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ORIGINAL

APPLICATIONS OF MEDICAL IMAGING IN THE MONITORING AND REHABILITATION OF PHYSICAL CONDITIONS IN ATHLETES

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ABSTRACT

By means of imaging, athletic injuries can be more comprehensively and accurately screened and functionally evaluated, so as to guide the treatment and rehabilitation after athletic injuries in a more targeted manner. Chronic injuries and tendinopathies of the Achilles tendon occur mostly in the middle and lower part of the Achilles tendon, which is the most frequent site of Achilles tendon rupture, and Achilles tendon rupture will lead to a huge impact on athletic injurie performance, and even end their athletic career prematurely. Ultrasound imaging technology can clearly and completely show the tissue and its continuity changes, which is helpful for the setting of rehabilitation program and the judgment of prognosis. The Siemens VTIQ provides quantitative information on the viscoelastic properties of the tissue, allowing an accurate and safe assessment of the elastic properties of the Achilles tendon. In this paper, the third generation ARFI technique, VTIQ technology, was applied to study the Achilles tendon of healthy youth and professional athletes to obtain the effects of exercise on the Achilles tendon and to provide medical imaging support for monitoring the health of the Achilles tendon in athletes and for the post-injury rehabilitation process.

KEYWORDS: Medical imaging; Athletic injuries; Monitoring; Rehabilitation

1. INTRODUCTION

Athletic injuries are a common problem in the training process of athletes and are an important factor affecting the development of their competitive level. Comprehensive and accurate assessment of athletic injuries is crucial for determining the treatment means, formulating the rehabilitation training program, and shortening the recovery time. With the development and popularization of imaging methods, ultrasound, magnetic resonance and other imaging methods are widely used in the evaluation of athletic injuries. At present, the imaging methods with more applications in the evaluation of sports injuries include M-ultrasound, tissue Doppler, and ultrasound elastography in ultrasound imaging, and structural image, magnetic resonance spectroscopy, and T1ρ imaging in magnetic resonance imaging, which play an important role in the evaluation of organic injuries such as muscle strains. At the same time, many sports injuries are difficult to recover to an optimal state after exhibiting organic changes, and early functional evaluation tools are urgently needed. The emergence of emerging functional imaging methods such as noninvasive perfusion imaging and oxygen metabolism imaging in recent years has shown great advantages in this regard and has positive potential application value. Further, based on the imaging data or daily monitoring data of athletes, rich machine learning and the rapid development of artificial intelligence technology have brought the possibility of automatic assessment and early warning of athletic injuries (Adib, BARAKAT, MASRI, SABOUR, & CAPAPÉ, 2021).

Athletic injury is a probable and urgent problem in the training and teaching of competitive sports. With the popularization of sports, the number of people suffering from athletic injuries is also increasing year by year (Thacker, Gilchrist, Stroup, & Kimsey Jr, 2004). In the field of sports medicine, the anatomical damage or physiological disorder of human tissues or organs caused by sports is called athletic injury (Anderson, 2003; van der Velde, 1995). An important reason for athletic injuries is that some of the technical action requirements in competitive sports are contrary to the anatomical and functional structure of human skeletal muscles and ligaments, or the exercise load exceeds the strength limit of the tissue (Caine, DiFiori, & Maffulli, 2006); the fatigue load caused by excessive fatigue in training of athletes can also cause chronic injuries to muscle tissues, tendons and ligaments (Nigg, 1985). In addition to this, athletic injuries due to venue, climate and collateral injuries also occur from time to time.

The site of athletic injuries is related to the characteristics of athletic programs and special techniques, and there are usually skin injuries, muscle and tendon injuries, fascia injuries, bursa injuries, joint injuries, bone injuries, epiphyseal injuries, nerve injuries, vascular injuries and internal organ injuries, etc. (Bahr & Krosshaug, 2005), of which muscle, tendon, joint and ligament injuries are the most common athletic injuries. These typical athletic injuries not only seriously affect the athletic performance of the athletes to obtain and improve, but also greatly affect their sports life, and even many athletes so that the entire athletic career is cut short, bringing serious losses to the country and individuals. Therefore, timely and effective early warning, treatment and rehabilitation are needed for athletic injuries, so as to avoid chronic recurrent injuries due to untimely or inappropriate treatment of injuries, which will affect the training effect and competition performance (Adams & Lasseigne, 2018).

