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Original Article

Comparison of changes in shoulder functions between biceps tenotomy and tenodesis in an animal model

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ABSTRACT

Objectives: Tenotomy and tenodesis of the long head of biceps tendon are effective pain-relieving treatments. However, there is no consensus on the functional outcome after these surgical procedures. We hypothesized that there would be no difference in ambulation parameters after recovery from the surgery between rats that underwent tenotomy versus tenodesis procedures.
Methods: Twenty-four New Zealand rats were used and randomly divided into three groups. Each group received one of the following surgeries: tenotomy, tenodesis, and sham operation. A video-based walking track system was applied for gait analysis at day −1, 1, 3, 5, 7, 14 and 21 for each rat. Temporal and spatial parameters were obtained, and asymmetric index was calculated for each parameter.
Results: Compared to the tenotomy and sham-operated groups, the rats in the tenodesis group had shorter stance phase, longer swing time, longer step length, smaller paw length, smaller intermediary toe-spread length, smaller toe-spread length, and larger foot angle right after the tenodesis procedure. After day 14, all parameters were equivalent to those of the sham-operated group. At the end of the study, there were no functional changes found in tenotomy and tenodesis groups compared with the sham-operated group and preoperative status.
Conclusion: Transient functional alterations in temporal and spatial parameters are found after tenotomy and tenodesis in a rat model. The functional changes in the tenodesis group existed for a longer period than in tenotomy group; however, and all parameters showed no significant differences when compared with the sham group at the conclusion of the study.

Introduction

Lesions of the long head of biceps (LHB) tendon are common and are thought to be a significant source of anterior shoulder pain and shoulder dysfunction.[1–4] Pathology of the LHB tendon ranges from tendinitis and instability to partial or complete rupture of the tendon.[3,5] Surgical treatments proposed are tenotomy and tenodesis. Tenotomy and tenodesis of the LHB tendon are effective pain-relieving treatments; however, there is no clear consensus on the optimal management of LHB tendon lesions.[3,6–14] Some authors advocate biceps tenotomy, as it is simple, quick, well-tolerated, and requires less protection in postoperative rehabilitation with a faster return to activity, while its disadvantage is the potential for a residual Popeye deformity due to retraction of the biceps muscle distally. Meanwhile, other groups prefer tenodesis because of its superior ability to allow the patient to return to physical activity

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and closer approximation of normal anatomy, although tenodesis procedures have the disadvantages of longer rehabilitation times, possible need for costly implants and higher technical difficulty.[3,6–11]

Some authors have suggested that the LHB tendon has the mechanical function of a humeral head depressor and a glenohumeral stabilizer, but the clinical implications, if any, are still controversial.[15–19] In the study by Walch et al., tenodesis or tenotomy may produce proximal migration of the humeral head, from the loss of the depressing function of the intra-articular portion of the LHB, although this observation was not statistically significant in data on postoperative clinical function.[4] Some studies performed comprehensive review of published literature to discuss the clinical outcome between patients who received tenotomy and those who received tenodesis.[8,9,18,20,21] The conclusion stated that there was little difference in the outcome measures of tenotomy compared with tenodesis, with the exception of the Popeye sign being present in 3%–70% of patients undergoing tenotomy; however most literature lacks quality evidence from prospective randomized studies to address the functional outcome of these two surgical procedures.[8,9,18,20,21]

Studies have established rat animal models to investigate the potential mechanism of alteration in shoulder function.[22,23] The ambulatory parameters, such as stride length, stride width, paw length, and paw width, were assessed to represent the measures of shoulder function. Therefore, these animal models may be useful in evaluation of the potential mechanisms behind functional deficits of the LHB tendon in the shoulder and investigating the underlying mechanisms of treatment modalities for human shoulder disorders, which may be difficult to achieve in the clinical setting.

The purpose of the study was to compare the functional outcome measures between tenotomy and tenodesis in a rat model with video-based walking track gait analysis system. Our hypothesis was that there would be no difference in ambulation parameters in rats that underwent tenotomy and tenodesis procedures after recovery from the surgery.

