pair of surgical scissors. Lastly, participants completed the Minnesota Manual Dexterity Placing and Turning Tests and the Lafayette Purdue Pegboard Test, as these are commonly accepted tests for gross-motor and fine-motor skills commonly used in surgery. Ultimately, these tests had no relevance once evaluated; however, this data was still collected.

Weeks 2-3:

All participants dedicated Weeks 2-3 to learning simple interrupted and simple continuous suturing techniques. They used the instructions and materials provided to them to practice at home for a recommended 30 minutes per day, five days per week, for 2.5 hours per week.

Week 4:

During Week 4, all participants had an in-person session with researchers for 1-2 hours to complete their first simulated long operation (SLO). Here, they had to perform both suturing techniques that they practiced on a dummy mannequin that contained 16 complex shapes: lacerations 1 – 16, respectively (L1 - L16). These lacerations were cut into a large suture pad, shown in Figure 3, and participants used 3-0 sutures during their SLO. *Please note*: Due to the limited availability of suturing material at the time of purchase, participants used 3-0 sized sutures made of either silk, nylon, polyester, or polypropylene, which was the most commercially available at the time. Due to time constraints and the need to purchase in bulk, this limitation should be noted.

Figure 3: Dummy Mannequin with Lacerations L1 - L16

L1, L6, L8, and L10 - L16 required participants to use simple interrupted suturing, while the remainder required simple continuous suturing. All participants were instructed to wear nitrile gloves, start suturing with L1, and work sequentially for 60 minutes to complete as much of the mannequin as possible. Before and after the 60-minute suturing session, researchers took participants' MVC readings on both hands with pinch and grip dynamometers. After the 60 minutes of suturing, participants described any pain and/or fatigue they experienced in the hands, wrists, fingers, and forearms and ranked it on a scale from 0 - 10 (0 = no pain, and 10 = sensation is making it increasingly more difficult to continue suturing). They pointed to areas they experienced pain by referencing Figures 4 and 5. After completing their first simulated long operation, experimental participants received a new set of instructions they were to follow for Weeks 5-8.

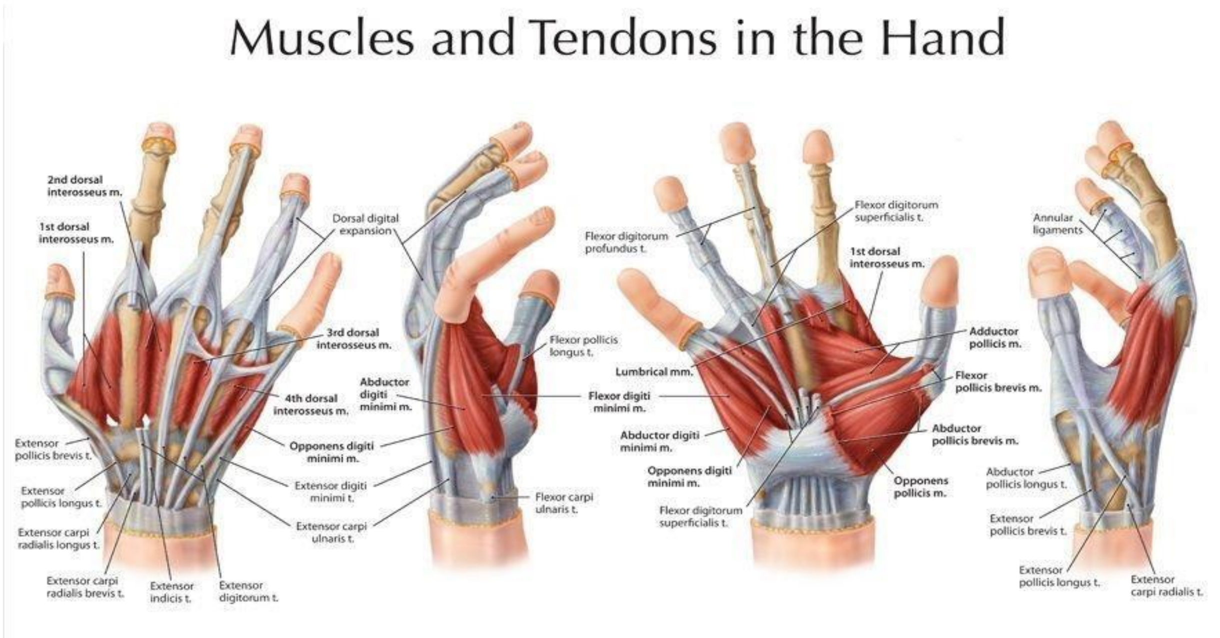


Figure 4. Hand Diagram

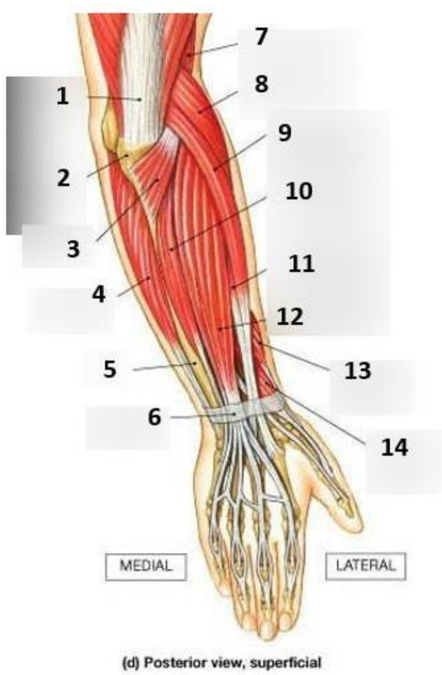


Figure 5. Forearm Diagram

<u>*Weeks 5-8*</u>:

During Weeks 5-8, eleven participants (eight male and three female) were placed in one of the two experimental groups (E1 and E2). They performed muscle-strengthening and endurance-building exercises daily (see Appendix C) using the adjustable hand gripper shown in Figure 6, targeting muscles in the hands, wrists, fingers, and forearms (in conjunction with regular suturing practice). While experimental participants exercised during that time, the control group continued practicing the two suturing techniques without any ergonomic interventions. Originally, researchers were going to remove participants that didn’t show improvements during weekly MVC checks; however, they determined this removal was unnecessary because participants dropped out of the study for other reasons.

Researchers customized each experimental participant's exercise regimen based on their initial maximum voluntary contraction (MVC) readings on pinch and grip dynamometers taken at the beginning of the study.

Figure 6. Adjustable Hand Gripper

The slight difference between each experimental group is outlined below.

Weeks 5 - 8 (By Group)

Control Group (n = 5):

Participants continued practicing simple interrupted and simple continuous suturing techniques for 2.5 hours/week, for a recommended 30 minutes per day, five days/week. During this time, they did not complete any muscle-strengthening or endurance-building exercises.

Experimental Group #1 (n = 6):

These participants practiced simple interrupted and simple continuous suturing techniques for 2.5 hours/week, for a recommended 30 minutes/day, five days per week. In addition, they completed daily muscle-strengthening and endurance-building exercises outlined in Appendix C.

Experimental Group #2 (n = 5):

These participants practiced simple interrupted and simple continuous suturing techniques for 1.25 hours/week, for a recommended 15 minutes/day, five days per week. In addition, they completed daily muscle-strengthening and endurance-building exercises outlined in Appendix C.

Week 9:

Lastly, in Week 9, participants completed their final simulated long operation using the same dummy mannequin previously mentioned in the section titled 'Week 4'. L1, L6, L8, and L10 - L16 required participants to use simple interrupted suturing, while the remainder required simple continuous suturing. All participants were instructed to wear nitrile gloves, start suturing with L1, and work sequentially for 60 minutes to complete as much of the mannequin as possible. Before and after the 60-minute suturing session, researchers took participants' MVC readings on both hands with pinch and grip dynamometers. After the 60 minutes of suturing, participants described any pain and/or fatigue they experienced in the hands, wrists, fingers, and forearms and ranked it on a scale from 0 - 10 (0 = no pain, and 10 = sensation is making it increasingly more difficult to continue suturing). They pointed to areas they experienced pain by referencing previously listed Figures 4 and 5. The following day, participants completed their final endurance tests, were debriefed about the conditions of each group, and returned all materials. Researchers broke the final SLO and endurance test sessions into two separate sessions to prevent participants from completing an endurance test already in a state of fatigue from 60 minutes of suturing. Similarly, researchers didn't want participants to begin the final SLO in a fatigued state either from completing the endurance tests directly before suturing. After completing both Week 9 sessions, researchers debriefed participants, and participants returned all materials.

