Asian J Sports Med. 2018 March; 9(1):e67661. doi: 10.5812/asjsm.67661.

Published online 2018 March 10. **Research Article**

# Early Short-Term Recovery of Single-Leg Heel Rise and ATRS After Achilles Tenorrhaphy: Cluster Analysis

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**Received** 2017 April 28; **Accepted** 2017 October 25.

## Abstract

**Background:** An early recovery of Achilles Tendon Rupture Score (ATRS) and single-leg heel raises after Achilles rupture is a desirable aim to favor the sport return, but is unknown if the patient' outcomes could be defined only by the kind of treatment.
**Objectives:** To determine the number of clusters obtained based on ATRS and number of repetitions of single-leg heel rises after 12-weeks of Achilles tenorrhaphy in patients treated with either immediate or traditional rehabilitation treatment, compare the identified clusters of short-term recovery of single-leg by heel rise repetitions and ATRS, compare the proportion of treatment and heel rise ability contained into the clusters, and compare the dimension of the ATRS between clusters.
**Methods:** Twenty-four patients (43.1 $\pm$ 8.2 years-old, BMI 29.2 $\pm$ 3.9 kg/m$^2$) treated with immediate or traditional rehabilitation were included. The single-leg heel rise repetitions, the single-leg heel rise ability/disability and ATRS patient-reported outcomes were evaluated 12 weeks after Achilles tenorrhaphy.
**Results:** The first cluster had high repetitions in heel rise and ATRS, principally treated by immediate rehabilitation. The second cluster had low repetitions in heel rise and ATRS, principally treated by traditional rehabilitation. The third cluster had the highest repetitions in heel rise but lower ATRS, treated only by immediate rehabilitation.
**Conclusions:** An early recovery of the heel rise capacity could be achieved after Achilles tenorrhaphy and it is more probable to achieve an faster treatment.

*Keywords:* Achilles Tendon, Surgery, Physiotherapy, Calf Muscle Strength

## 1. Background

Thirty percent deficit in calf muscle strength after Achilles tenorrhaphy is frequently reported (1) and principally affects middle-aged males active in recreational sports (2). This calf muscle deficit appears to have a profound impact on the patient's recovery process. Patients who were unable to perform early or short-term single-leg heel rise; which is recovering the single-leg heel rise performance after three months post Achilles tenorrhaphy, obtained higher patient-reported symptoms, kinesiophobia and lower capacity to develop physical activity (2). By the way, Achilles tendon total rupture score (ATRS) outcomes at three months after Achilles tenorrhaphy has been identified as a predictor of the patient's ability to return to sports after 1 year (3) and has been described as the most frequent outcome after Achilles acute rupture (1). Unfortunately, previous reports of the literature showed that only the 50% of rehabilitated patients could perform an early single-leg heel rise 3 months after tenorrhaphy regardless of treatment (2-4). It is expected that patient-reported outcomes and ability to return to sports will be affected by a delayed, poor or null capacity to develop single-leg heel rise.

Although only half of patients achieve an early single-leg heel rise regardless of treatment (5), a systematic review by Kearney et al. (5) and van der Eng et al. (6) suggests that the deficit in calf muscle strength after Achilles tenorrhaphy could be potentially improved by early rehabilitation treatments (5, 6). These treatments give mobility and/or weight bearing within the first weeks after Achilles

tenorrhaphy allowing early controlled strength training (2-4, 7, 8). This period has been discussed as an important neurophysiological window to obtain performance changes that involve the triceps-surae muscles (9, 10). Recently, a clinical randomized controlled trial found that an early treatment improved the medial gastrocnemius contraction during the first 12 weeks after Achilles tenorrhaphy (8). Therefore, an early recovery of repetition and ability (favorable cases over total cases) to perform single-leg heel rise appears to be a millstone in patient recovery following an Achilles tenorrhaphy (2, 4).

Currently, there is a lack of knowledge regarding whether higher repetitions and ability to perform single-leg heel rises at the third month is generated by early treatment, where controlled strength training is given during the first four weeks after Achilles tenorrhaphy. Moreover, it is relevant to know what the ATRS characteristics of patients who recover and do not recover early performance of single-leg heel rises are. To assess these assumptions, Lloyd's algorithm also known as k-means clustering which permits partitioning a group of data into a small number grouped by similitude, could potentially permit finding groups of patients which could exist during the patient's recovery process given by the two most relevant outcomes described by the literature; ATRS, and single-leg heel rises. The algorithm partitioning n samples, xi = 1,. . .,n, in k clusters to find the positions $\mu_i$ of the cluster, minimizing the square Euclidean distance d from the samples of cluster, such as the equation one summarized.