Materials and methods

Animal groups

A total of 24 New Zealand rats (350–450 g) used in this study were obtained from the Laboratory Animal Center, National Cheng Kung University, Taiwan. All animal procedures were approved by the guidelines of the Institutional Animal Care and Use Committee at National Cheng Kung University. Eight rats were randomly assigned to each of the following three groups: sham-operated control, a single shoulder LHB tenotomy, or a single shoulder LHB tenodesis.

Surgical procedures

The operation was conducted under aseptic precaution. The rats were anesthetized with a mixture of Zoletil 50 (0.9 mL/kg; Virbac, France) and Rompun (0.1 mL/kg; Bayer, Germany). The forelimb of each rat was shaved and sterilized. A 1.5-cm longitudinal incision was made on the anterolateral aspect of the shoulder. The deltoid muscle was cut and the LHB tendon was identified in the biceps groove. In the sham-operated group, the incision was closed without further procedure. In the tenotomy group, the transverse ligament was cut, and the LHB tendon was cut at the level of transverse ligament. In the tenodesis group, the LHB tendon was cut after the release of the transverse ligament. A 2 mm hole in diameter was created at the distal edge of the bicipital groove, and the LHB tendon was then fixed to the hole with sutures.

The skin incision was then closed. After surgery, the animals were placed in a clean cage under a heating lamp until they recovered completely from the effects of the anesthesia.

Video-based gait pattern recording

For quantitative ambulatory assessments, ambulatory parameters were determined at days −1 (1 day prior to repair surgery) and at 1, 3, 5, 7, 14, 21 days after the surgery. A video-based walking tract system was utilized for gait analysis; the design of a walking track for observing footprints was adopted from previous studies.[22–25] Animals were tested in a confined transparent walkway 6 cm wide x 80 cm long, with a reflection mirror tilted at 45° placed under the walking track (Fig. 1). The tilted mirror reflects the soles and gives a direct lateral view of the forelimbs of the rat walking on the track. A high-speed digital video camera (Casio EX-F1, Japan) was placed perpendicular to the walkway and was used to capture images. The video capture rate was set at 60 frames per second at a high pixel resolution of 2816 × 2112 pixels. A successful trial was defined as at

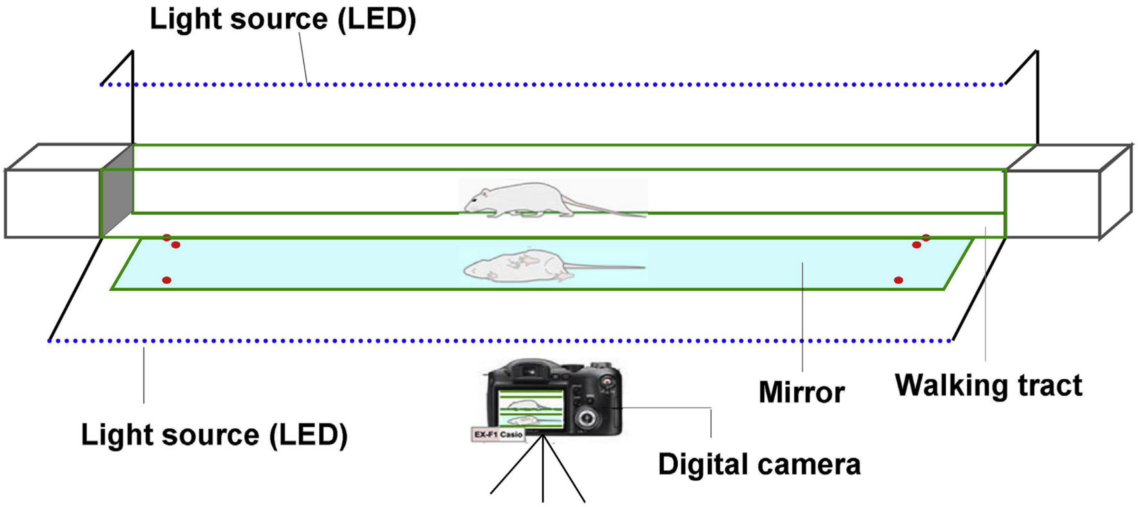

Fig. 1. Illustration of the video-based walking track system. A reflection mirror was placed under the walking track with 45° tilted. The red dots on the walking tract were used for calibration. A high-speed digital camera placed 1 m in front of the walking track was used for capturing images.

least one complete gait cycle without stopping. Each animal completed 6 successful trials per day to ensure the consistency of the data, and the data from these successful trials would be averaged.