Overuse injury of tendon, also known as "tendinopathy", is a common disease in orthopedics, sports medicine, rehabilitation, occupational and geriatric medicine. In recent years, it has been found that the occurrence and development of Achilles tendon tendinopathy is related to many factors, and sports injury is the main causative factor of Achilles tendon tendinopathy. de Jonge S et al. (de Jonge et al., 2011) reported for the first time on the incidence of Achilles tendon tendinopathy in the general population, and the results of the survey showed that the Achilles tendon tendinopathy of 35% of the patients was related to sports. Achilles tendon tendinopathy is a highly prevalent disease among tendinopathies, which can be manifested as acute or chronic, with acute injuries being dominated by extrinsic factors and chronic injuries being caused by the interaction of internal and external factors. Intrinsic factors include gastrocnemius-flounder muscle dysfunction, age, gender, weight, height, high arched feet, and ankle joint instability. Extrinsic factors include excessive motion of the coronary surface of the hind foot, especially lateral heel strike and compensatory pronation, which leads to a "whipping action" of the Achilles tendon, making it more susceptible to tendinopathy. In patients with Achilles tendinopathy, inversion of the ball of the foot is also common. Subtle injuries within the tendon can also be the result of non-uniform exertion, which can result in abnormal loading, inter-fibre friction, and localized damage to the muscle fibers. Achilles tendon fatigue injury will actively repair; the mechanism of repair may be the original tendon cells to the extracellular matrix regulation. However, if the Achilles tendon cannot adapt to long-term repeated overload, the tendon after injury cannot be effectively repaired, which will lead to the release of cytokines to further regulate cellular activity and aggravate the Achilles tendon injury. Scott RT et al (Scott, Hyer, & Granata, 2013) and Klein EE et al (Klein, Weil Jr, Weil Sr, & Fleischer, 2013) confirmed that body mass index and Achilles tendon tendinopathy, the study pointed out that the higher the body mass index, the greater the risk of Achilles tendon tendinopathy; the longer the duration of exercise, the greater the risk of Achilles tendon tendinopathy. Waldecker U et al (Waldecker, Hofmann, & Drewitz, 2012) showed that anatomical disorders of the hind foot are closely related to Achilles tendon tendinopathy. Although the development of Achilles tendon tendinopathy is related to a variety of factors, and as the main risk factor of athletic injuries, there is a lack of clinical data to confirm what kind of athletic injuries or sports-related factors are related to Achilles tendon tendinopathy.

High-level athletes with high athletic intensity are more likely to cause ankle instability and muscle fiber injuries. This paper investigates Achilles tendon tendinopathy in track and field athletes based on imaging methods to determine the specific risk factors for Achilles tendon tendinopathy in track and field athletes, which will provide track and field athletes with a theoretical basis for more scientific and effective training methods, and thus further prevent the occurrence of Achilles tendon tendinopathy in track and field athletes effectively.

2.Methodology

2.1 Subjects of study

2.1.1 Athlete group

In the group of professional young athletes, the majority of the students were students of various majors in the physical education faculties of institutions of higher learning, and some of them were members of professional sports teams, and the criterion was whether or not they held the professional athlete's identification. Of the 54 people in this group, 27 were male and 27 were female, with an average age of (22.59±1.72) (18-26 years old), and their height and weight were about (174.89±8.62) cm (158-193 cm) and (66.43±8.6) Kg (43-88 kg), respectively. There were 33 volunteers for ball games (basketball, soccer, volleyball, and tennis) and 21 volunteers for track and field (including 4 for aerobics and sports performance). The professional athlete volunteers were internally divided into 32 people in the ball sports group, of which 21 and 11 were men and women respectively, and 22 people in the track and field sports group, of which 6 were men and 16 were women.

2.1.2 Youth control group

In the young control group, there were 39 young people, all of them were selected from students of higher education institutions, who were healthy and had moderate exercise, had no history of Achilles tendon disease and had no clinical manifestations of Achilles tendon pain in their daily lives. There were 17 males and 22 females, with an average age of (22.82±2.22) years (20-28 years old), height and weight of (169.03±7.30) cm (157-183 cm) and (62.31±9.41) Kg (44-85 kg), respectively.

2.2 Monitoring instruments

Siemens Acuson S3000 ultrasound machine, pre-installed with the VTIQ system, equipped with a 9L4 probe at 4-9 MHz, selecting the YJSMSK mode, examining to a depth of 3.5 cm, and optimizing the images according to the subject's condition.

2.3 Monitoring methods

Volunteers were placed prone on the examination bed with their feet placed at the end of the bed in a completely relaxed and pendulous state. The volunteer's Achilles tendon was examined in three segments: the upper segment (about 1/3 of the Achilles tendon from the confluence of the calf muscles), the middle segment (the middle 1/3 of the Achilles tendon), and the lower segment (the Achilles tendon from the Achilles node down 1/3 of the

Achilles tendon). The acquisition results are shown in Fig. 1.

