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Research Article

# Measuring Resident Experience Level in an *in-vitro* Organic Tendon Repair Model

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## ABSTRACT

**Aim:** Tendon injuries remain challenging to treat, and successful outcomes depend on surgical precision and experience. Simulation-based models are widely used to develop these skills. This study aimed to evaluate the effect of surgical experience on tendon repair quality using an in vitro chicken tendon model, focusing on tensile strength and repair time.

**Material and Methods:** The third deep flexors of 60 adult chicken feet were used in this study. Residents were divided into three groups by experience level as novice (Group A), intermediate (Group B), and experienced (Group C), with two residents per group. Each repaired approximately 10 chicken deep flexor tendons using a standardized technique. Repairs exceeding a 5-mm suture boundary or showing excessive bulk were excluded and repeated. Repair duration and ultimate tensile force (N) were recorded. Groups were compared to evaluate the effect of residents' experience on operative time and tendon repair strength.

**Results:** Experienced residents achieved significantly higher tensile strength (34.55±6.51 N) compared to intermediate (24.65±6.53 N) and novice (14.91±4.50 N) groups ($p<0.001$). Pairwise comparisons revealed significant differences for all groups. Repair time showed a non-significant trend toward shorter duration with 324.75±80.42 s in the experienced group compared to the 385.50±108.41 s in Group A, 370.75±69.38 s in Group B ($p=0.082$)

**Conclusion:** Surgical experience was associated with significantly higher tendon repair strength, and repair time also showed a trend favoring experienced residents. The chicken tendon model provides a low-cost, accessible tool for objective training and assessment.

**Keywords:** Injuries, tendon, gallus gallus domesticus, residency, medical, medical education.

## INTRODUCTION

Tendon injuries are among the most difficult hand injuries to manage. Appropriate repair under the right conditions and in the right manner is necessary to ensure the best outcomes. Tendon injury treatment requires a high degree of surgical intervention. Therefore, tendon repair is an important surgical skill for plastic and orthopedic surgery residents. Affected tendons should be identified and repaired early. The recovery process and results after surgical intervention may vary among individuals. In some patients, functional limitations in finger movements may occur due to reasons before, during, or after the operation. To obtain successful results in tendon repair, the surgical technique must be applied correctly. Surgical experience is important for achieving better results. Experience depends not only on the duration of residency and specialization but the number the operations observed, assisted, and performed will also be decisive. Personal skills also play a significant role. Several studies have been performed on simulation models of tendon repair to refine or improve surgical skills or evaluate adequacy (1-5). Several organic (animal or cadaveric) and synthetic (catheters, licorice, silicone, etc.) models have been proposed as suitable for tendon repair simulation (1-5). Synthetic materials poorly reproduce the physical appearance and qualities of human tendons, which may limit their application in surgical skill training (1). Organic materials reproduce the qualities of human tendons and are widely used in surgical skill courses (1). Organic tendon materials are obtained from cadavers and animals (6,7). Pig, rat, chicken, and dog tendons are used in animal research, but chicken tendons are structurally and anatomically more similar to human tendons (3,7,8). Chicken tendons are easily available, inexpensive, and their anatomy is well known and easy to work with (7-9). In plastic surgery and orthopedics training, tendon repair training is initiated early for residents. However, not all residents have the opportunity to observe or practice the same number of tendon repairs. To evaluate the skills and training of the residents, tendon repair was simulated using organic materials, and a study was planned to investigate the relationship between the level of competence and the duration of residency or the number of applications. Tendon tensile strength was measured to evaluate the success of the operation. The most commonly used method to evaluate the success of tendon repair surgery in vitro is the measurement of tensile strength (6,8-10). Several instruments have been used for these measurements (8,9). The two ends of the tendon are fixed in the tension field of the device, and the force is measured at the moment of rupture or change in resistance (6,8-10).

This study aimed to evaluate the effect of surgical intervention experience and the level of training of residents that would provide minimal competence on tendon repair in vitro using chicken tendons.