Results

Using Excel, chi-square statistical analysis was used to evaluate the following metrics listed below.

Precision Metric

Researchers compared the distance between the final two complete sutures at the end of each 60-minute simulated long operation (SLO) to determine if experimental participants demonstrated a decrease in distance. Researchers opted to measure this distance because it signifies the moment at which participants experienced the highest level of fatigue throughout the simulated long operation. If participants ended their SLO while completing a laceration requiring simple interrupted suturing, the following distance was measured, as shown in Figure 7. Similarly, if participants ended their SLO while completing a laceration requiring simple continuous suturing, the following distance was measured, as shown in Figure 8.

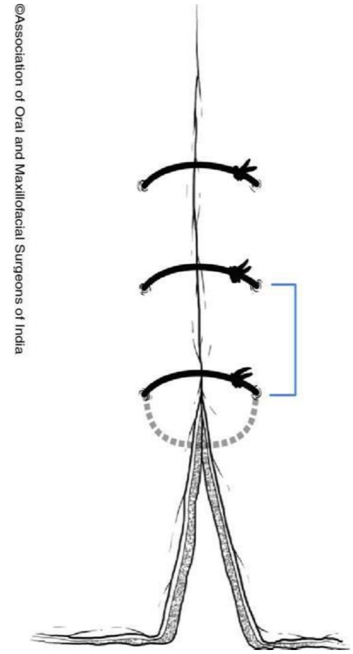


Figure 7. Distance Measured Between Final Two Simple Interrupted Sutures

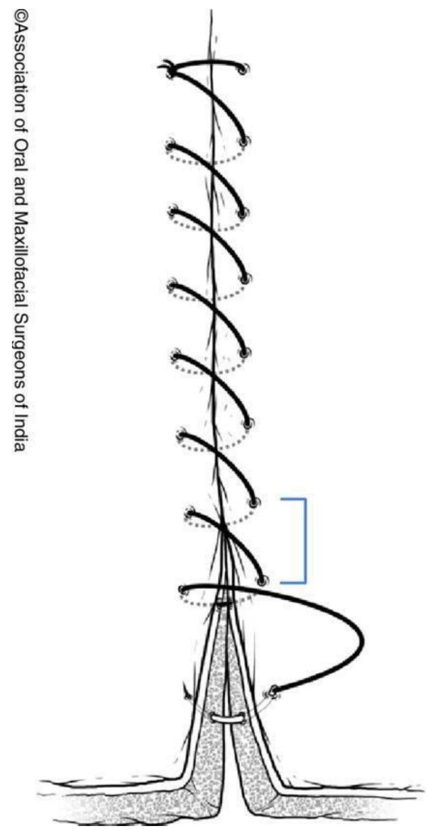


Figure 8. Distance Measured Between Final Two Simple Continuous Sutures

Of the 11 participants experimented on, 75% (n = 9) experienced either a decrease in distance or experienced no change in distance, while 45% (n = 5) experienced only a decrease in distance. Of the 16 participants, five that experienced a decrease came from the experimental group, and only one came from the control group. Four experienced an increase in distance between the two groups, and six experienced no change in distance. A chi-square analysis resulted in a p-value>0.05, indicating no significant evidence suggesting that being in the experimental group has a statistically relevant effect on the distance between the final two sutures. For data analysis, see Table 2.

Table 2. Chi-Square Analysis of Precision Metric

OBSERVED	Decrease or Same	Increase	Total
Control	3	2	5
E1 & E2	9	2	11
Total	12	4	16
EXPECTED	Decrease or Same	Increase	Total
Control	3.75	1.25	5
E1 & E2	8.25	2.75	11
Total	12	4	16
p-value = 0.3502			

Pinch and Grip Maximum Voluntary Contractions (MVCs)

Pinch and grip maximum voluntary contractions (MVCs) were collected at the beginning and end of the study.

Pinch MVC

Of those experimented on, 72% (n = 8) increased their pinch maximum voluntary contraction (MVC) on either their dominant or non-dominant hand, and 45% (n = 5) increased their pinch MVC on both their dominant and non-dominant hand. Six participants experienced a decrease in their pinch MVC on their dominant hand between both experimental and control groups, while 10 experienced an increase. Similarly, seven participants experienced a decrease in their pinch MVC between both groups on their non-dominant hand, while only seven experienced an increase.

Grip MVC

Eighty-one percent (n = 9) of those experimented on increased their grip MVC in either their dominant or non-dominant hand, while 72% (n = 8) experienced an increase in their grip MVC on both their dominant and non-dominant hand. Chi-square analyses on both hands for pinching and gripping MVCs resulted in four p-values>0.05, suggesting that there is no significant evidence to suggest that being in the experimental group had a statistically relevant effect on pinch or grip strength for either hand. See Tables 3 – 6.

Table 3. Chi-square Analysis of Pinching MVCs on Dominant Hand

Dominant							
OBSERVED	Decrease	Increase	Total	**EXPECTED**	Decrease	Increase	Total
Control	2	3	5	Control	1.875	3.125	5
E1 & E2	4	7	11	E1 & E2	4.125	6.875	11
Total	6	10	16	Total	6	10	16
p-value = 0.8892							

Table 4. Chi-square Analysis of Pinching MVCs on Non-Dominant Hand

Non-Dominant							
OBSERVED	Decrease	Increase	Total	**EXPECTED**	Decrease	Increase	Total
Control	3	2	5	Control	2.1875	2.8125	5
E1 & E2	4	7	11	E1 & E2	4.8125	6.1875	11
Total	7	9	16	Total	7	9	16
p-value = 0.3770							

Table 5. Chi-square Analysis of Gripping MVCs on Dominant Hand

Dominant							
OBSERVED	Decrease	Increase	Total	**EXPECTED**	Decrease	Increase	Total
Control	2	3	5	Control	1.25	3.75	5
E1 & E2	2	9	11	E1 & E2	2.75	8.25	11
Total	4	12	16	Total	4	12	16
p-value = 0.3502							

Table 6. Chi-square Analysis of Gripping MVCs on Non-Dominant Hand

Non-Dominant							
OBSERVED	Decrease	Increase	Total	**EXPECTED**	Decrease	Increase	Total
Control	1	4	5	Control	0.9375	4.0625	5
E1 & E2	2	9	11	E1 & E2	2.0625	8.9375	11
Total	3	13	16	Total	3	13	16
p-value = 0.9312							

Pinch and Grip Endurance Testing

At the beginning and end of the study, the researchers instructed participants to perform as many full pinch and grip contractions on both hands using an adjustable hand gripper set at a resistance level equivalent to 75% of their initial MVCs. Seventy-two (n = 8) percent of those experimented on increased the number of complete contractions during the pinching endurance test on their dominant hand, while 81% (n = 9) increased in their non-dominant hand. Similarly, 63% of those experimented on experienced an increase in the number of complete contractions during the gripping endurance test on their dominant hand, and 63% experienced an increase in their non-dominant hand. Three participants performed fewer pinching contractions between both groups, while 10 performed more. A chi-square analysis of both dominant and non-dominant hands resulted in p-values>0.05, suggesting that there is no significant evidence to suggest that being in the experimental group had a statistically relevant effect on pinching or gripping endurance test performance for either dominant or non-dominant hands. See Tables 7 – 10.