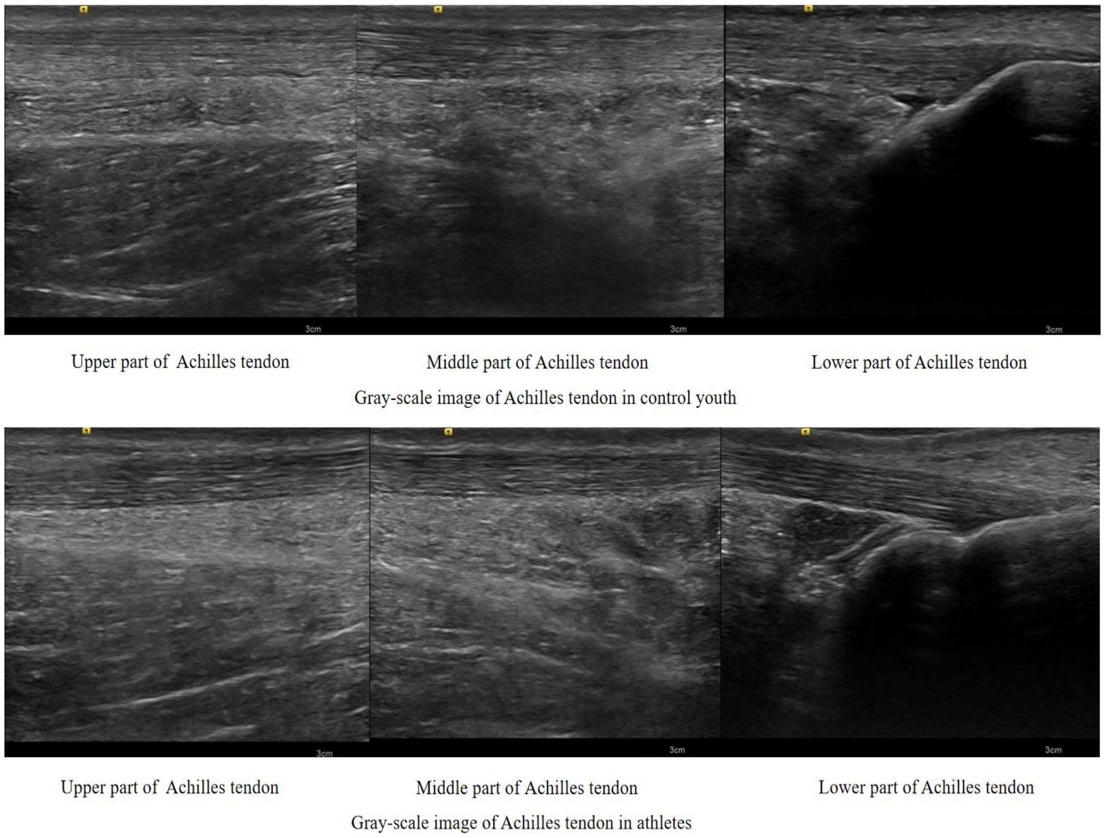

Figure 1: Schematic diagram of sample Achilles tendon grayscale maps for different groups

Firstly, 2D, color Doppler and energy Doppler ultrasound were used to routinely scan and observe the characteristics of 2D gray-scale images of different segments of the Achilles tendon, focusing on whether the edges of the Achilles tendon were smooth and parallel, whether the internal fibers were regular in their alignment, whether there were hypoechoic areas and strongly echogenic calcification points, whether there was any accumulation of fluid in the peripheral bursa of the Achilles tendon, whether there were any foci of ossification of the peripheral soft tissues of the Achilles tendon, whether there were any formation of bone cumbersome, and whether there were any bone erosions of the Achilles tendon, especially at the point of attachment. The color Doppler mode was then activated to reduce the sampling range and observe the blood flow in and around the Achilles tendon. Energy Doppler was then activated to further observe the distribution of blood flow in and around the Achilles tendon itself.

The thickness of the Achilles tendon was measured at 1 cm and 2 cm from the Achilles tendon attachment site, and the images were recorded three times. The probe was then placed longitudinally, perfectly perpendicular to the Achilles tendon, and after acquiring a satisfactory 2D long-axis image of the Achilles tendon, the VTIQ mode was activated. This study focused on the quality and velocity modes of VTIQ. In the quality mode, the hardness from hard to soft was displayed under the image from dark to light red, yellow, green, and blue, respectively. The sampling frame was adjusted to the smallest size (1.0 cm × 1.0 cm), and the sampling frame was placed to cover the Achilles tendon to be examined. First, a qualifying mass image of the Achilles tendon is obtained; a qualifying mass image is one in which the Achilles tendon is more uniform in color and more clearly demarcated from other tissues. Then the velocity mode was activated. the VTIQ image is shown in Fig. 2.