## 2. Objectives

The purpose of this study is 1, determine the number of clusters generated based on ATRS and repetition of single-leg heel rises after 12 weeks of Achilles tenorrhaphy in patients treated with either immediate or traditional rehabilitation treatment; 2, compare the identified clusters of short-term recovery of single-leg by heel rise repetitions and ATRS; 3, compare the proportion of treatment and heel rise ability contained in the clusters; and 4, compare the dimension of the ATRS between clusters.

We hypothesized that 1, the clusters identified will differ in single-leg heel rise repetitions and ATRS; 2, the cluster with higher repetitions in single-leg heel rise will be mainly rehabilitated by immediate treatment; 3, the cluster with the lowest repetitions in single-leg heel rise has a higher proportion of patient rehabilitated by traditional treatment; 4, the ATRS dimensions are different between the clusters identified.

## 3. Methods

### 3.1. Design and Setting

The participants in this study were patients from the clinical randomized controlled trial performed at Instituto Traumatologico (Santiago, Chile). Patients were randomly assigned to either traditional or immediate physical therapy rehabilitation. Traditional rehabilitation was considered if physical therapy was performed between week four and 12 post surgery while immediate rehabilitation was considered if it was performed between day one and week twelve after surgery. The inclusion criteria were patients between 30 and 55 years old, mid-substance Achilles complete rupture, percutaneous double Dresden technique (11), history of intermittent exercise routine (> 30 minutes of physical activity, once or twice per week), soccer players, first Achilles tendon injury, and possibility of participation in rehabilitation and evaluations. The exclusion criteria were history of tendinous injuries, autoimmune diseases and trauma, orthopaedic alterations of the lower limb and steroid therapy or history of steroid therapy in the past. This study randomized patients into either immediate or traditional treatment forming two balanced groups.

### 3.2. Sample and Sampling

Twenty-four patients (mean ± SD: 42.3 ± 9.7 years-old, Height 1.71 ± 0.06 m, weight 86.1 ± 14.4, BMI 29.2 ± 3.9 kg/m$^2$) who attended the evaluation 3 months after the injury were included in this study. All patients were informed about the study and gave written consent to be included. In accordance with the declaration of Helsinki, the ethical approval was obtained from the institutional review board of the Instituto Traumatologico (Santiago, Chile).

### 3.3. Codes of Ethics

Enough information about the purposes of the study was given to the participants and they were asked to sign the written informed consent approved by the ethics committee of Instituto Traumatologico (Santiago, Chile). The informed consent was generated according to the Helsinki principles.

### 3.4. Treatment

An immediate and traditional treatment detailed previously by De la Fuente et al. (7) and De la Fuente et al. (8) were used in this study. Days 1 to 28 were spent on inpatient education, wound and tendon protection, controlled mobilisation and weight bearing for immediate group while the traditional group remained immobilised

$$arg_c \min \sum_{i=1}^{k} \sum_{x \in c_i} d(x, \mu_i) = arg_c \min \sum_{i=1}^{k} \sum_{x \in c_i} ||x - \mu_i||_2^2 \quad (1)$$

and non-weight bearing. Days 29 to 56 were spent on inpatient education, tendon protection, controlled stretching, and isometric and concentric strengthening. Days 57 to 84 were spent on inpatient education, stretching, and controlled eccentric and plyometric strengthening. All patients received rehabilitation treatment for 1.5 hours 3 times per week by two independent physical therapists, the first gave the immediate treatment and the second the rest of the treatment performed in foot and ankle service of Instituto Traumatologico (Santiago, Chile). To ensure the fidelity of patients one day before the physical therapy session, the patients were called by their therapist.

### 3.5. ATRS Patient-Reported Outcome

The ATRS questionnaire was used to evaluate the symptoms and function of the patient included in the study before single-leg heel rise test. The reliability and validity of the questionnaire were described by Nilsson-Helander et al. (12) and the ATRS at present is the most appropriate and the most used patient-reported outcome measure after Achilles tendon rupture (1, 5). The score and their dimension were registered according to Nilsson-Helander et al. (12). The ATRS ranges from 0 to 100 and the dimension ranges from 0 to 10; a lower score indicates more symptoms and greater limitations of physical activity.