Table 7. Chi-square Analysis of Pinching Endurance Test on Dominant Hand

Pinching Endurance									
Dominant									
OBSERVED	Decrease	Increase	Neither	Total	**EXPECTED**	Decrease	Increase	Neither	Total
Control	1	2	2	5	Control	0.9375	3.125	0.9375	5
E1 & E2	2	8	1	11	E1 & E2	2.0625	6.875	2.0625	11
Total	3	10	3	16	Total	3	10	3	16
p-value = 0.3093									

Table 8. Chi-square Analysis of Pinching Endurance Test on Non-Dominant Hand

Pinching Endurance									
Non-Dominant									
OBSERVED	Decrease	Increase	Neither	Total	**EXPECTED**	Decrease	Increase	Neither	Total
Control	1	3	1	5	Control	0.9375	3.75	0.3125	5
E1 & E2	2	9	0	11	E1 & E2	2.0625	8.25	0.6875	11
Total	3	12	1	16	Total	3	12	1	16
p-value = 0.2976									

Table 9. Chi-square Analysis of Gripping Endurance Test on Dominant Hand

Gripping Endurance									
Dominant									
OBSERVED	Decrease	Increase	Neither	Total	**EXPECTED**	Decrease	Increase	Neither	Total
Control	1	3	1	5	Control	1.5625	3.125	0.3125	5
E1 & E2	4	7	0	11	E1 & E2	3.4375	6.875	0.6875	11
Total	5	10	1	16	Total	5	10	1	16
p-value = 0.2862									

Table 10. Chi-square Analysis of Gripping Endurance Test on Non-Dominant Hand

Gripping Endurance									
Non-Dominant									
OBSERVED	Decrease	Increase	Neither	Total	**EXPECTED**	Decrease	Increase	Neither	Total
Control	2	2	1	5	Control	1.875	2.8125	0.3125	5
E1 & E2	4	7	0	11	E1 & E2	4.125	6.1875	0.6875	11
Total	6	9	1	16	Total	6	9	1	16
p-value = 0.2789									

Pain Evaluation Comparison

No statistical significance was found when evaluating participants' perceived pain between both simulated long operations; however, there were some common trends. The five most common areas participants experienced pain were the webbing of the hand, thumb, fingers, wrist, and forearm. Figure 9 illustrates the number of participants that experienced pain in each of the aforementioned areas in each group. More specifically, researchers suspect pain was experienced in the following muscles; however, a more extensive evaluation is necessary to confirm what muscles were affected (e.g., electromyography):

Webbing of Hand: abductor pollicis, adductor pollicis, abductor pollicis brevis, flexor pollicis brevis, and first dorsal interosseus.

Thumb: opponens pollicis, abductor pollicis brevis, and flexor pollicis brevis

Fingers: pain experienced on the fingers was due to how the medical instruments were held with respect to the anthropometry of each participant's hands, usually on the knuckles of the thumb, middle, and ring fingers.

Wrist: flexor carpus radialis, flexor carpus ulnaris, and palmaris longus

Forearm: flexor digitorum profundus, flexor pollicis longus, flexor carpi radialis, and flexor carpi ulnaris

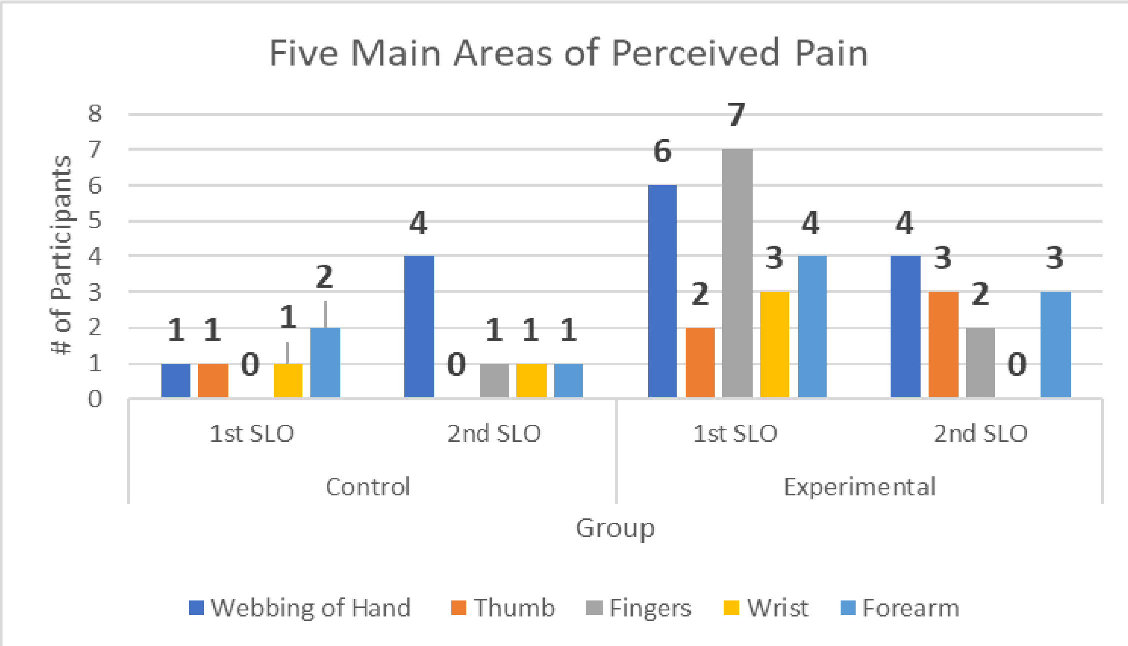


Figure 9. Bar Chart of Perceived Pain Among All Participants Between SLO #1 and SLO #2

Figures 10 - 17 depict where pain was experienced in the abovementioned areas and how many participants experienced it in each simulated long operation. As the blue hue deepens in richness, the number of participants who reported pain in that region increases. Among the control group, the number of participants experiencing pain in the webbing of the hand and fingers increased, while pain occurring in the wrist, thumb, and forearm either decreased or remained the same between both SLOs. Among the experimental group, the number of participants that experienced pain in the webbing of the hand, fingers, wrist, and forearm decreased, while pain occurrences in the thumb increased.