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## MATERIAL AND METHODS

### Study Design and Groups

Freshly slaughtered (same day) feet of 24-week-old chickens were used for the study. The animals used in this study were protected in accordance with the Guide for the Care and Use of Laboratory Animals, and approval was obtained from local animal research ethics committee of Bolu Abant İzzet Baysal University (07.08.2024, 2024/16). Within the scope of the study, resident surgeons were divided into three groups according to the year of experience. The groups were formed such that each participant performed an equal number of chicken tendon repairs. The tendons were randomly assigned to the groups (n=20), with each group comprising two resident surgeons. *Group A: Novice group with one year of experience:* Surgeons in this group do not perform tendon repairs in clinical practice, but only assist. Each resident assisted in at least 25 tendon repairs. *Group B: Intermediate group with two years of experience:* Surgeons in this group performed flexor and extensor tendon repairs in clinical practice. The residents in this group performed at least 50 tendon repairs. *Group C: Advanced group with three years or more of experience:* Surgeons in this group performed flexor and extensor tendon repairs in clinical practice. The residents in this group performed at least 100 tendon repairs.

The surgeons in each group performed the repairs under the supervision of clinical faculty members, following appropriate and identical repair steps. Two data sets were compared between the groups. Duration of the repair procedure and the tensile strength of the tendons after repair. For this purpose, the duration of each repair procedure and the tendon tension force were measured.

### Operation Procedure

The third deep flexors of 60 adult chicken feet were used. After the chicken feet were fixed on the operating table, the skin of the volar aspect of the third toe was dissected vertically. Prominent fat pads divided by deep transverse skin fissures were observed, which were separated to reveal the tendon sheaths (Figure 1). The common tendon sheath, consisting of a thin elastic connective tissue membrane surrounding the flexor tendons of the chicken, was dissected to reveal the flexor profundus tendon (Figure 2). After the length and width of the tendon were measured, the tendon was cut at the center of its length using an 11 no scalpel. Then 0.5 cm was marked on both ends of the tendons (Figure 3) and if the suture went beyond this line, the procedure was canceled and renewed. The tendons were sutured with a 3/0, 16 mm, 3/8 cutting needle, propylene suture (Doğsan Corp., Istanbul, Türkiye). At the end of tendon suturing, if there was clumping and lumping in the tendon, the procedure was canceled and asked to be performed again on a new tendon. Participants repaired the tendons using the modified Kessler technique and completed the repair using a simple running suture with a 6/0 polypropylene suture (Figure 4). During the surgical procedure, the tendons were kept moist by dripping with saline. Immediately after the suturing was completed, the tensile strength was measured using a specially designed device.

### Measurement of Operation Time

The chronometer was started when the tendon was dissected, and the surgeon took the needle holder with polypropylene thread and forceps and stopped when the last suture was completed, and the thread was cut with scissors.

### Tension Force Measurement

The sutured tendon was freed by cutting it from both ends. Both ends of the tendon were fixed with compression clamps to a specially designed tension-measuring device. Progressive force was then applied to the suture line using the device (PCE-FB 0013, PCE Instruments, Germany). The moment when the resistance force started to decrease (due to rupture or tearing of the tendon at the suture line) was measured and recorded in kgf value (Figure 5).

### Statistical Analysis

The normality of data distribution was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated with Levene's test. Differences among the three groups were analyzed using one-way analysis of variance (ANOVA). When a statistically significant difference was detected, Tukey's HSD post-hoc test was used for pairwise comparisons between groups. A p-value $<0.05$ was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics version 28.0 (IBM Corp., Armonk, NY, USA).