### 3.6. Single-Leg Heel Rise Test

Prior to testing, warm up for 5 minutes on a stationary bicycle was performed according to Olsson et al. (2). The repetitions of single-leg heel raise test was considered the maximum number of heel lifts with the knee extended in a standing position (13). The patients were allowed to use one finger to maintain balance, and the test was performed on a flat surface (14) for one minute at the end of week 12 post-tenorrhaphy.

The ability to perform single-leg heel raise was defined as favourable cases over a total of cases and expressed in percentage. A favourable case was defined if the patient was able to lift the heel more than 2 cm assessed by a parallel camera of 1 megapixel acquiring data at 30 Hz according to the criteria of Brorsson et al. (4).

### 3.7. Data Analysis

Descriptive data were reported as mean (standard deviation) for anthropometric data, percentage (proportion) for contingency Tables, and the rest of manuscript as median and range (minimum-maximum). To determine the number of clusters for this study, the machine learning k-means algorithm previously introduced, where centroids based in the number of clusters are generated in a random manner until converge minimizing the Euclidean distance of samples against the centroid, was used. The selection of the number of clusters was selected based in the lowest ratio between the average and range of square sum of error (SSE) to assess and select the most appropriate ratio between stability and internal cohesion of the clusters. A low ratio by a low average of SSE and high range of SSE express a stable and internally cohesive cluster and the criteria to choose the number of clusters. Thus, twenty-four possible clusters were evaluated in accordance with the boundaries of the sample, and one thousand times the algorithm ran to identify the range of cluster assessed, performed 24000 classifications. To determinate the clusters, all analyses were performed using the MATLAB software (Mathworks, inc., Natick, MA, USA).

To compare the three identified clusters for anthropometric characteristics, single-leg heel rise and ATRS, the Kruskall-Wallis test was performed. Then after, a Dunn's analysis for multiple comparisons was performed. To determine if the proportion of treatments and ability/disability of single-leg heel rise were different between clusters, the chi-square and exact Fisher test were performed. Against chi-square calculation lower than 1 and at least 20% of the expected values lower than 5, to get valid chi-square calculation the contingency raw Tables will be adjusted combining the most near centroid of clusters. Finally, to compare each dimension of ATRS between clusters, the Wilcoxon rank test was performed. For all test the level of significance was set to $P < 0.05$. All statistical analyses were performed using the GraphPad software (GraphPad Software, inc., La Jolla, CA, USA).

## 4. Results

The number of clusters based in ATRS and single-leg heel rises repetitions after 12 weeks of Achilles tenorrhaphy in patients treated with one of two rehabilitation programs; immediate and traditional rehabilitation treatment is summarized in the Table 1. The comparison of three identified clusters of short-term recovery of single-leg heel rise repetitions and ATRS are summarized in the Table 2 and Figure 1. The proportions of treatments and ability of single-leg heel rise of clusters were summarized in

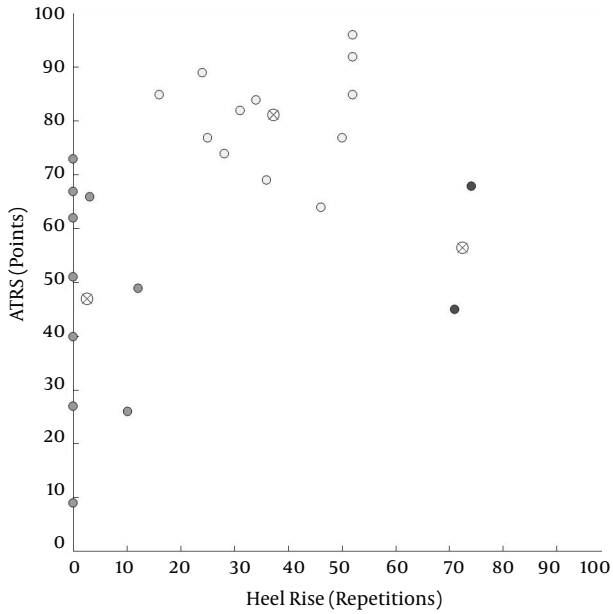
the Table 3. The comparisons of ATRS' dimensions between clusters are summarised in the Table 4.