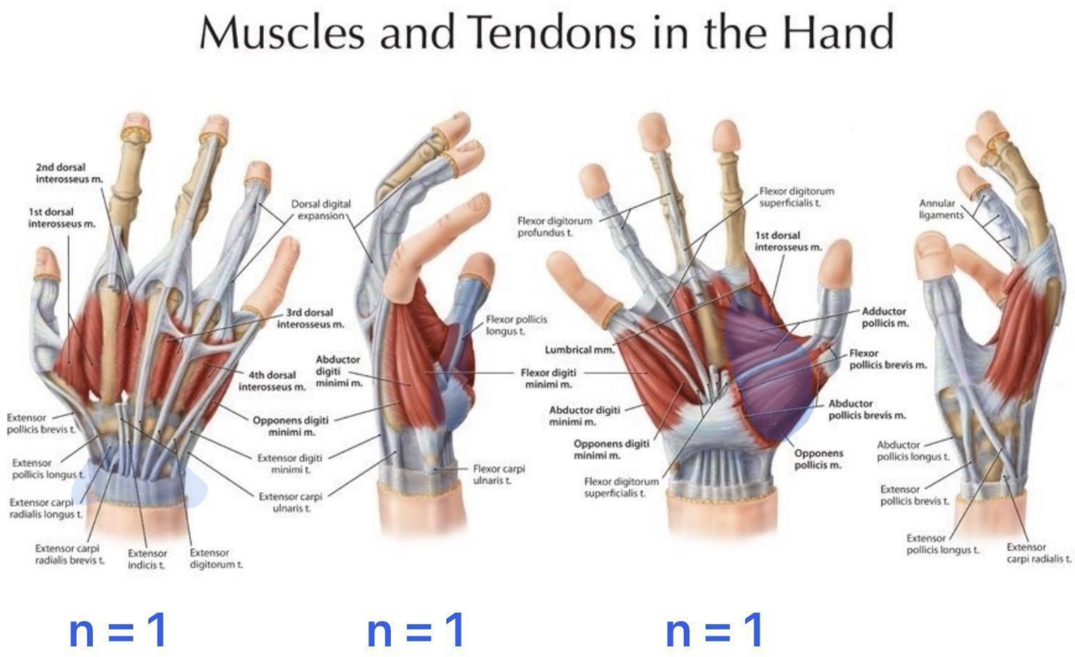


Figure 10. Control Group Perceived Pain in Hand After 1st SLO

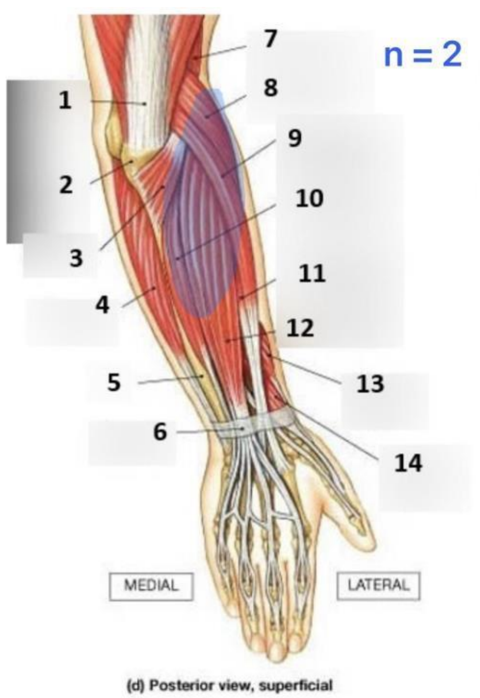


Figure 11. Control Group Perceived Pain in Forearm After 1st SLO

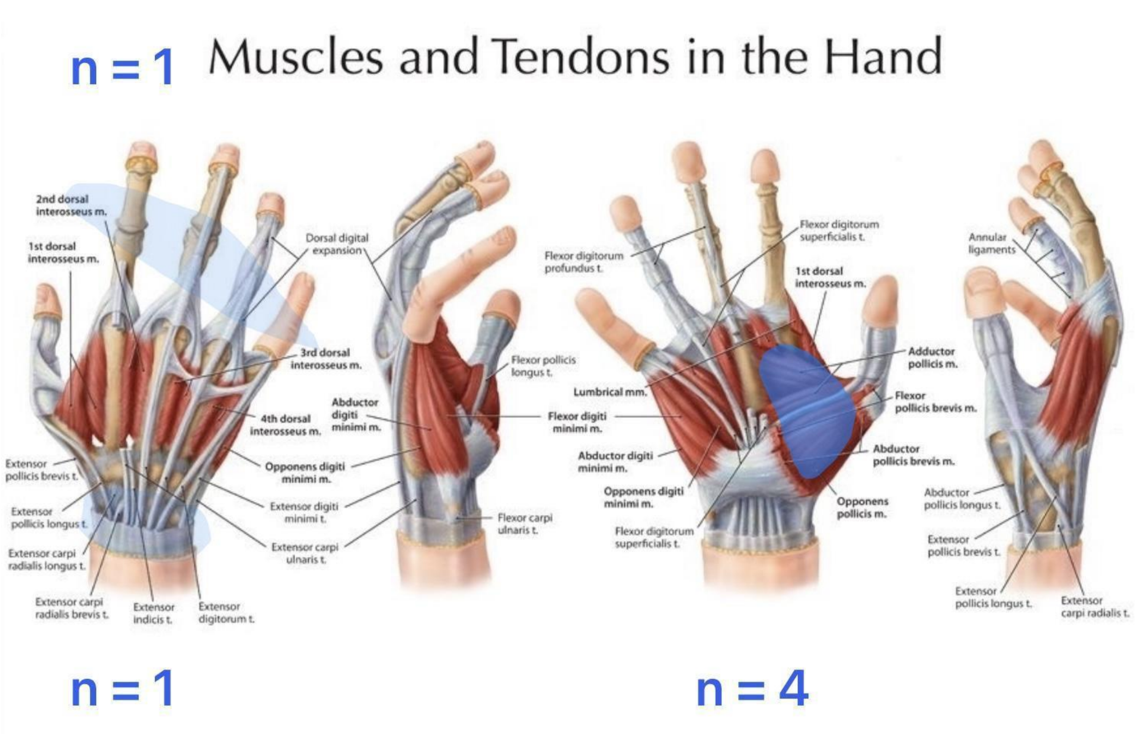


Figure 12. Control Group Perceived Pain in Hand After 2nd SLO

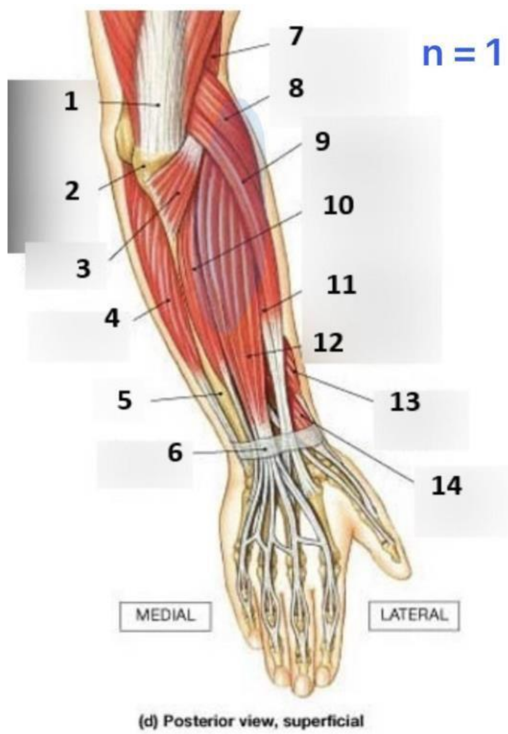


Figure 13. Control Group Perceived Pain in Forearm After 2nd SLO

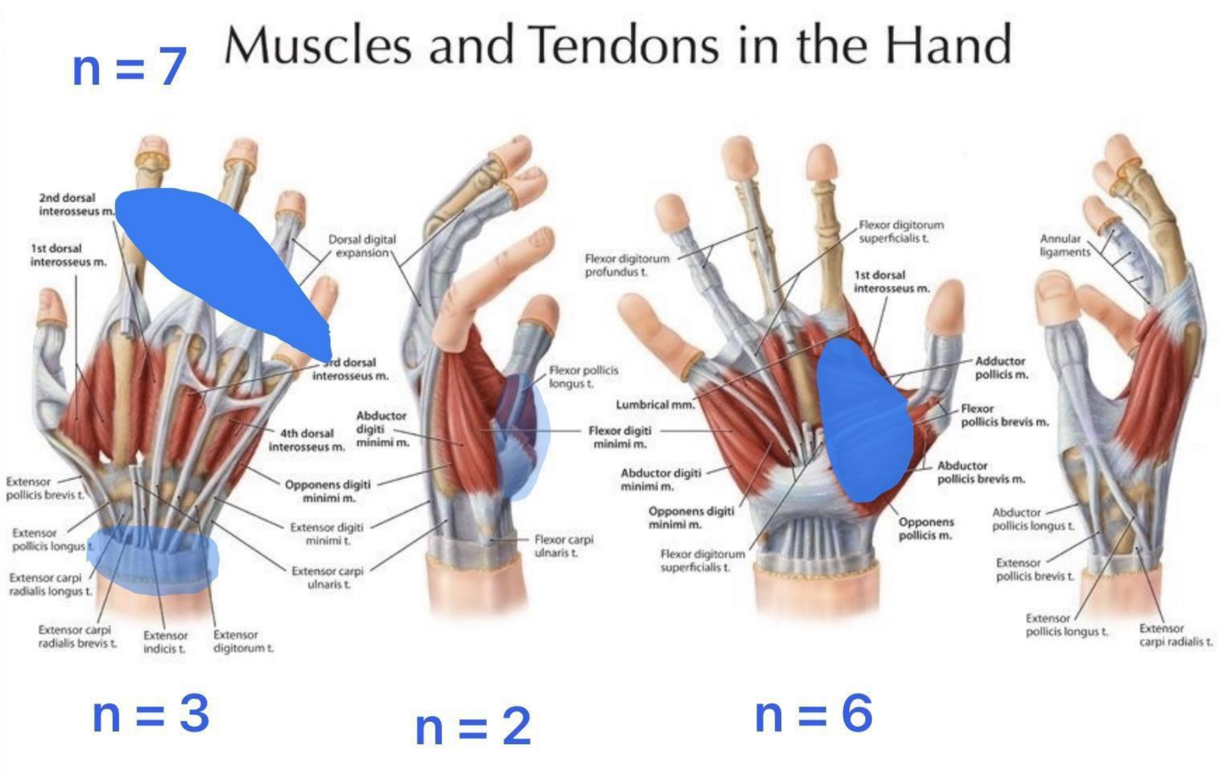


Figure 14. Experimental Group Perceived Pain in Hand After 1st SLO

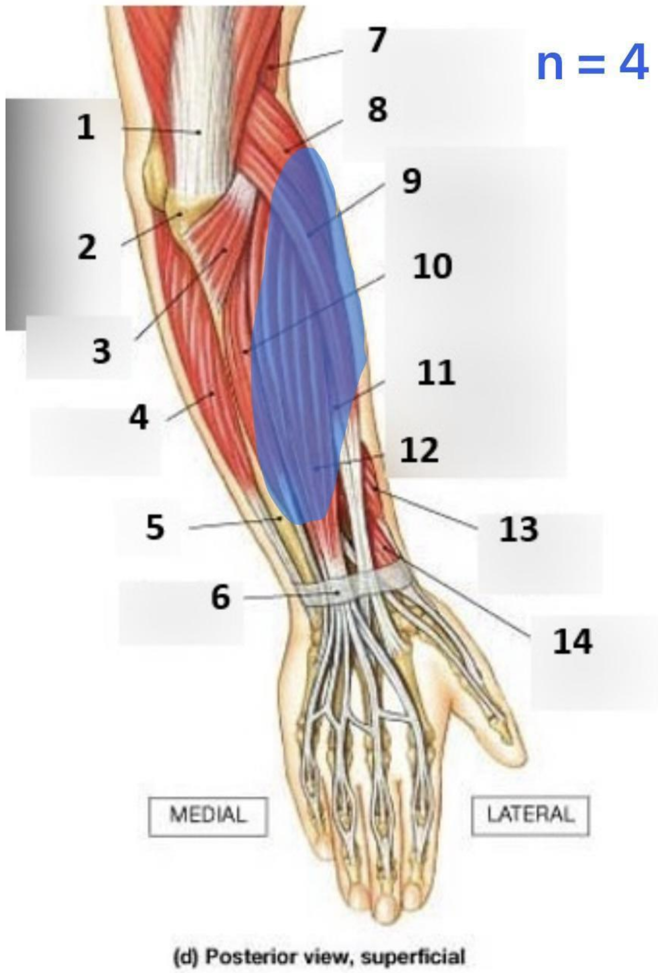


Figure 15. Experimental Group Perceived Pain in Forearm After 1st SLO

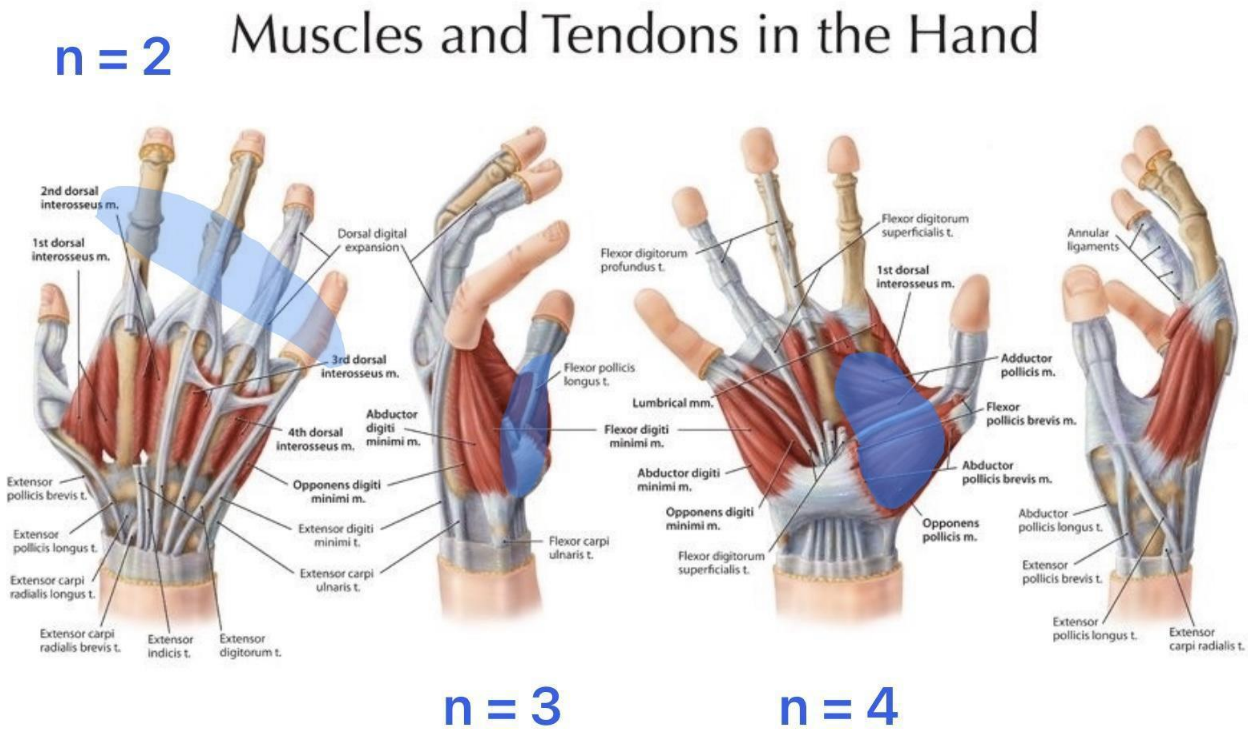


Figure 16. Experimental Group Perceived Pain in Hand After 2nd SLO

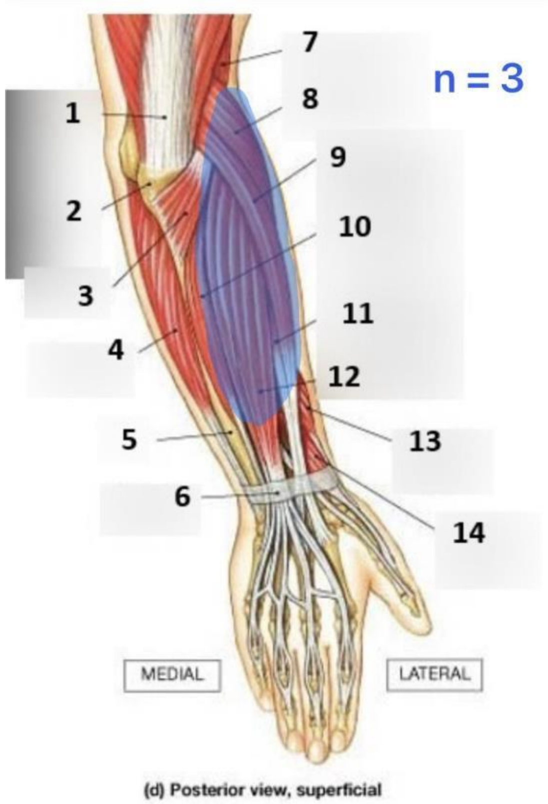


Figure 17. Experimental Group Perceived Pain in Forearm After 2nd SLO

Discussion, Limitations, and Future Work

Discussion:

Precision Metric

Upon evaluating the precision metric among experimental participants, 75% (n = 9) experienced either a decrease in distance or experienced no change in distance, while 45% (n = 5) experienced just a decrease in distance. This finding suggests that consistent resistance training may aid in the precise placement of sutures, though a more extensive study should be conducted to confirm this. Further, consistent resistance training for the hands, wrists, fingers, and forearms may aid in retaining precise suture placement for a longer period of time. Ensuring proper suture placement is key to the healing process and minimizing scar visibility, as this can be something people become self-conscious