Extraction of gait parameters

Image processing was performed by MATLAB software designed by our laboratory (The Math-Works, version 7.6. R2008a). For all trials, the system was calibrated to calculate the pixel-to-distance ratio at any plane using three pairs of red circle markers on the walking track.

The temporal gait parameters of the present study included cycle time, stance time, and swing time. The stance and swing time were normalized by cycle time before further analysis. The spatial gait parameters of the present study included step length, step width, stride length, foot angle and paw parameters, including paw length (PL), intermediary toe-spread length (ITS), toe-spread length (TS) and foot angle (Figs. 2–3).

To determine the level of asymmetry between the experimental and control sides, the asymmetry index (AI) was calculated for all related parameters. The AI of the ankle joint angle, spatial and temporal parameters was calculated according to following formula[25]:

$$AI = \frac{|NS| - |ES|}{0.5 \times (|NS| + |ES|)} \times 100$$

NS = non-experimented site
ES = experimented site

Statistical analysis

The analysis was done with SPSS 16.0 software (SPSS, Inc, Chicago, IL, USA).

Kruskal-Wallis test used to evaluate temporal and spatial parameters among the tenotomy, tenodesis and sham-operated groups. Post hoc analysis with Mann-Whitney *U* test was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Mann-Whitney *U* test was used to evaluate each parameter in each group between day −1 and postoperative day 21, while the significance was set at $p < 0.05$.

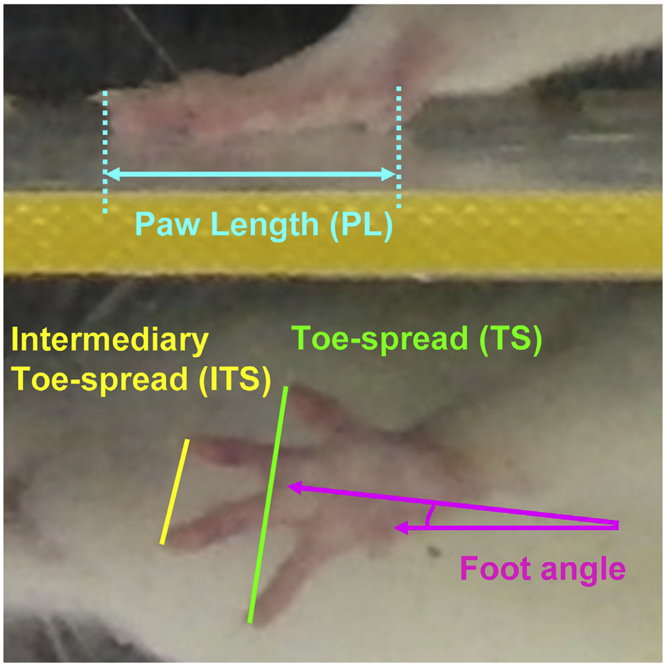

Fig. 3. Diagram of paw parameters. Palm length was obtained from the sagittal view. Intermediate toe-spread (distance between the second and third toes), toe-spread (distance between the first and forth toes), and foot angle were obtained from the reflection mirror.

