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Development and Evaluation of Rhinoplasty Spreader Graft Suture Simulator for Novice Surgeons

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Abstract

Objective: Surgical simulators aimed at mimicking elements of rhinoplasty surgery, specifically those aimed at improving cartilage suturing, are not available. Here we present a surgical simulator for spreader graft placement that uses cartilage rather than synthetic materials, and gauge improvement using objective measures for suture placement accuracy, speed, and efficiency of hand motion.

Methods: 22 otolaryngologists in two groups (residents (10) and experts (12)) were instructed to secure the two spreader graft specimen into position with three mattress sutures on a nose model that used porcine septal cartilage as a proxy for the human counterpart. Hand motion was tracked using an electromagnetic position sensing device. Time required to complete the suture task, total hand displacement, cumulative number of hand motion direction changes, and accuracy of suture insertion were measured. These measurements were compared between the two cohort groups for construct validity. The subjects completed a survey to evaluate realism and value of the model.

Results: The expert group had a lower mean time required to complete the task ($p < 0.05$), total hand displacement ($p < 0.01$), and number of hand motion direction changes ($p < 0.001$). No significant difference was observed between the two groups in suture precision measurement. The subjects agreed on the face validity and usefulness of the trainer.

Conclusions: Our study suggests that the simulator may be a useful tool to objectively gauge suturing efficiency. Devices such as this may be useful for developing skill with suturing cartilage tissue and potentially be used as a means to assess resident acquisition of surgical skill.

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Keywords

Rhinoplasty; Nasal Reconstruction; Spreader Graft; Simulator; Electromagnetic Tracker

Introduction

Surgical simulators aimed at training young surgeons to perform complex tasks have been extensively utilized and their outcomes rigorously evaluated, providing a path for national certification examinations that assess skill sets based upon dexterity[1–3]. While high-fidelity simulators that allow a full surgical procedure to be performed are exciting, simulators that facilitate a variety of task-specific maneuvers may allow evaluation of surgical skills over time. The need for instructional surgical simulation is readily apparent as federally mandated duty-hours potentially limit surgical exposure and subsequently the loss of opportunities of autonomous operations[4]. Likewise, with resident surgical skill evaluation it is now incumbent upon the training programs to objectively evaluate surgical skill, and as rhinoplasty is inherently cosmetic, true teaching opportunities may be too few to provide adequate experience.

In otolaryngology, surgical simulation has naturally favored endoscopic sinus surgery and temporal bone surgery[5–8]. These are operations that traditionally have limited surgical exposure and often allows only one surgeon to perform the task, making teaching challenging[9]. Novice and expert surgeons alike have reported that the use of these simulators and cadaver dissections facilitate the acquisition of surgical skills. Similarly, rhinoplasty operations provide limited exposure in a narrow operative field which may preclude ideal visualization of surgical maneuvers. In comparison to traditional methods where novices acquire surgical skills by initially assisting and subsequently operating on patients, the narrow margin for error and the technical precision in cosmetic surgery requires trainees to acquire additional practice. Access to appropriate patients suitable for residents to perform elements of the operation is yet another limitation, as most cosmetic surgery patients are operated on by an attending with a fellow in assistance. Suturing cartilage is unique to facial plastic surgery, and the skills required to handle these tissues differs from what is potentially developed in soft tissue operations. While practice modalities for rhinoplasty have been studied, no model has focused on emulating open graft-specific placement using material that resembles septal cartilage in a human nose[10,11].

To validate the effectiveness of training models for surgery[12–19], precision and accuracy of suture placement have been used as a method to measure and compare the skill of residents and experts objectively[20,21]. More recently, hand motion has been objectively tracked using either optical or electromagnetic devices in laparoscopic, robotic, and open surgery, and also for assessment of IV insertion and sonography procedures[14–16,19]. Efficiency and economy of motion quantified by task completion time, path length, and number of movements/ direction changes correlated with the level of expertise[15,18,19,22,23].

The aim of this study is to evaluate a surgical trainer that mimics spreader graft placement using fresh porcine cartilage tissue, and electromagnetic motion tracking as objective outcome measures. We compared residents' and expert rhinoplasty surgeon performances for reliability and construct validity. Following evaluation, face validity and content validity of the spreader graft model was assessed to evaluate the effectiveness of the model as a training tool.