**Table 1.** Cluster Determination[a]

| Number of Clusters | Range of SSE | Average of SSE | Ratio |
|---|---|---|---|
| **One cluster** | 0.0000 | 1.0462 | 0.0000 |
| **Two clusters** | 0.4291 | 0.4363 | 0.9835 |
| **Three clusters** | 0.1428 | 0.3112 | 0.4589[b] |
| **Four clusters** | 0.2610 | 0.2278 | 1.1457 |
| **Five clusters** | 0.2061 | 0.1732 | 1.1900 |
| **Six clusters** | 0.3515 | 0.1370 | 2.5657 |
| **Seven clusters** | 0.2515 | 0.1112 | 2.2617 |
| **Eight clusters** | 0.2617 | 0.0944 | 2.7722 |
| **Nine clusters** | 0.7612 | 0.0961 | 7.9209 |
| **Ten clusters** | 1.3446 | 0.1308 | 10.2798 |
| **Eleven clusters** | 1.4024 | 0.1825 | 7.6844 |
| **Twelve clusters** | 2.0760 | 0.2539 | 8.1764 |
| **Thirteen clusters** | 1.9595 | 0.3240 | 6.0478 |
| **Fourteen clusters** | 3.0566 | 0.4103 | 7.4497 |
| **Fifteen clusters** | 2.4794 | 0.4752 | 5.2176 |
| **Sixteen clusters** | 2.5485 | 0.5179 | 4.9208 |
| **Seventeen clusters** | 3.1583 | 0.5562 | 5.6784 |
| **Eighteen clusters** | 2.7021 | 0.5991 | 4.5103 |
| **Nineteen clusters** | 3.1671 | 0.6859 | 4.6174 |
| **Twenty clusters** | 3.2887 | 0.6901 | 4.7655 |
| **Twenty-one clusters** | 2.6752 | 0.7292 | 3.6687 |
| **Twenty-two clusters** | 2.8509 | 0.7632 | 3.7355 |
| **Twenty-three clusters** | 3.2785 | 0.7836 | 4.1839 |
| **Twenty-four clusters** | 2.8900 | 0.8312 | 3.4769 |

Abbreviation: SSE, Sum of Square Errors.
[a]The range and average of SSE are value in $10^3$.
[b]Lowest ratio with range of SSE < average of SSE.

**Figure 1.** Clustering Analysis




In light gray is shown the samples of cluster 1, in gray is shown the samples of cluster 2, in dark gray is shown the samples of cluster 3, and the criss-cross closed in circle are shown the centroids of clusters.

## 5. Discussion

The principal finding of the present study was that three groups of patients were differentiated between in heel rise and ATRS patient-reported outcomes, regarding the early recovery of the single-leg heel rise repetitions.

Based in the proximity of data respect to centroids generated in a random manner one thousand times assessing the lowest ratio between range and the average of SSE criteria', this study found three groups of patients based in the ATRS and heel rise repetitions outcomes. The first cluster represented patients with high repetitions in heel rise and ATRS (Table 2), principally treated by immediate rehabilitation (Figure 1, see light grey circles; Table 3). The second cluster represented patients with low repetitions in heel rise and ATRS (Table 2), principally treated by traditional rehabilitation (Figure 1, see grey circles; Table 3). The third cluster represented patients with the highest repetitions in heel rise but lower ATRS (Table 2), treated only by immediate rehabilitation after Achilles tenorrhaphy (Figure 1, see dark grey circles; Table 3). These findings suggest the existence of more than two groups of patients based on functional outcomes, where the single-leg heel rise was the strongest variable to differentiate between groups. This assumption is in accordance with Brorsson et al. (4), who referred the short-term ability to perform single-leg heel rise as an important marker of recovery and prognosis after Achilles rupture (4). However, the association of clusters with one kind of treatment (Table 3) contrast with the findings of Olsson et al. (2), who found that the single-leg heel rise ability after Achilles rupture does not depend on rehabilitation performed. In our study, the contingency Tables indicate a higher probability to develop a single-leg heel rise if an immediate treatment after Achilles tenorrhaphy is given.