of. Proper suture placement is also important to the healing process because it evenly distributes tension on the skin. An uneven distribution of tension can lead to improper healing or, worse, a higher risk of infection (Waheed and Council, 2019).

Pinch and Grip MVC

Originally, researchers hypothesized that MVCs would increase after the ergonomic intervention. After evaluating the pinch and grip maximum voluntary contractions, of those experimented on, 72% (n = 8) increased their pinch maximum voluntary contraction (MVC) on either their dominant or non-dominant hand, and 45% (n = 5) increased their pinch MVC on both their dominant and non-dominant hand. Eighty-one percent (n = 9) of those experimented on increased their grip MVC in either their dominant or non-dominant hand, while 72% (n = 8) experienced an increase in their grip MVC on both their dominant and non-dominant hand. These findings suggest that actively engaging in consistent resistance training that targets the hands, wrists, fingers, and forearms can increase the overall pinch and grip strength of the dominant and non-dominant hands. Researchers suspect that improvements in participants' non-dominant side occurred for two reasons: 1) the muscles in the hands, wrists, fingers, and forearms are quite resilient to resistance given that they're used on a daily basis, and 2) most participants weren't used to exposing their non-dominant side to regular resistance training before the augmentation. Therefore, regular resistance training during the augmentation period of this study resulted in an increase in strength that their non-dominant side was not used to.