Methods

Subjects

A total of 10 otolaryngology residents at our academic institution (ranging from postgraduate years 1 to 5) and 12 practicing facial plastic surgeons with significant rhinoplasty experience (>10 years) from multiple institutions completed the given tasks on the trainer and completed the survey.

Nasal Model

Porcine costal cartilages were obtained from a local abattoir. One large cartilage graft (2 × 15 × 25 mm) mimicking the quadrangular cartilage and two cartilage grafts used as spreaders (2 × 5 × 20 mm) were prepared using a costal cartilage graft sectioning device[24]. The dimensions of the spreader grafts were obtained by averaging spreader graft dimensions of 30 consecutive rhinoplasty patients previously operated on by the senior author. On the lateral face of the cartilage grafts, three pairs of ink dots were marked 4 mm apart from each other, with each pair placed 2 mm from each other (Figure 1). This provided a framework for suture placement.

To simulate performing spreader graft procedure on a patient, a jig was 3D printed to emulate the contour of the human nasal septum (Formlabs, Somerville, MA) and fastened to a plastic skull (Figure 2 B–C). Cartilage representing the dorsal quadrangular cartilage was secured using nut and bolt. The subjects were asked to position two spreader grafts bilaterally on the sides of the dorsal quadrangular cartilage and secure the three layers of cartilages using two 30 gauge needles. The set-up of the study in shown in Figure 2A.

Data Collection

“Suture” and “Tie” Tasks—The task was segmented into two types of skills for assessment: “suture” and “tie”. “Suture” task was defined as inserting the curved suture needle through the three layers of cartilages (1 quadrangular cartilage and 2 spreader graft cartilages). The “suture” task was followed by a “tie” task, which was defined as completing 1 surgeon’s knot proceeded by 4 single knots. Each subject performed 3 “suture” tasks and 3 “tie” tasks.

In the “suture” assessment, the subjects were required to pass a curved needle through the cartilage graft-septum complex such that the pathway is perpendicular to the plane of the cartilage, and does not drift caudally or cephalically. Ideally, the needle entered and exited at the same level and distance from the anterior edge of the septal cartilage on the opposite side. In addition, the subject was required to insert the needles as close to the pre-marked dots as possible (Figure 1). An assistant cut the suture when directed by the subject. 5–0 PDS II violet monofilament suture (Ethicon, Cincinnati, OH) was used for all suturing.

During the entirety of the task, a digital video camera mounted above the subject and recorded the procedure.

Tracking Hand Movements with Electromagnetic Tracker—trakSTAR (Ascension Technology, Shelburne, VT), a real-time position tracking system with 6 degrees of freedom sensors, was used to measure the xyz coordinates of the hand location in mm relative to time (Figure 3). trakSTAR is an electromagnetic tracking unit that utilizes pulsed direct-current magnetic fields to track position of the attached sensors. The trakSTAR sensors was secured to the back of the subject's dominant hand. Time taken to complete the task and position data from the trakSTAR device was recorded starting from when the subject initiated suturing to when the subject made the last tie.

Questionnaire—After the completion of the tasks, the subjects completed a questionnaire to rate content validity and usefulness of the training model (Table 1). Question 1 rated the availability of current practice modalities for rhinoplasty. A score of 1 indicated that sufficient modes of practice are available, while a score of 5 indicated that insufficient modes of practice are currently available. Questions 2 and 3 rated the face validity of the spreader graft model, with 1 indicating that the model reflects an actual spreader graft procedure and 5 indicating that it is nothing like an actual spreader graft procedure. Question 4 and 5 rated the content validity, with 1 indicating that the spreader graft model was useful for training, and 5 indicating that it is not useful. The questions are listed in Table 2.

Data Analysis

Four task-specific modes of evaluations were completed to assess time, efficiency and accuracy: 1) total time taken to complete the given task, 2) path length traveled by the hand in completing the task, 3) number of hand movement made in completing the task, 4) accuracy of needle insertion.

Total Time Taken to Complete Task—The time taken to complete the task was averaged for the resident and the expert groups and Student's t-Test was performed.

Path Length Traveled—Using the recorded video, the time intervals during which each "suture" and "tie" was performed were defined. These time intervals were correlated with the time data collected by trakSTAR, from which the corresponding position data for each "suture" and "tie" were defined. Then, the position data was used in the algorithms implemented in Matlab (MathWorks, Natick, MA) to calculate the total path length traveled (mm) for each "suture" and "tie" task. The mean of the 3 "suture" and 3 "tie" were calculated for each subject. Subsequently, the mean of the path length of the subjects in corresponding resident and expert groups were calculated. Student t-tests were done between the resident and expert group.