Results

Baseline data was collected the day prior to the surgery

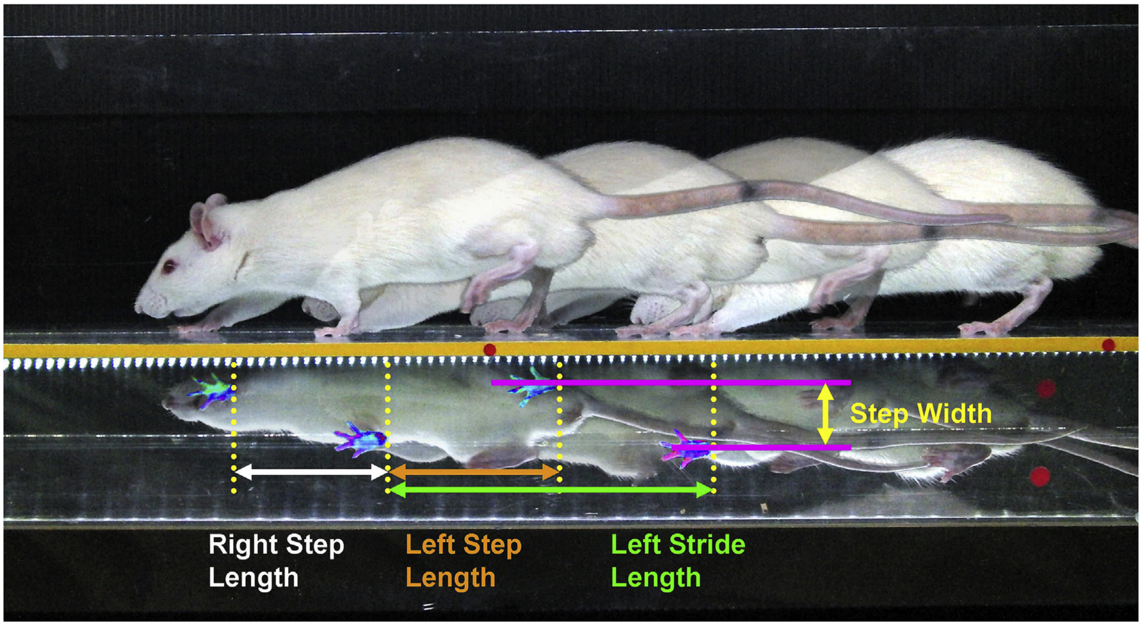

Fig. 2. Schema of step length, stride length, and step width from the captured images.

Table 1

The asymmetry index (AI) (mean ± SD) of temporal parameters in gait analysis in the tenotomy group, the tenodesis group, and the sham-operated group. In the tenodesis group, the AI of stance phase was significantly higher and the AI of swing phase was significantly lower than in the tenotomy group and the sham-operated group on post-operated days 1, 3, 5 and 7.

		Day -1	*Day 1*	*Day 3*	*Day 5*	*Day 7*	*Day 14*	*Day 21*
STP	Tenotomy	−5.82 ± 7.1	8.48 ± 12.0*	2.00 ± 5.2*	2.57 ± 5.5*	3.54 ± 6.2*	0.26 ± 6.1	−0.40 ± 6.0
	Tenodesis	3.31 ± 5.5	41.40 ± 18.2*#	52.08 ± 23.2*#	41.14 ± 14.0*#	18.8 ± 13.3*#	4.98 ± 7.0	4.61 ± 7.6
	Sham	−1.20 ± 5.0	1.59 ± 8.8#	3.22 ± 4.1#	2.12 ± 2.5#	1.93 ± 4.6#	0.51 ± 6.0	4.14 ± 10.3
SWP	Tenotomy	2.92 ± 7.2	−16.76 ± 17.0*	−4.50 ± 12.2*	−6.57 ± 9.8*	−0.47 ± 12.7*	−0.54 ± 8.5	3.25 ± 8.9
	Tenodesis	−7.47 ± 4.6	−71.54 ± 26.5*#	−78.22 ± 25.9*#	−66.67 ± 23.0*#	−31.71 ± 22.5*#	−13.83 ± 16.2	−3.78 ± 8.0
	Sham	−0.35 ± 11.9	−4.50 ± 8.7#	−7.40 ± 5.5#	−5.40 ± 2.6#	−4.35 ± 8.2#	1.79 ± 11.2	−6.87 ± 10.8

STP = stance phase, SWP = swing phase, Sham = Sham-operated.

* Significant difference ($p < 0.017$) between tenotomy group and tenodesis group with Mann-Whitney *U* test with a Bonferroni correction.

Significant difference ($p < 0.017$) between tenodesis group and sham-operated group with Mann-Whitney *U* test with a Bonferroni correction.

(day −1), and the results showed no significant differences among the three groups for all ambulatory parameters (Tables 1 and 2).

Sham-operated group

The sham-operated group was made as a post-operation standard. All parameters collected postoperatively in this group were not significantly different from the baseline data on days −1 (Tables 1 and 2).