The ATRS was different for cluster one and two, but no difference was found for cluster one/two with three (Table 2). Furthermore, the dimension about strength, fatigue,

**Table 2.** Cluster Characteristics Results[a]

| Variables | Cluster 1 | Cluster 2 | Cluster 3 | P Value |
|---|---|---|---|---|
| **Age, years-old** | 44.5 (30.055.0) | 41.0 (39.0 - 43.0) | 43.5 (34.0 - 55.0) | 0.8663 |
| **Height, m** | 1.71 (1.60 - 1.75) | 1.74 (1.58 - 1.83) | 1.65 (1.61 - 1.68) | 0.1407 |
| **Weight, kg** | 80.0 (62.1 - 98.0) | 93.0 (62.1 - 99.0) | 67.5 (60.0 - 75.0) | 0.1135 |
| **BMI, kg/m$^2$** | 27.6 (24.3 - 33.5) | 31.1 (26.7 - 34.5) | 24.9 (23.1 - 26.6)[b] | 0.0470 |
| **Single-leg heel rise, rep.** | 35.0 (16.0 - 52.0)[c] | 0.0 (0.0 - 12.0) | 72.5 (71.0 - 74.0)[b] | < 0.0001 |
| **ATRS, pts.** | 83.0 (64.0 - 96.0)[c] | 50.0 (9.0 - 73.0) | 56.5 (45.0 - 68.0) | 0.0005 |

Abbreviations: BMI, Body Mass Index; ATRS, Achilles Tendon Total Rupture Score.
[a] Data are expressed as median (minimum - maximum).
[b] Statistical difference between cluster 2 and 3 ($P < 0.05$).
[c] Statistical difference between cluster 1 and 2 ($P < 0.001$).

**Table 3.** Raw and Adjusted Contingency Tables[a,b,c]

| Variables | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|
| **Raw cluster-treatment contingency table** | | | |
| Immediate treatment, (No. of treated patient/total),% | 75.0 (9/12) | 10.0 (1/10) | 100 (2/2) |
| Traditional treatment, (No. of treated patient /total),% | 25.0 (3/12) | 90.0 (9/10) | 0 (0/0) |
| $X^2 = 11.4$ | | | |
| P value = 0.003 | | | |
| | **Cluster 1** | **Cluster 2** | **Cluster 3** |
| **Raw cluster-single-leg rise ability/disability contingency table** | | | |
| Single-leg heel rise ability, (No. of favorable cases /total),% | 100 (12/12) | 30.0 (3/10) | 100 (2/2) |
| Single-leg heel rise disability, (No. of non-favorable cases /total),% | 0 (0/12) | 100 (7/10) | 0 (0/0) |
| $X^2 = 13.84$ | | | |
| P value = 0.001 | | | |
| | Cluster 1 and 3 | Cluster 2 | |
| **Adjusted cluster-treatment contingency table** | | | |
| Immediate treatment, (No. of treated patient/total),% | 78.6 (11/14) | 10.0 (1/10) | |
| Traditional treatment, (No. of treated patient /total),% | 21.4 (3/14) | 90.0 (9/10) | |
| P value = 0.003 | | | |
| | Cluster 1 and 3 | Cluster 2 | |
| **Adjusted cluster-treatment contingency table** | | | |
| Single-leg heel rise ability, (No. of favorable cases /total),% | 100 (14/14) | 30.0 (3/10) | |
| Single-leg heel rise disability, (No. of non-favorable cases /total),% | 0 (0/14) | 100 (7/10) | |
| P value = 0.0003 | | | |

Abbreviation: No., Number.
[a] Data are expressed as percentage (proportions).
[b] The contingency raw Tables were adjusted combining the cluster with lower Euclidean distance between them centroids to generate Chi-square calculation greater than 1 and at least 20% of the expected values greater than 5 to get valid Chi-square calculation.
[c] $X^2$ (Chi-square statistic).

pain, activities of daily living, walking quickly upstairs, running and jumping, were less symptomatic in the cluster one compared with two. This suggests that patients with lower ATRS have more chances to be part of cluster two than one and higher probability to obtain a poor/null ability to develop a single-leg heel rise, risking their ability