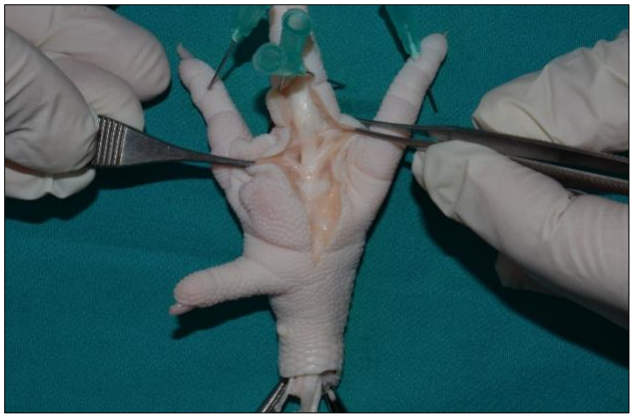


**Figure 1.** The common tendon sheath.

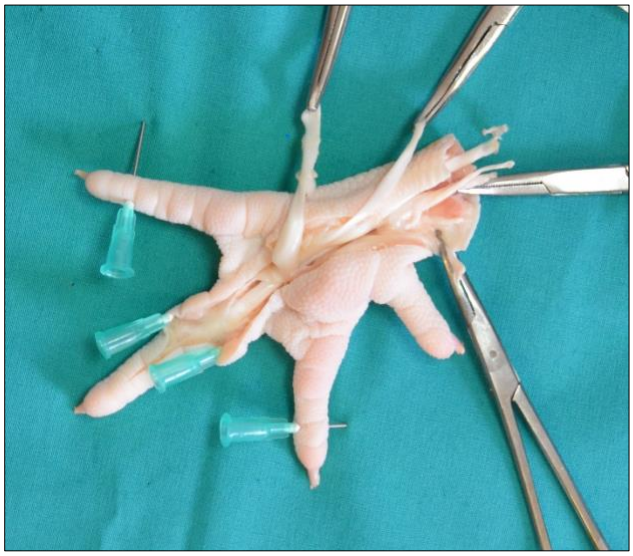


**Figure 2.** The flexor profundus tendon.



**Figure 3.** 0.5 cm marked on both ends.




**Figure 4.** Repaired tendon.

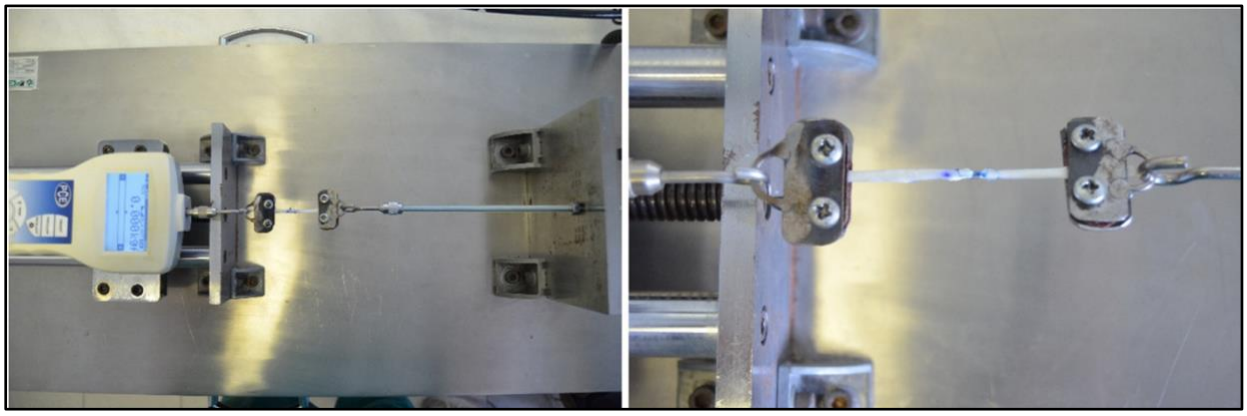


**Figure 5.** The tensile strength measurement.

## RESULTS

### Tendon Length and Width

Tendon length measurements ranged from 35 to 53 mm, with a mean of 44.80±4.03 mm. The mean tendon length was similar across groups, and no statistically significant difference was found between the three groups (p=0.644). Tendon width measurements varied between 3.8 and 5.5 mm, with a mean of 4.63±0.44 mm. Similarly, there was no statistically significant difference between the groups (p=0.736). These findings indicate relatively consistent tendon dimensions among the specimens (Table 1).

### Tensile Strength

The tensile strength measurements ranged from 6.50 to 44.00 N, with an overall mean value of 25.70±10.06 N. The mean tensile strength was 14.91±4.50 N in Group A, 24.65±6.53 N in Group B, and 34.55±6.51 N in Group C. One-way ANOVA revealed a statistically significant difference in tensile strength among the groups (F=56.58, p<0.001). Post-hoc analysis showed statistically significant differences between all groups. The difference between Groups A and B was 12.74 N (p<0.001), between Groups A and C was 19.64 N (p<0.001), and between Groups B and C was 6.90 N (p=0.001).

### Repair Time

The mean repair time was 385.50±108.41 s in Group A, 370.75±69.38 s in Group B, and 324.75±80.42 s in Group C. There was a borderline significance between groups in favor of Group C (p=0.082). The overall mean repair time was calculated as 360.33±89.99 s, and ranged between 180 and 600 s.

Overall, increased surgical experience was associated with higher tensile strength values and shorter repair times.