Temporal parameters

The AI of stance phase and swing phase were significantly different among the tenotomy, tenodesis and sham-operated groups on postoperative day 1, 3, 5 and 7 (p= < 0.001 and < 0.001, <0.001 and < 0.001, <0.001 and < 0.001, 0.004 and 0.013 respectively). Post hoc analysis revealed that tenodesis group had significantly larger stance phase and smaller swing phase than the tenotomy and sham-operated groups (Table 1). The AI of stance phase and swing phase in post-operative day 21 were not significantly different from those in preoperative days in tenotomy, tenodesis and sham-operated groups (p = 0.266 and 0.909, 0.927 and 0.315, 0.589 and 0.484 respectively).

Spatial parameters

There was a significant difference in the AI of step length among the tenotomy, tenodesis and sham-operated groups on post-operative day 1 (p = 0.011). Post-hoc analysis showed that the AI of step length in tenodesis group was significantly smaller than the

Table 2

The asymmetry index (AI) (mean ± SD) of spatial parameters in gait analysis in tenotomy group, tenodesis group, and sham-operated group. The AI of step length was significantly lower in the tenodesis group than in the sham-operated group on post-operated day 1. The AI of intermediary toe-spread length was significantly larger in the tenodesis group than in the tenotomy group and the sham-operated group on post-operated days 1, 3, and 5. The AI of toe-spread length was significantly larger in the tenodesis group than in the tenotomy group and the sham-operated group on post-operated days 1, 3, 5 and 7. The AI of foot angle was significantly smaller in the tenodesis group than in the tenotomy group and the sham-operated group on post-operated day 1.

	StepL	StepW	StrideL	PL	ITS	TS	FtAng
Day -1							
Tenotomy	−9.11 ± 12.4	−9.43 ± 7.5	6.94 ± 4.1	2.15 ± 4.3	3.43 ± 11.7	1.01 ± 4.9	16.9 ± 55
Tenodesis	−4.66 ± 6.6	9.11 ± 14.4	−0.88 ± 1.8	0.46 ± 4.5	−4.04 ± 4.9	−0.61 ± 2.3	−36.9 ± 72
Sham	−2.28 ± 11.3	−2.05 ± 3.7	−2.75 ± 4.7	1.15 ± 4.7	−1.83 ± 6.0	−6.16 ± 5.1	−42.6 ± 79
Day 1							
Tenotomy	−14.60 ± 16.9	3.60 ± 9.5	1.68 ± 3.7	0.12 ± 6.4	0.19 ± 13.8*	1.60 ± 7.4*	−14.40 ± 33.6*
Tenodesis	−36.42 ± 28.9#	−0.72 ± 8.4	−0.92 ± 5.4	2.88 ± 15.7	18.66 ± 12.2*#	12.61 ± 7.6*#	−127.25 ± 68.0*#
Sham	3.98 ± 10.6#	2.30 ± 8.0	−0.25 ± 3.6	−0.46 ± 6.5	2.02 ± 3.2#	−2.62 ± 4.4#	58.5 ± 126.3#
Day 3							
Tenotomy	−4.19 ± 7.9	−0.99 ± 10.2	2.36 ± 3.3	3.90 ± 1.6	2.38 ± 7.0*	0.42 ± 3.1*	23.49 ± 87.2
Tenodesis	−28.78 ± 49.2	−4.61 ± 14.4	−0.67 ± 5.7	15.51 ± 20.4	23.52 ± 19.2*#	18.48 ± 13.2*#	−23.62 ± 183.6
Sham	0.54 ± 8.5	6.21 ± 5.6	−0.32 ± 3.2	1.21 ± 1.4	1.23 ± 6.9#	−2.90 ± 3.9#	46.11 ± 66.2
Day 5							
Tenotomy	0.68 ± 8.7	2.77 ± 7.8	1.46 ± 2.2	0.22 ± 4.6	−4.48 ± 6.1*	−3.51 ± 5.6*	−294.6 ± 852.1
Tenodesis	−23.43 ± 24.2	0.73 ± 7.8	1.23 ± 3.4	5.33 ± 4.3	15.74 ± 15.2*#	13.21 ± 7.2*#	−52.58 ± 131.6
Sham	−3.06 ± 9.3	7.63 ± 6.7	0.35 ± 2.6	2.56 ± 5.6	−1.22 ± 8.9#	−1.04 ± 5.6#	38.69 ± 87.0
Day 7							
Tenotomy	4.44 ± 10.6	7.75 ± 4.4	0.12 ± 2.7	1.30 ± 3.0	−5.14 ± 9.3	−1.55 ± 7.2*	9.03 ± 78.5
Tenodesis	−8.58 ± 10.7	5.10 ± 10.1	−2.58 ± 5.8	3.49 ± 2.5	8.46 ± 10.3	8.46 ± 8.1*#	−2461.26 ± 6760.0
Sham	−1.11 ± 7.4	7.72 ± 9.4	1.78 ± 5.8	−1.03 ± 6.9	1.93 ± 5.7	−1.22 ± 4.3#	81.57 ± 95.1
Day 14							
Tenotomy	3.61 ± 3.0	5.22 ± 6.1	0.08 ± 1.5	−0.76 ± 3.4	−1.70 ± 7.6	−1.60 ± 4.3	0.12 ± 36.8
Tenodesis	3.95 ± 4.4	3.03 ± 9.6	−0.18 ± 1.8	3.32 ± 2.23	8.08 ± 9.4	3.60 ± 7.2	151.91 ± 36.8
Sham	−1.68 ± 3.9	5.74 ± 10.1	1.92 ± 1.7	1.03 ± 1.7	0.01 ± 10.1	−0.63 ± 2.3	−0.48 ± 64.1
Day 21							
Tenotomy	4.50 ± 5.3	1.19 ± 6.0	1.21 ± 3.3	1.12 ± 2.0	1.67 ± 6.3	−1.65 ± 5.3	18.16 ± 59.9
Tenodesis	6.07 ± 3.8	−0.92 ± 9.0	3.75 ± 2.0	1.80 ± 2.0	0.14 ± 6.5	2.15 ± 3.9	33.02 ± 73.5
Sham	1.41 ± 7.1	5.13 ± 6.5	0.71 ± 1.1	0.12 ± 3.3	2.76 ± 2.9	−2.11 ± 5.2	57.54 ± 83.0