Number of Hand Movements—Discrete movements were defined as detected change in velocity greater than 15mm/s[19]. Using Matlab algorithms, the change in velocity at each recorded time was calculated. The number of occurrences when the change in velocity was greater than 15mm/s were calculated for each "suture" and "tie" task. Similar to analysis of path length traveled, the means were obtained for resident and expert group and Student t-test was done.

Accuracy of Needle Insertion—To estimate suture placement accuracy, the sutured cartilage was removed from the jig, placed adjacent to a ruler, and photographed from both sides. The distance from the actual suture insertion site to the center of the target mark was measured for each of the six target markings using image processing software (ImageJ, NIH, Bethesda, MD).

Results

The experts performed the task in significantly less time (mean 254 s) than the residents (mean 312s) ($p < 0.05$) (Figure 4A). The experts had significantly less path length traveled for both “suture” task (4206.2mm experts, 6708.6mm residents, $p < 0.001$) and the “tie” task (2004.3mm, 2958.3mm residents, $p < 0.01$) (Figure 4B). The experts had significantly less hand movements made for both “suture” task (192.6 experts, 334.8 residents, $p < 0.001$) and the “tie” task (108.6 experts, 195.4 residents, $p < 0.001$) (Figure 4C).

A greater difference was observed in the path length and number of hand movements between the expert and resident groups during the “suture” than during the “tie”. In addition, a greater standard deviation in all of the parameters were observed in the resident group than in the expert group.

The precision of suture insertion into the cartilage is illustrated in Table I. While the mean of distance from the suture insertion site to the center of the marked dot is smaller for the expert group than the resident group, the difference was not significant.

Table 2 shows the results of the validation questionnaire. Both the resident group and the expert group agreed about: 1) the current lack of opportunities to develop spreader graft skill (question 1), 2) the face validity of the model (questions 2 and 3), 3) the usefulness of the model for training (questions 4 and 5), and 4) increase in confidence of the surgeon after using the model (question 4), and 5) recommendation of the model for any otolaryngology residents to improve his/her skill with this maneuver (question 5).

Discussion

Precision suture placement in cartilage is a challenging task and a skill that requires years to acquire precision and accuracy. Cartilage is an unforgiving tissue unlike soft tissues from which vast majority of head and neck surgeons’ surgical skill set is derived. Cartilage can be inadvertently damaged by multiple attempts at needle passage or by the aggressive use of forceps. Torque produced by angular placement of the needle when a straight perpendicular trajectory is required may result in compromise of cosmetic outcomes. Unfortunately, skill acquisition in rhinoplasty for otolaryngology residents in rhinoplasty is limited. Recently, it has been reported that that the average otolaryngology resident only performs 25 rhinoplasty operations[25]. Plastic surgery residents perform an order of magnitude fewer[26]. This is amplified by changes in surgical training imposed by duty hour restrictions[4,27].

It should come as no surprise that experienced rhinoplasty surgeons spend less time and made less hand movements than the residents. Figure 4A shows that the experienced group had a significantly faster task completion time than the resident group. The total time taken to complete the task is a reflection of the efficiency of the surgeon, and has been shown in similar studies to have strong correlation with expertise level[15,23]. While the difference in the time taken to complete the task may be statistically significant, the difference of approximately 1 minute may not have clinical significance, and therefore may not result in overly increased operative time when a resident is included in the operative case[28]. Nevertheless, when one considers the time required to perform several maneuvers during primary and revision cases, and the relative complexity of spreader grafts compared to other grafting techniques, this may amount to a clinically significant finding. In addition, it was demonstrated that the total path length traveled and the number of movements in both suture and tie task was significantly smaller in the expert group compared to the resident group. The economy of motion improves in the experienced hands along with the subjective progress in aptitude[15,29]. This is in correspondence with the results found in studies with laparoscopic surgery, robotic surgery, and other open surgeries[15,29,30].