**Table 1.** Comparison of shearing tensile forces and suturing times in groups.

| | Group A (n=20) | Group B (n=20) | Group C (n=20) | p | Overall (n=60) |
|---|---|---|---|---|---|
| **Tendon length** (mm) | 44.25±4.42 | 44.70±4.16 | 45.45±3.59 | 0.644 | 44.80±4.03 |
| **Tendon width** (mm) | 4.59±0.49 | 4.59±0.44 | 4.69±0.38 | 0.736 | 4.63±0.44 |
| **Tensile force** (N) | 14.91±4.50 | 24.65±6.53 | 34.55±6.51 | **<0.001** | 25.70±10.06 |
| **Time** (seconds) | 385.50±108.41 | 370.75±69.38 | 324.75±80.42 | 0.082 | 360.33±89.99 |

## DISCUSSION

There are many factors affecting the durability of flexor tendon repairs, including atraumatic technique, number of threads passing through the repair site, epitendinous sutures and caliber of the core suture, dissection technique, type of injury causing damage, caliber and quality of the thread and needle, and the surgeon's experience. Since there is no wound healing in in vitro studies, the change in the resistance force during the tension applied when measuring the suture caliber occurs when the tendon suture ruptures or when the suture tears, pulls, or peels off one of the tendon ends and remains as an intact ring (7,9). The suture should be thick enough not to break easily but not damage the tendon. Taras et al. (7) used braided polyester sutures in their study and reported that 4/0 and 5/0 threads broke, whereas 3/0 and 2/0 threads remained intact. In our study, we used 3/0 polypropylene and observed that the thread did not rupture but separated from the tendon during

the tensile testing. In the study by Taras et al. (7), most of the modified Kessler repairs failed by suture pullout with larger (3/0, 2/0) suture calibers, while most of the modified Bunnell and double-grasping techniques failed by suture rupture at a higher tensile strengths. They reported that the Bunnell and double-grasping techniques held the tendon better; therefore, there was no pullout until thread rupture. In our study, we used modified Kessler and running sutures for tendon repair. The thread did not rupture in any attempt, and we only recorded the pullout measurements. Lawrence and Davis (10), in their tendon repair study on in vitro porcine flexor tendons with 4/0 polypropylene, nylon, braided polyester, and steel wire, found that tension resulted in thread rupture in all the subjects. The characteristics of the needle are also important for preventing tendon injuries. The thickness or thinness of the needle, and its sharpness or bluntness, can lead to different results; thick or blunt needles cause more trauma. In our study, we used 3/0 atraumatic threads with sharp 3/8 needles. Chicken flexor similarity to the human hand in terms of anatomical and functional properties (shear resistance, elasticity, seam tensile strength, and excursion) and their availability (7,8). Anatomical evaluation revealed that the most suitable tendon for the study was the third finger flexor profundus in terms of length and diameter.

In the tendon repair technique applied in this study, knot size and bulk at the repair site are important factors, as excessive bulk may impair tendon gliding and cause snagging within the pulleys. Therefore, the repair site was evaluated by independent observers for excessive bulk. When excessive bulk was detected, the procedure was repeated using a new tendon specimen.

The analysis demonstrated that residents with greater surgical experience achieved higher tendon tensile strength values. Residents with three or more years of experience produced the strongest repairs, with a mean tensile strength of 34.55±6.51 N. In contrast, residents with one year of experience generated lower tensile strength values, with a mean of 14.91±4.50 N. These findings suggest that increasing surgical experience improves the biomechanical strength of tendon repair. This finding reveals that tendon repair techniques and applications improve with experience and emphasizes the importance of clinical practice. Simultaneously, the experienced group completed the sutures in a shorter time. While shorter times may reflect residents' practical skills and technical efficiency, longer times may indicate potentially complex repair situations or a lack of experience. Colak et al. (8) tested tensile force durability with a modified Kessler, measuring a 2 mm gap of 9.63 N and a load to failure of 56.7 N, with an average repair time of 240 seconds. In our study, the avarage time of 600 seconds in Group A indicated that the surgeons did not gain sufficient practical skills for repair. Tendon tension strength values increase in proportion to the experience of the surgeons, and surgical procedure times are shortened. Tendon lacerations are urgent procedures frequently encountered in emergency rooms and are among the traumas that residents in teaching and research hospitals begin to treat at an early stage. As experienced surgeons achieve higher tensile strength with shorter repair times, in vivo training under laboratory conditions before clinical applications will shorten the time required for residents to gain experience and increase the overall success rate of tendon repairs. Saarensilta et al. (11) reported no difference in outcomes between residents and specialists in acute Achilles tendon rupture repairs; however, the duration of surgery was longer for resident surgeons.