Pinch & Grip Endurance Test

Similarly, for pinch and grip endurance testing, 72% (n = 8) of those experimented on increased the number of complete contractions during the pinching endurance test on their dominant hand, while 81% (n = 9) increased in their non-dominant hand. Similarly, 63% of those experimented on experienced an increase in the number of complete contractions during the gripping endurance test on their dominant hand, and 63% experienced an increase in their non-dominant hand. These findings seem to suggest that actively engaging in consistent resistance training targeting the hands, wrists, fingers, and forearms can aid in improving the endurance of muscle groups responsible for pinching and gripping motions commonly used in surgery. Improving the overall endurance of these muscle groups can potentially delay the inevitable onset of fatigue that occurs during long operations.

Pain Evaluation

Researchers suspect that the pain experienced in the webbing of the hand, wrist, and forearm was caused by the repetitive pinching motion in the dominant hand from using the needle driver. More specifically, pinching caused pain in the webbing of the hand, while twisting most likely caused pain in the wrist and forearm. Pain experienced in the fingers was most likely due to the anthropometry of each participant's hand, given that all medical instruments used were the same size. In other words, smaller participants with smaller hands experienced more pain in their knuckles because they were capable of inserting their fingers into the loops on the surgical scissors, while larger participants with larger hands were not. Pain in the thumb, forefinger, and middle finger on the non-dominant side was most likely due to the pinching motion used when handling the forceps, creating pain and fatigue in those areas. Overall, experimental participants experienced a reduction in pain in the webbing of the hand, fingers, and forearm after undergoing their ergonomic intervention; however, other pain happened in other places in a seemingly random fashion.

<ins>Limitations</ins>:

This study suffered from several limitations. Due to the longitudinal nature of this study, researchers experienced a higher-than-expected attrition rate among participants. Researchers sought to retain more participants; however, only 16 fully completed it, resulting in statistically insignificant results. Researchers suspect that if a future iteration of this study was completed with more participants and over a longer period of time, then statistically significant results may be found; however, time constraints only allowed for 16 participants.

Among experimental participants, all muscle-strengthening and endurance-building exercises had to be completed at home and on the participants' own time. Researchers originally structured it this way to allow participants to choose when they performed the exercises. However, ideally, all participants would have been able to partake in the exercises in a more controlled setting and simultaneously with one another. A future iteration could be conducted regularly in a classroom setting. Unfortunately, scheduling those more controlled sessions was very impractical due to scheduling conflicts. A future iteration of this study could monitor participants more regularly with electromyography (EMG) on a more routine basis and over the course of a longer period of time. Researchers chose four weeks of augmentation based on their general knowledge of muscle growth and development when one is consistently exposed to resistance training.

To the best of the researchers' knowledge, participants practiced their suturing and exercises per their instructions, but there is no tangible proof. Also, given that all participants had to suture on the same dummy mannequin suture pad containing the 16 complex shapes during the first and second simulated long operations, the material began to fray, which may have affected the participants' ability to suture effectively. There wasn't enough material to continue remaking a suture pad large enough to replace the one on the dummy mannequin. Similarly, the quality of the medical instruments used (needle driver, forceps, and surgical scissors) was not the highest due to budget constraints. Lastly, the adjustable hand grippers didn't have a dial to show the exact resistance reading; therefore, a degree of guesswork was required, despite researchers demonstrating how to properly adjust the device.

Future Work

For future versions of this study, it would be beneficial to increase the number of participants and extend the duration of the study. Additionally, incorporating electromyography to examine affected muscles, potentially with medical students as subjects, could enhance researchers' comprehension. Electromyography, or other wearable devices, would enable more accurate monitoring of muscle movements and exertion while participants perform suturing tasks. Another future iteration could involve video recording analysis to determine if specific techniques may be associated with an increased risk of muscle pain and fatigue.

References

Anon, (n.d.). *CONTINUOUS SUTURE TECHNIQUE – Katsan Medican Devices.* [online] Available at: https://www.katsanas.com/en/continuous-suture-technique/#:~:text=CONTINUOUS%20SUTURE%20TECHNIQUE- [Accessed 20 Apr. 2023].

Li, W.-J. (2021). Basic Training of Orthopedic Suture Techniques. *Springer eBooks*, pp.57–74. doi:https://doi.org/10.1007/978-981-33-6330-4_5.

Streitz, M. (2021). *How To Do Plastic Surgical Repair With Buried Deep Dermal Sutures - Injuries; Poisoning*. [online] MSD Manual Professional Edition. Available at: https://www.msdmanuals.com/professional/injuries-poisoning/how-to-care-for-wounds-and-lacerations/how-to-do-plastic-surgical-repair-with-buried-deep-dermal-sutures [Accessed 24 Apr. 2023].

Veeraraghavan, R. (2021). *7 Simple Continuous Suture. ResearchGate*. Available at: https://doi.org/10.1007/978-981-15-1346-6_11 [Accessed 24 Apr. 2023].

Veeraraghavan, R. (2021). *4 Simple Interrupted Suture Technique. ResearchGate*. Available at: https://doi.org/10.1007/978-981-15-1346-6_11 [Accessed 24 Apr. 2023].

Waheed, A. and Council, M. (2019). *Wound Closure Techniques*. [online] Nih.gov. Available at: https://www.ncbi.nlm.nih.gov/books/NBK470598/.

Appendix A. Approval for Research (IRB)

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office of Research Ethics
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 04/14/2022

To: Kristina Schaffhausen   Richard T Stone

From: Office of Research Ethics

Title: The Effects of Muscular Endurance and Strengthening Exercises on Suturing Performance Among Novices

IRB ID: 22-029

Submission Type: Initial Submission   **Review Type**: Expedited

Approval Date: 04/14/2022   **Approval Expiration Date:** N/A

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, including the **recruitment materials and informed consent documents that have the IRB approval stamp**.
- Retain signed informed consent documents **for 3 years after the close of the study,** when documented consent is required**.**
- **Obtain IRB approval prior to implementing any changes** to the study or study materials.
- **Promptly inform the IRB of any addition of or change in federal funding for this study.** Approval of the protocol referenced above applies only to funding sources that are specifically identified in the corresponding IRB application.
- **Inform the IRB if the Principal Investigator and/or Supervising Investigator end their role or involvement with the project** with sufficient time to allow an alternate PI/Supervising Investigator to assume oversight responsibility. Projects must have an eligible PI to remain open.
- **Immediately inform the IRB of** (1) **all serious and/or unexpected** adverse experiences involving risks to subjects or others; and (2) **any other** unanticipated problems **involving risks** to subjects or others.
- IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are

protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

- Your research study may be subject to **post-approval monitoring by Iowa State University's Office of Research Ethics**. In some cases, it may also be subject to formal audit or inspection by federal agencies and study sponsors.

- Upon completion of the project, transfer of IRB oversight to another IRB, or departure of the PI and/or Supervising Investigator, please initiate a Project Closure to officially close the project. For information on instances when a study may be closed, please refer to the IRB Study Closure Policy.

If your study requires continuing review, indicated by a specific Approval Expiration Date above, you should:

- **Stop all human subjects research activity if IRB approval lapses**, unless continuation is necessary to prevent harm to research participants. Human subjects research activity can resume once IRB approval is re-established.

- **Submit an application for Continuing Review** at least three to four weeks prior to the **Approval Expiration Date** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.