For both total path length traveled and the number of hand movements, a greater significance was observed in the “suture” than in “tie”. This may be due to the complexity of the “suture” task in comparison to the “tie” task. Because medical student suturing skills labs frequently focus on soft tissue suturing as opposed to cartilage, most novice surgeons may be unfamiliar with suturing through the complex cartilage structure[31]. Meanwhile, the knot tying task is comparable in both the cartilage model and in soft tissue model with regard to overall technique. In addition, when placing the sutures, the surgeon must be astute to the potential damage cartilage may sustain following repetitive suture attempts[32]. Lastly, overly aggressive tension created during suturing may cause the suture to cheesewire through the tissue[32], a known issue that disrupts the integrity of the graft.

No significant difference was observed between the residents and the experts in the accuracy measurement. In actual rhinoplasty surgeries, cartilages are not regularly pre-marked with dots, and surgeons make sutures in areas based on needs of the particular situation. The markings used for standardization may have created an artifact for expert surgeons, explaining the lack of difference in accuracy between the residents and experts. Additionally, several expert surgeons generally utilize a straight needle for this procedure and not a curved one as given in this study. Nevertheless, the pre-marked dots on the cartilages may allow residents practice and improve the accuracy of needle insertion, as the task of passing a curved needle through three layers of cartilage in a straight manner may be difficult for the novice. Furthermore, it provides an objective mean to measure the accuracy by setting a target. Not having a target would complicate the task, as each operator has a varying sense of what is ideal.

In addition, the resident group was generally younger than the expert group, which may have led to the decline in precise needle insertion by experts. The increase in hand tremor and loss of vision correlated with aging may have led the older expert group to insert the sutures with less precision[33,34]. Furthermore, many of the expert surgeons recruited usually wear loupes while performing these procedures. The decline visual acuity for subjects over 40 years of age is pronounced by lack of magnification device such as loupes[35]. While the markings were created as the ideal point for suture entry, we did not analyze whether the position correlated with “proper” placement of the spreader grafts as a whole.

In designing the study, we decided omit the process of cutting the spreader graft and provided standardized grafts prepared using a cartilage sectioning device[24] to avoid introducing misclassification bias of varying cartilage thickness which may affect the outcome of economy of motion during suturing. As for the pinning process of the cartilages, while it was not analyzed in our study, the authors acknowledge the importance of mastering graft placement prior to suturing and will include this in future skill-acquisition analysis. In addition, while we were unable to compare the differences in skill level between residents with varying years of experience due to the small sample size, a future study with larger multi-institutional group or one analyzing residents of different levels (i.e. at a national meeting) would add further dimension to our study.

While electromagnetic tracker unit may be sensitive to metal objects that can potentially distort the magnetic field, it was utilized in this study to track the hands of the subjects because of its ease of availability and its allowance for fluidity of movement. Other tracking systems such as optical tracking unit requires the target to be in the sight of the tracking system, which may limit the movement of the surgeon as he has to be aware that his hands are in the field of vision[36]. In contrast, electromagnetic tracker does not require that a direct line of sight is maintained, which allows fluidity of movements that mimics a real surgery.

On the whole, there is a general consensus from participants that sufficient models for practicing this technique are not readily available, and that our system would be useful and should be recommended for resident training. The questionnaire results suggest that the spreader graft model is a plausible training modality for residents.

Several limitations exist with this study. While our survey participants agreed that this model accurately reflected in vivo suturing, there are clear differences between suturing porcine costal cartilage on a practice model and human septal cartilage with respect to their biomechanical properties[37]. Nevertheless, the triphasic properties of costal cartilage mimic a nasal cartilage closer than an artificial material such as rubber or elastomer. Secondly, the participants were given a wide exposure with the model, one that is not afforded to the surgeon constrained by a limited surgical field and overlying skin/soft tissue envelope. Nonetheless, the wide exposure of the cartilage may allow novice surgeons who are working with cartilage for the first time to have a visual orientation of the procedure. Thirdly, generalizability of the survey remains a key limitation as the model is designed to test one specific skill as opposed to broader applicability that may be available in other surgical simulations. Nevertheless, the overwhelming majority of participants agreed that residents would benefit from this model despite the potential limitations. Lastly, our study is inherently limited by the use of one rhinoplasty grafting technique in an artificial model. The purpose of this design was to determine whether 1) grafting techniques could be quantitatively assessed, and 2) whether there was consensus on the need for such a device. In the future, we hope to perform studies using greater sample size, measuring skill acquisition over time, and use cadaveric tissue to further validate the model and provide greater breadth of technique exposure.