StepL = step length, StepW = stepth width, StrideL = stride length, PL = palm length, ITS = intermediary toe-spread length, TS = toe-spread length, FtAng = foot angle, Sham = Sham-operated.

*Significant difference ($p < 0.017$) between tenotomy group and tenodesis group with Mann-Whitney *U* test with a Bonferroni correction.

Significant difference ($p < 0.017$) between tenodesis group and sham-operated group with Mann-Whitney *U* test with a Bonferroni correction.

sham-operated group ($p = 0.008$). The AI of ITS length were significantly different among the tenotomy, tenodesis and sham-operated groups on postoperative day 1, 3 and 5 ($p = 0.011$, 0.007 and 0.003 respectively). The post-hoc analysis showed that the AI of ITS length in tenodesis group was significantly larger than in the tenotomy and sham-operated groups on postoperative day 1, 3 and 5 (Table 2). The AI of TS length were significantly different among three groups on postoperative day 1, 3, 5 and 7 ($p = 0.004$, <0.001, <0.001, and 0.010 respectively). The post-hoc analysis showed that the AI of TS length in tenodesis group was significantly larger than in the tenotomy and sham-operated groups on postoperative day 1, 3, 5 and 7 (Table 2). The AI of foot angle was significantly different among three groups on postoperative day 1 ($p = 0.001$). The post-hoc analysis showed that the AI of TS in tenodesis group was significantly smaller than in the tenotomy and sham-operated groups on postoperative day 1 (Table 2). All the parameters on postoperative on day 21 were not different from that on preoperative day in the tenotomy and tenodesis groups. Table 2 summarized the results of spatial parameters in three groups on preoperative day and postoperative days.

Discussion

The purpose of the study was to figure out the functional alternation of the shoulder after tenotomy and tenodesis with a video-based walking track gait analysis system. To observe the level of asymmetry of the forelimbs, the AI was calculated for all related parameters. The greater AI value indicated the smaller value on the experimental limb. Our results suggested that the experimental limbs after the tenodesis procedure had shorter stance phase, longer swing time, longer step length, smaller intermediary toe-spread length, smaller toe-spread length, and larger foot angle right; these parameters improved with time, and all parameters were not significantly different from those in the tenotomy and sham-operated groups after day 14. At the end of the study, there were no functional changes found in tenotomy and tenodesis groups, compared with the pre-operative results and sham-operated group. Although no animal model can fully parallel the human condition, evaluation of the functional alternations after tenotomy and tenodesis procedures in an animal model can provide further information regarding the role of LHB tendon and the difference in functional changes between these procedures.