Appendix B. List of General Instructions for All Participants on Simple Interrupted and Simple Continuous Suturing Techniques

Instructions*:*

Please read the following material on simple interrupted and simple continuous suturing techniques. Then, watch the provided YouTube videos and begin practicing for 2.5 hours per week for the next four weeks. Do NOT use any additional/outside resources. The researchers recommend you practice for 30 minutes each day, five days per week. You will also be required to perform a series of daily muscular endurance and strengthening exercises for your hands, wrists, fingers, and forearms using pinching and gripping motions (listed below). Please ensure that you are spending enough time on ***both*** *suturing techniques, and remember to practice the exercises on* ***both*** *hands. During these four weeks, you are encouraged to eat meals that are higher in protein, fruit and vegetable intake as your muscles develop from the exercises; however, do not go against any of your dietary needs. After four weeks, you will be asked to perform a simulated long operation that you will schedule with the researchers.*

The following explanations of simple interrupted and simple continuous suturing techniques are courtesy of an internet source and are not words written directly by the researchers

Simple Interrupted Suturing Technique

Some suturing techniques are quite specialized, but others are so versatile that they become almost second nature to medical professionals. Simple interrupted and simple continuous suturing techniques are commonly used in surgery for all kinds of wound closures. Simple interrupted sutures fall into the latter category because they can be used in multiple situations and wound locations.

One of the primary risks of closing a wound with sutures is the possibility of the patient breaking a stitch. Whether the knots were tied improperly, an inappropriate suturing material was used, or the patient resumed activity too quickly, a broken stitch can potentially lead to wound dehiscence, which is when the wound edges pull apart and reopen the tissue layers. When a wound is closed with a continuous running suture, only a single suture strand is used across the length of the laceration. Should that strand break, the rest of the suture will lose its tension, greatly increasing the likelihood of wound dehiscence.

The simple interrupted suture provides some protection against this possibility. Rather than using a single strand to pull the wound edges closed, simple interrupted sutures consist of multiple stitches placed close together, which distributes tension more evenly across the length of the wound site and helps to keep the tissue edges from coming apart even if one suture breaks. The name for this technique comes from the fact that the individual stitches aren't connected to one another.

When to use a simple interrupted suture

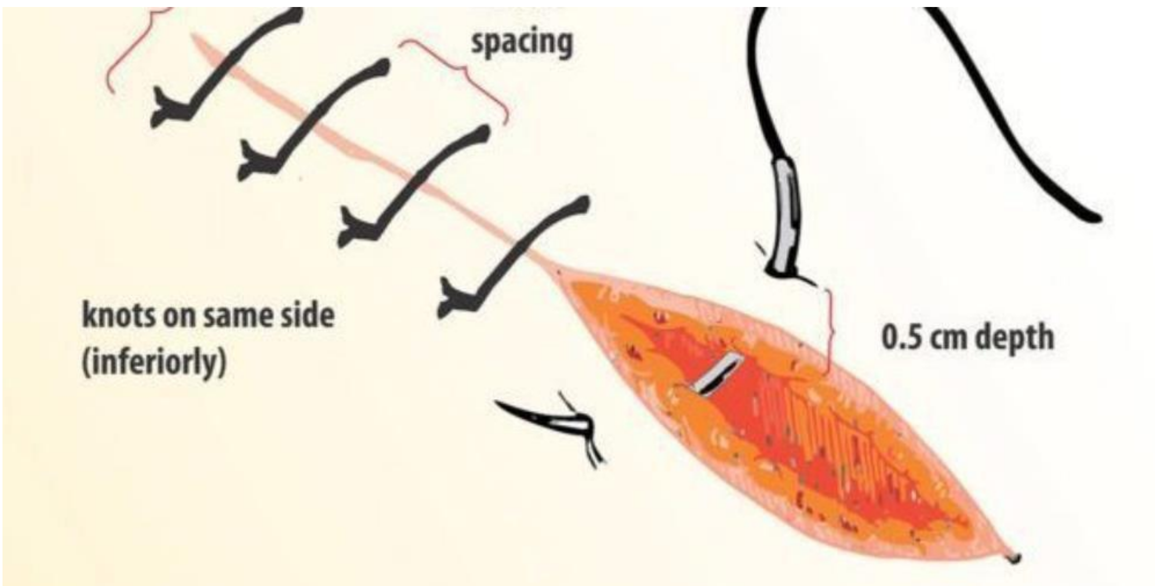
The short answer is almost any time! Simple interrupted sutures are among the most commonly used techniques in wound closure because they offer a number of advantages over a continuous running stitch. They are easier to place since they consist of only a single, shorter strand. Used together, they offer much higher tensile strength over a greater area. In the event of an infection or a broken stitch, individual sutures can easily be removed and replaced without compromising wound closure. This is especially valuable in the event of infection, which may require a portion of the wound to be cleaned or drained of fluid.

Disadvantages of simple interrupted sutures

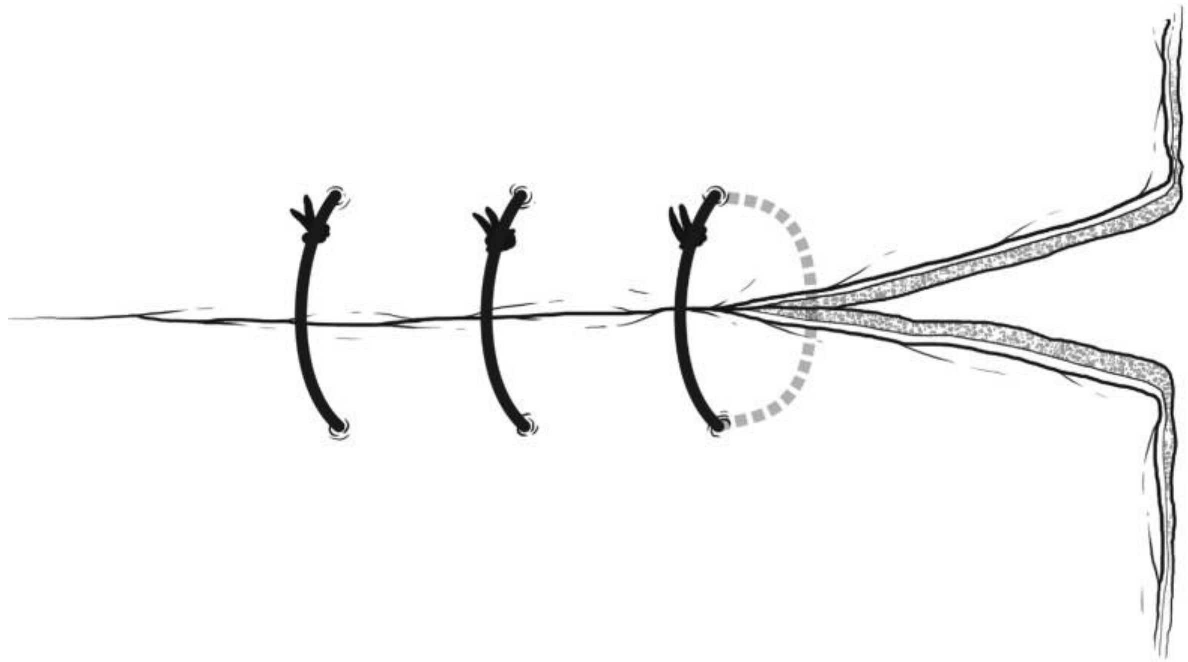
Unfortunately, some of those unique characteristics can also create complications. Each suture must be tied off with its own knot. If the knot is not tied correctly, it could cause damage to the surrounding tissue or lead to an infection. Since each suture must be carefully placed along the wound edges, closing a laceration with simple interrupted sutures can often be quite time-consuming. More importantly, if the wound edges are not properly aligned, significant scarring could result as the wound heals.

Please watch the following YouTube video for a tutorial on simple interrupted suturing:

1. https://www.youtube.com/watch?v=NnKdmjX5pWU Overall Introduction to Suturing
2. https://www.youtube.com/watch?v=Akyr4zlBS9E (0:00 – 3:52) for Simple Interrupted



Example #1 of Simple Interrupted Suturing



Example #2 of Simple Interrupted Suturing

Simple Continuous Suture Technique

It is a suture technique that provides a way to close the wound with a single suture. It is similar to the simple interrupted suture technique, but unlike simple interrupted sutures, knots are not tied at every stitch. Only the first and last stitches are fixed by knotting. It is easy to apply, frequently preferred suturing technique that provides eversion.

Initially, a simple interrupted stitch is placed at one end of the wound. This suture is knotted but not cut. Simple continuous sutures are placed over the length of the wound, re-penetrated the epidermis, and passed dermally or subcutaneously. It is important to place each stitch on equal distance in the simple continuous suture technique. The application is terminated by a single knot at the end of the suture line. If a wound is longer than can be easily closed by simple interrupted or interrupted horizontal mattress suture, a continuous suture technique can be used to perform the closure efficiently.