**Table 4.** ATRS' Dimension Comparisons[a]

| Variables | Cluster 1 | Cluster 2 | Cluster 3 | P Value |
|---|---|---|---|---|
| 1. Are you limited due to decreased strength in the calf/Achilles tendon/foot? | 8 (4 - 10)[b] | 5 (2 - 8) | 6 (5 - 7) | 0.0265 |
| 2. Are you limited due to fatigue in the calf/Achilles tendon/foot? | 9 (5 - 10)[b] | 5.5 (2 - 10) | 5 (3 - 7) | 0.0065 |
| 3. Are you limited due to stiffness in the calf/Achilles tendon/foot? | 9 (4 - 10) | 7 (2 - 10) | 5.5 (3 - 8) | 0.2192 |
| 4. Are you limited due to pain in the calf/Achilles tendon/foot? | 10 (8 - 10)[b] | 6 (3 - 10) | 6 (4 - 8) | 0.0025 |
| 5. Are you limited during activities of daily living? | 10 (10 - 10)[b] | 7.5 (0 - 10) | 8 (8 - 8) | 0.0037 |
| 6. Are you limited when walking on uneven surfaces? | 10 (7 - 10) | 8 (0 - 10) | 6.5 (5 - 8) | 0.0437 |
| 7. Are you limited when walking quickly up the stairs or up a hill? | 10 (8 - 10)[c] | 6 (0 - 8) | 5.5 (5 - 6) | 0.0004 |
| 8. Are you limited during activities that include running? | 6.5 (4 - 10)[b] | 0 (0 - 7) | 5.5 (5 - 6) | 0.0110 |
| 9. Are you limited during activities that include jumping? | 5 (0 - 10)[b] | 0 (0 - 7) | 4 (4 - 4) | 0.0030 |
| 10. Are you limited in performing hard physical labor? | 7 (2 - 10) | 3 (0 - 8) | 4.5 (3 - 6) | 0.0529 |

[a] Data are expressed as median (minimum - maximum).
[b] Statistical difference between cluster 1 and 2 ($P < 0.001$).
[c] Statistical difference between cluster 1 and 2 ($P < 0.05$).

to return to sports (15). We suspect that the worse results for the cluster two could be associated with early pathological neurophysiological alteration involved to generate plantarflexion force i.e. muscular velocity conduction, but this is still unknown in the literature.

The identification of cluster number three characterized by highest values of single-leg heel rise repetitions but middle value of ATRS shows non-statistical difference in respect to patients which achieved high levels of ATRS, suggesting the existence of group of patients with the highest motor recovery but with lower auto-perception of their functionality. This could be associated with a poor expectative of motor recovery by patients resulting in lower ATRS outcomes, a clinically important difference (12) which needs special attention of the physicians and physical therapist to control the possible wrong decision of the patient in generating an overtraining.

At week twelve after Achilles tenorrhaphy there is a decrease in terms of physical activity and significant increase in the ability of performing single-leg heel rise and the number of repetitions achieved with immediate rehabilitation. However the literature mentions that only half of patients could reach adequate recovery of physical activity level (16) and early recovery of the ability to perform the single leg-heel rise (2, 17), but the present study only found poor and null ability to perform single-leg heel rise when the a traditional treatment was performed. Moreover, this study found that three functional groups existed. This suggests that the rehabilitation process chosen directly affects the functional results of the patient, making essential an early treatment after the Achilles tenorrhaphy so that better functional outcomes could be reached.

As a limitation of the study, our research does not contemplate neurophysiological variables. This could help to understand the neurophysiological process involved in the force deficits and rehabilitation after Achilles tenorrhaphy. Future investigations should also address this point. Therefore, further studies are needed to understand the neurophysiological basis of early recovery in single-leg heel rise and create more specific motor exercises to optimise the functional outcomes of patients.

## Footnotes

**Authors' Contribution:** Study concept and design, Carlos De la Fuente, Carlos Cruz-Montencinos; acquisition of data, analysis and interpretation of data, Drafting of the manuscript, Carlos De la Fuente, Constanza De la Fuente, Carlos Cruz-Montencinos, Roberto Pena y Lillo, Claudio Chamorro, Hugo Henriquez; analysis and interpretation of data, and Critical revision of the manuscript for important intellectual content, Carlos De la Fuente, Carlos Cruz-Montencinos, Constanza De la Fuente, Roberto Pena y Lillo, Claudio Chamorro, Hugo Henriquez; statistical analysis, Carlos De la Fuente, Carlos Cruz-Montencinos, Claudio Chamorro; administrative, technical, and material support, Carlos De la Fuente, Roberto Pena y Lillo; study supervision, Carlos De la Fuente.

**Implication for Health Policy Makers/Practice/Research/Medical Education:** Determine the kind of clustering of patients after being treated after early rehabilitation of Achilles tenorrhaphy is a necessary knowledge in order to begin the sport return phase. This knowledge will permit knowing the condition of patients

by two clinical tests possible to perform during the first three months post-op, where no jumps or other activities are permitted due the risk or re-rupture of Achilles tendon.

**Financial Disclosure:** The authors declare they do not have any conflict of interest.

**Funding/Support:** The present research was supported by authors.

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