Collectively, the spreader graft model has demonstrated to be a reasonable training model with objective assessment for residents as evidenced by statistically significant difference between the resident and the expert groups. The standardized components of this study allowed for objective assessment and comparison of the subjects' surgical performance. The uniform sizes of the grafts, the availability of the markings, the use of same lighting, and the use of same equipment allowed the participants to be evaluated under similar conditions. The standardization also allows for future study of the advancement of the surgeon's skills over time.

Conclusion

The rhinoplasty simulator is a novel objective platform that allows surgeons to practice on cartilage rather than artificial materials. Efficiency of hand movement evaluated by the rhinoplasty simulator is associated with surgeon skill level, suggesting that the simulator may be a useful tool to objectively assess and train surgeons. In alignment with participant feedback, our device may be useful for developing skill with suturing cartilage and may be valuable when used as an objective measure to assess resident acquisition of surgical skill.

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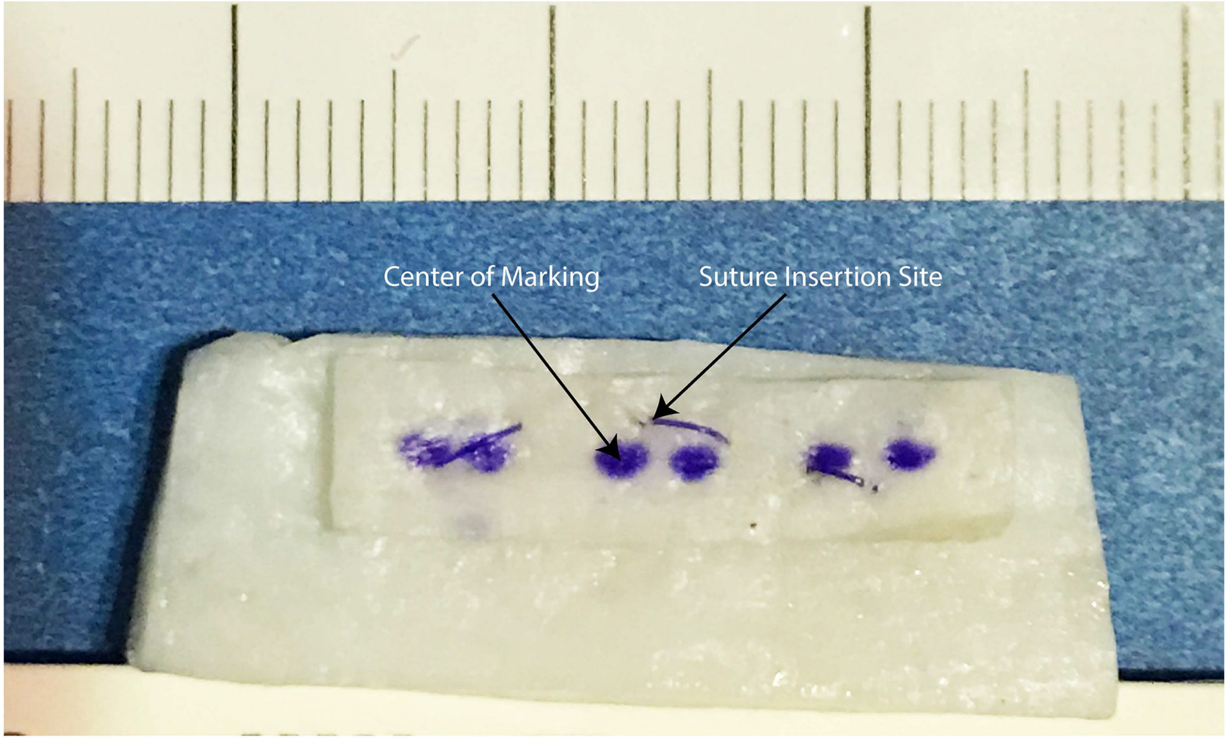

Figure 1.

Example of a sutured cartilage utilized for precision analysis. The pixel to distance ratio was calibrated first using the ruler. Then, the distance between the middle of the pre-marked dot and the suture insertion site was measured.