In the tenodesis group, the experimental limbs had significantly longer swing phase and shorter stance phase than the sham-operated group, while the contralateral sites had longer stance phase and shorter swing phase, compared with the tenotomy group and sham-operated group. It appears that the animals choose to reduce the time of weight bearing on the injured limb. Our results also revealed that this phenomenon may improve gradually in the following days. Prior to day 14, the asymmetry of stance phase was not different from the sham-operated group. In contrast to the tenodesis group, the stance phase and swing phase in the tenotomy group were not significantly different from the sham-operated group after the surgery. It is possible that the tenodesis procedure may produce more pain than tenotomy after surgery, and the animals chose to decrease the operated limbs' contact time on the ground to decrease the discomfort sensations.

The significantly smaller AI of step length in tenodesis group on postoperative day 1 revealed that the experimental limbs in tenodesis group had longer step length than the non-experimental limbs. Similar to tenodesis group, the AI of step length in tenodesis group also became smaller, but it was not significantly different from that in either tenodesis group or sham-operated group. The symmetry of the step length improved gradually, and the AI of step length in the tenodesis group was no longer significantly different from the sham-operated group after day 3. The above findings appear to correspond to the findings in temporal parameters. With smaller step length and shorter swing phase on the healthy side, animals could perform a longer stance phase, which allows the experimental limbs a longer swing phase and longer step length. In this way, the operated limbs would only contact the ground for a brief time which may decrease discomfort. With the improvement of discomfort, the asymmetry of step length on both sides then improved. Additionally, since side dominance in rats was not established, the influence of dominant side limb could not be eliminated or factored into the results. The above differences of step length, stride length and swing phase could have possibly been due to pain in the tenodesis group and may not emanate from the surgery of the tendon itself.

Considering paw parameters, the tenodesis group had significantly larger AI of ITS and TS length than the tenotomy group and sham-operated group in the beginning of postoperative days. The above findings indicated that the experimental limbs in the tenodesis group had smaller ITS and TS length than the non-experimental limbs initially after the surgery. The ITS length and TS length of experimental limbs became greater gradually, and the asymmetry of these parameters was not significantly different from those of the tenotomy and sham-operated groups since day 14. These paw parameters may reflect the contact force on the ground; it is reasonable that the animals tried not to place as much force on operated feet as non-operated feet in the initial period after the surgery.

Compared with the tenotomy group, the functional change of shoulder in the tenodesis group lasted longer in the present study. This suggests that the negative effects caused by the tenodesis procedure were more severe, and more time was needed for recovery after the surgery. This finding seemed to be compatible with the clinical situation. Zhang et al.[26] prospectively evaluated patients older than 55 of age with reparable rotator cuff tear receiving tenotomy or tenodesis for long head biceps lesions in shoulders. They found that the pain scores on the VAS were significantly higher in tenodesis group, and faster pain relief could be observed in tenotomy group.[27] Similar results could also be noted in patients younger than 55 years. Friedman et al.[6] compared several clinical outcomes between younger patients who underwent either biceps tenotomy or tenodesis, and they found that complaints of pain were higher in the tenodesis group. Hsu et al.[9] performed a review of clinical outcomes, and they found that bicipital pain associated with tenodesis was more likely to occur.

Limitations

This study had some potential limitations. First, the animals in the study could not subjectively reveal their opinion. Therefore, the satisfaction after the procedure could not be evaluated, and the severity of pain would only be reflected by other temporal and spatial parameters. Second, upper extremities of animals in the present study were weight-bearing, while they are not in human patients. Therefore, the functional structures of the shoulder in rats were not totally consistent with the human's condition. In addition, the current study evaluated only temporal and spatial parameters. Combining the methods in this study with other measurement methods, such as the use of a force plate, may provide additional information for evaluating shoulder function, similar to a motion analysis system used for human subjects.

Conclusions

Transient functional alterations in temporal and spatial parameters are found after tenotomy and tenodesis in a rat model.

The functional changes in the tenodesis group existed for a longer period than in tenotomy group; however, and all parameters showed no significant differences when compared with the sham group at the conclusion of the study.

Conflict of interest statement

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asmart.2018.11.001.

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