In our study, we measured the force by applying tension to the tendon suture line immediately after repair. As this was an in vitro study, no healing occurred. The differences between the tension forces were determined by the atraumatic placement of the tendon sutures at the correct points with the correct grasping method and sufficient tissue grasping while holding the tendon, passing the needle, and tightening the knots. The distance to place the sutures was allowed to be a maximum of 0.5 cm from the cut edge to ensure that each procedure met the same standards. The results of the study showed that surgeons with three years of experience achieved higher tension forces than those with less experience. This increase suggests that with experience, the surgeons' technical skills and hand-eye coordination improved; therefore, they were able to place the sutures better and with less trauma to the tendon. The increase in tension indicates that the tendon suture passes through the correct layers to adequately grasp the tendon tissue. The significantly higher tension force in Group C indicates that experience improves atraumatic and accurate suturing techniques. In the tensile force measurement, the device applies a gradually increasing force to the suture line and records the maximum when the resistance begins to decrease. Because there is no wound healing in the measurement, the decrease in force occurs when the threads begin to peel off the tendon. This highlights the importance of the assistants' technical skills in selecting the grasping points during thread placement and ensuring the correct thickness of the thread when passing it through the tendon. The advantage of in vitro studies over in vivo studies is that there is no wound healing. Because wound healing occurs in in vivo studies, small technical errors can be covered by the quality of wound healing. In the in vitro study, if grasping is not provided from the correct point in the in vitro study, that is, when the technique is not good enough, and force is applied, the thread is stripped from the tendon.

A key methodological limitation of this study is the small number of residents per group (only two per experience level), with each performing multiple tendon repairs (approximately 10 tendons per resident). This introduces potential clustering and pseudoreplication, as repeated measures from the same resident are not fully independent (5). Consequently, the effective sample size is closer to n=6 (2 residents × 3 groups) rather than n=60 tendons. Due to the lack of individual resident identifiers, a mixed-effects model to account for resident-level effects could not be applied. Although tendon-level analysis was retained as the primary approach—owing to the objective biomechanical nature of the outcomes and consistency with similar in vitro tendon simulation studies (5)—results should be interpreted cautiously as exploratory trends in a small cohort. Future studies with larger resident cohorts and tracking individual effects would improve statistical robustness and generalizability.

Additionally, exclusion of technically inadequate repairs (those exceeding the 5-mm suture boundary or exhibiting excessive bulk) ensured standardized specimens for

biomechanical testing but may have introduced selection bias, particularly in the novice group, where such failures are more common during the learning curve (5). While this controlled approach mimics clinical quality thresholds, it limits representation of real-world variability in resident performance.

Furthermore, all observed failures occurred due to suture pullout rather than suture rupture, indicating that the tendon-suture interface is likely the primary limiting factor in early repair strength under in vitro conditions, consistent with previous biomechanical studies (7,10). This observation has clinical relevance, as sufficient initial repair strength is essential for safe implementation of early mobilization protocols, which are known to enhance functional outcomes in flexor tendon repair (12).

Although the in vitro design enables controlled and objective biomechanical assessment, it does not account for biological healing processes that significantly contribute to tendon repair in vivo (9). In this context, simulation-based training models—such as the chicken tendon model employed here—offer a reproducible, low-cost platform for skill development prior to clinical exposure (5). Moreover, the reliance on objective biomechanical parameters rather than subjective assessments strengthens the validity of the findings and supports more precise evaluation of surgical performance (5).

As another limitation, this study was performed under in vitro conditions using chicken foot samples. Considering the complex nature of tendon injuries and individual differences, these findings should be supported by further research in clinical practice. It should also be kept in mind that the technical skill level of each surgeon and environmental factors may also have an impact on the results. Because the study was in vitro, the measurement of experience level only included the evaluation of instant tensile strength and application time based on the technique. When performed in vivo, adhesions, bulk that will affect the passage through the pulleys, and other factors will be added.

## CONCLUSION

In this study, the modeling of the use of poultry tendons in an in vitro environment for the evaluation and development of residents' experience was investigated, and the effect of the experience factor on tendon tension force was demonstrated the effect of the experience factor on tendon tensile strenght. The findings revealed the importance of the effect of surgeons' experience on tendon repair performance and its outcomes. This model can be easily used for resident training purposes. Fresh chicken feet can be used to train residents to improve the quality of tendon dissection and suture placement techniques.

## DECLARATIONS

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**Ethical Approval:** This study was approved by the Animal Research Local Ethics Committee of Bolu Abant İzzet Baysal University (Date: 07.08.2024, number: 16).

**Plagiarism Statement:** This article has been evaluated for plagiarism, and no instances of plagiarism were detected.

**Use of Artificial Intelligence (AI) Tools:** The authors declare that no AI tools were used in the creation of this article.

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