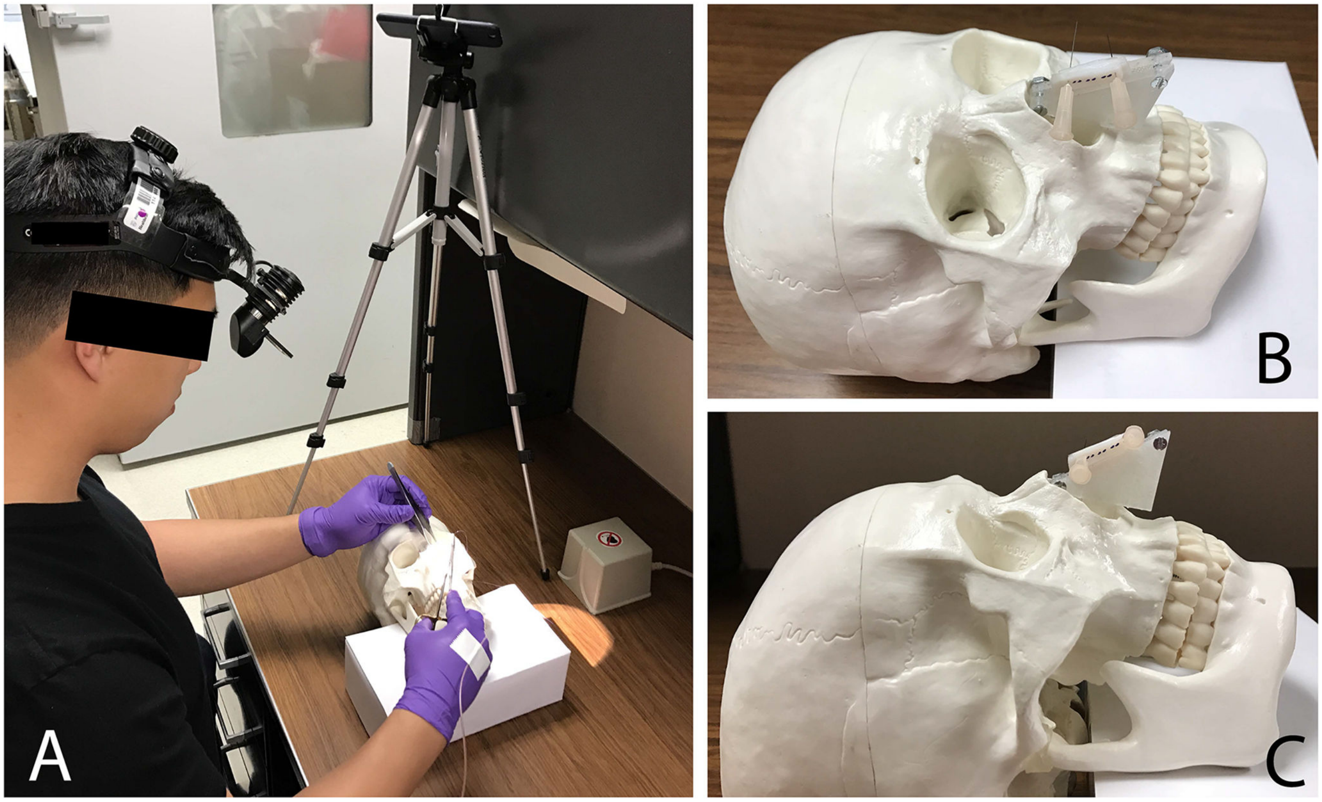

Figure 2.
(A) Study setup. (B) View angle #1. (C) View angle #2.

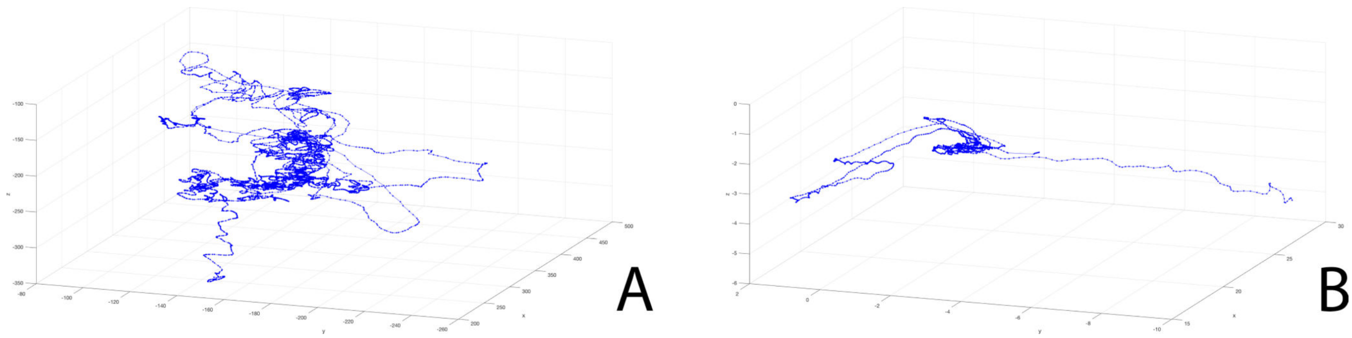

Figure 3.