The most frequently used continuous suture technique is the non-locked suture technique. In this technique, the distance between the stitches is about 1 to 1.5 cm. When placing a non-locked continuous suture; it is useful to provide a slight tension on the placed suture loop while the next tissue transition is performed. This prevents the suture from loosening in the tissue when performing any additional sutures. The tension may be provided by the surgeon's hand or by the assistant, not by the needle holder.

Advantages

The primary advantage of this technique is its simplicity and speed of stitch placement over other techniques. The suture length used is less. It ensures that the tension is evenly distributed along the suture line. It is useful for long wounds where wound tension is minimized with properly placed deep sutures. It is also useful for fixing a full or split-thickness skin graft. There is less scarring compared to the simple interrupted suture technique. Closing the tissue using a simple continuous suture technique is an advantageous technique because of its hemostatic properties and reduced tissue deterioration. When using this technique, there is not a requirement to knot each stitch; this makes suturing a long wound faster and leaves fewer knots to collect debris.

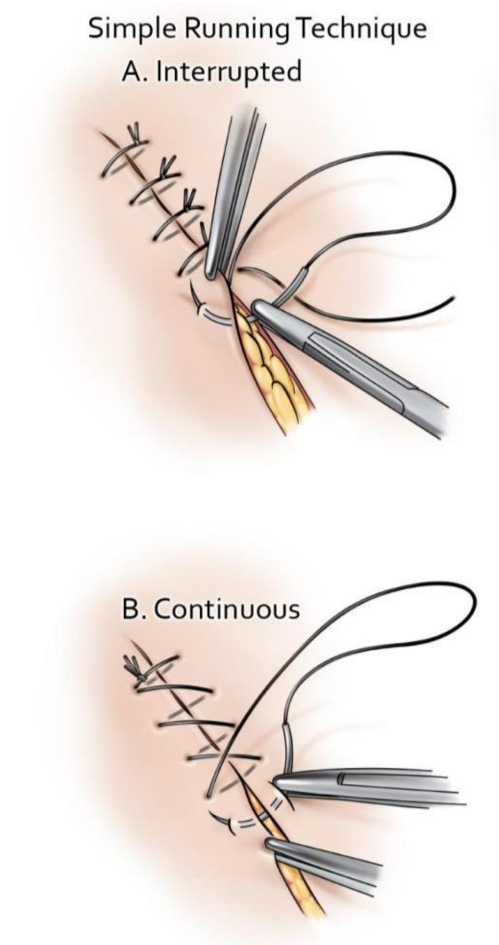
Disadvantages

The possibility of tissue dehiscence may be higher in tissues closed by this technique, because only two ends of the suture line are knotted. If one of the knots is damaged or opened, the entire suture line will be damaged. One of the disadvantages is that continuous suturing allows for the transmission of infection along the suture line. If continuous suture technique is used in infected tissues, the risk of infection transmission can be reduced by choosing a monofilament material as a suture type. Monofilament sutures are not capable of accommodating microorganisms like multifilament sutures. A disadvantage of a continuous suture is that if a suture enters or breaks through the tissue, the entire suture has to be loosened or removed.

Please watch the following YouTube video for a tutorial on simple continuous suturing:

1. https://www.youtube.com/watch?v=Akyr4zlBS9E (9:32 – 11:05) for Simple Continuous/Running

Example #1 of Simple Continuous Suturing Technique



Visual comparison between simple interrupted and simple continuous suturing techniques

Appendix C. List of Exercises for Experimental Participants During Weeks 5-8

Complete all exercises on both hands every day for the next four weeks using the adjustable hand gripper provided to you.

Please note: All participants received short videos on how to perform all of the numbered exercises listed below; however, they are not shown in this document.

Please note: All numbered exercises listed below were customized to each participant based on their respective maximum voluntary contraction (MVC) readings obtained at the beginning of the study on pinch and grip dynamometers.

Muscle-Strengthening & Endurance-Building Exercises:

1. Hand grip holds at __% of MVC (kg.) using all 5 fingers

   Complete 5, 1-minute holds with 30 seconds of rest between each hold

   a. Week 5 = 80%; Week 6 = 85%; Week 7 = 90%; Week 8 = 95%

2. Pinch grip holds at ___(kg) using thumb, index, and middle finger

   Complete 5, 1-minute holds with 1 minute of rest between each hold

   a. Week 5 = 5 kg; Week 6 = 5 kg; Week 7 = 10 kg; Week 8 = 10 kg

3. Hand grip hold until failure at MVC (kg). Perform a grip hold until failure (until you cannot hold anymore) at your recorded MVC

4. Pinch grip hold until failure at _(kg). Perform a pinch hold at the following resistances each week for the next four weeks.

   a. Week 5 = 5 kg; Week 6 = 5 kg; Week 7 = 10 kg; Week 8 = 10 kg

5. Maximum amount of pinches at _(kg) in 1 minute using thumb, index, and middle fingers. Perform as many pinches as you can in 1 minute at each of the following resistances.

   b. Week 5 = 5 kg; Week 6 = 5 kg; Week 7 = 10 kg; Week 8 = 10 kg

6. Maximum amount of grips at _ % of MVC (kg) in 1 minute. Perform as many grips as you can in 1 minute at each of the following resistances.

   c. Week 5 = 80%; Week 6 = 85%; Week 7 = 90%; Week 8 = 95%

7. Sets of 10 pinches at 5 kg. increments, until failure to perform 10 pinches (starting at 5 kg). If you cannot exceed 5 kg of resistance, then perform 4 sets of 10 pinches at 5 kg of resistance.

8. Sets of 10 grips at 5 kg increments, until failure to perform 10 grips (starting at 75% of MVC). If you cannot exceed a resistance above 75% of your MVC, then perform 4 sets of 10 grips at 75% of your MVC.

9. Maximum amount of pinches until failure at 5 kg of resistance.

10. Maximum amount of grips at MVC until failure

11. Pinch twists (3 sets of 10 reps) at ___(kg)

    a. Week 5 = 5 kg; Week 6 = 5 kg; Week 7 = 10 kg; Week 8 = 10 kg

12. Grip twists (3 sets of 10 reps) at __% of MVC (kg)

    a. Week 5 = 80%; Week 6 = 85%; Week 7 = 90%; Week 8 = 95%

CHAPTER 3. GENERAL CONCLUSION

The study's findings offer insights into the effects of muscle-strengthening and endurance-building exercises on suturing performance and related factors, such as perceived pain and fatigue. The results indicate that consistent resistance training can improve performance and reduce pain in the hands, wrists, fingers, and forearms, which are crucial for surgical procedures.

The 45% decrease in the distance between the final two complete sutures observed among the experimental participants is particularly noteworthy, as it demonstrates the potential for resistance training to enhance the precision and accuracy of suturing. The 45% and 72% increases in pinch and grip MVC, respectively, highlight the benefits of resistance training in improving overall hand strength, which is essential for performing various surgical tasks, including suturing. Furthermore, the reduction in pain in the webbing of the hand, fingers, and forearm after the ergonomic intervention underscores the importance of addressing ergonomic factors in surgical environments. Overall, the results of this study provide a case for the potential incorporation of resistance training and ergonomic interventions into the training and practice of medical professionals. By doing so, it may be possible to reduce the risk of injury, improve surgical performance, and enhance patient outcomes.

Several limitations must be addressed before drawing definitive conclusions. For instance, the small sample size limits the generalizability of the results. Additionally, the study did not identify the specific muscles impacted by resistance training, which could provide further insights into the mechanisms underlying the observed improvements in performance and pain reduction. Further research is needed to address these limitations and to identify the optimal resistance training protocols and ergonomic interventions for medical professionals. Such research could have significant implications for improving the safety, efficiency, and quality of surgical procedures, which could ultimately benefit patients, medical professionals, and healthcare systems as a whole. In conclusion, this study highlights the potential benefits of resistance training and ergonomic interventions for medical professionals, particularly with respect to suturing performance and related factors. The findings underscore the importance of incorporating such interventions into medical training and practice and provide a compelling rationale for further research in this area.