Path of subjects' dominant hand as detected by trakSTAR, an electromagnetic tracker, during "suture". (A) shows and a resident's hand, and (B) shows an expert's hand.

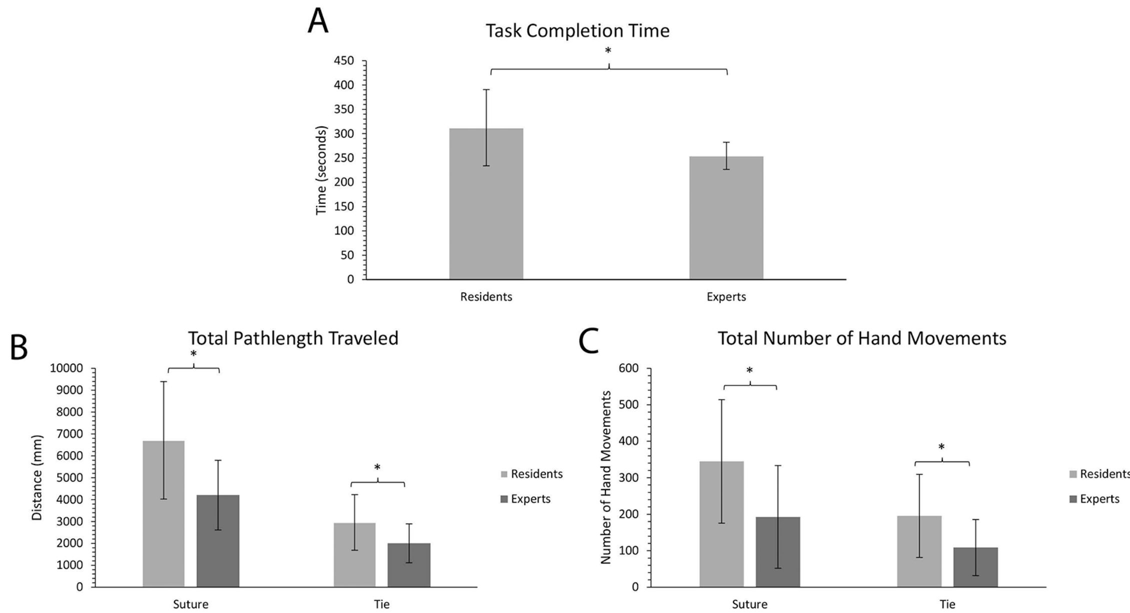

Figure 4.

Plots showing (A) time taken to complete the suturing of the spreader grafts (B) total path length traveled by the hand during suture and tie (C) total number of hand movements during suture and tie. Standard deviation bars are shown for each subset category.

Table 1.

Suture precision measurements. Photographs of the cartilage with grafts sutured by subjects were used to measure the distance between the suture insertion point and the midpoint of pre-marked dot.

	Residents (SD) n = 10	Experts (SD) n = 12	p value
Left Face	1.00 ± 0.25 mm	0.92 ± 0.13 mm	0.63
Right Face	1.10 ± 0.33 mm	0.84 ± 0.16 mm	0.10

Table 2.

Questionnaire results providing face and content validity of the spreader graft model. 1 indicates that the participant strongly agrees, and 5 indicates that the participant strongly disagrees.

	Score	
Question	**Residents (n = 10)**	**Experts (n = 12)**
1. Sufficient modes of practice are currently available to practice securing spreader grafts	4	4.3
2. Securing the spreader grafts on the simulator closely reflected suturing of a spreader graft on an actual patient	2.3	2.3
3. I feel that I can accurately demonstrate my skill in securing spreader grafts with the simulator	2.1	2.6
4. Practicing on the simulator would increase the confidence level of a resident in suturing cartilage on an actual patient	1.5	1.8
5. The cartilage graft suturing model should be recommended for any otolaryngology residents to improve his/her skill	1.5	1.5