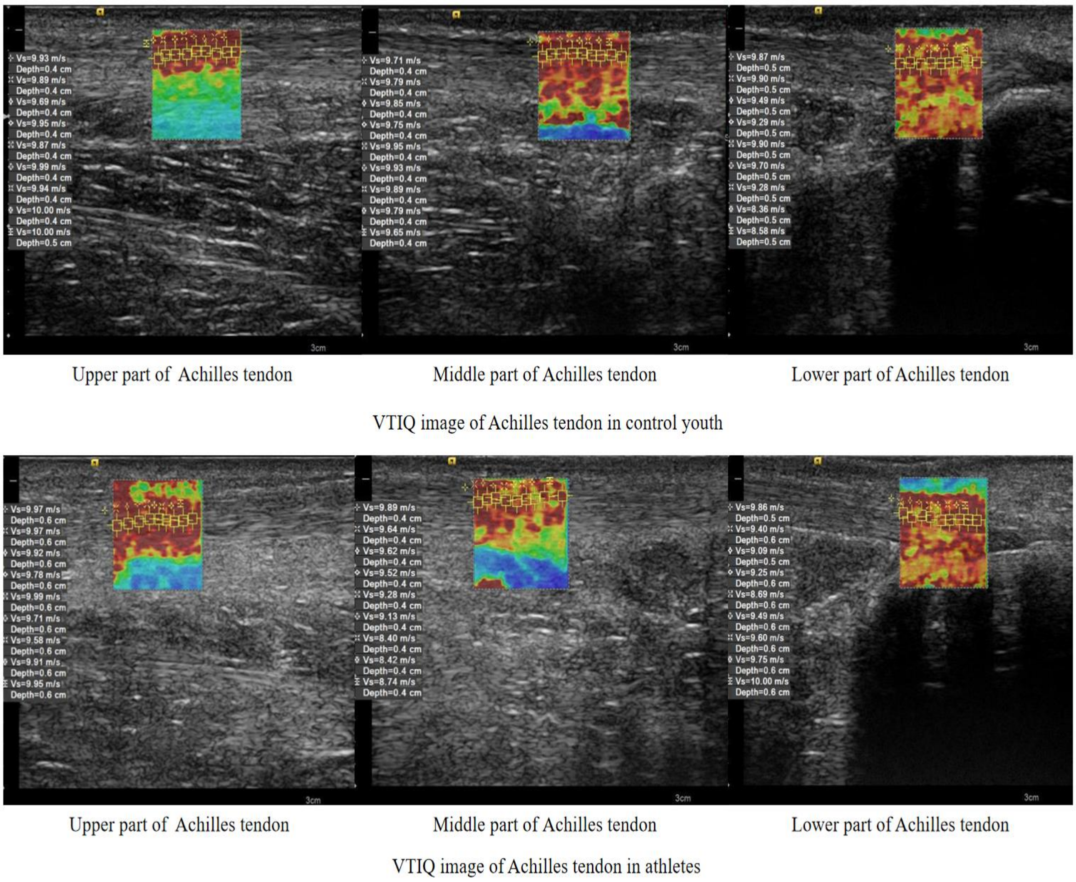

Figure 2: Schematic diagram of sample Achilles tendon VTIQ maps for different groups

Adjust the velocity mode range to 0.5-10 m/s, walk along the Achilles tendon in the sampling frame, place the ROI of the region of interest on the Achilles tendon to obtain SWV values, and the minimum range of the ROI is 1 mm × 1 mm, and walk along the Achilles tendon in the region of interest to obtain successive values to obtain SWV values of the Achilles tendon. When each segment of the Achilles tendon was examined, 9 SWV values were obtained consecutively in the sampling frame, and three examinations were performed to obtain a total of 27 SWV values in 3 groups. Each group of SWV values was averaged by removing the highest and lowest values, and the three groups of data were further averaged, and this average value was the SWV value for that segment of the Achilles tendon.

3. Monitoring results

3.1 Comparison of Achilles Tendon Thickness

In the youth control group, the thickness of the left side at 1cm and 2cm from the heel bone attachment was about (3.50±0.26) mm and (4.41±0.28) mm, respectively, and the thickness of the right side at 1cm and 2cm from the heel bone attachment was about (3.52±0.37) mm and (4.30±0.31) mm, respectively; In the athlete group, the thickness at 1cm and 2cm from the heel bone attachment on the left side was about (3.42±0.29)mm, (4.44±0.2)mm, and the thickness at 1cm and 2cm from the heel bone attachment on the right side was about (3.40±0.25)mm, (4.23±0.26)mm, respectively. There was no statistically significant difference in the thickness of the Achilles tendon at the same distance on the left side of the volunteers in both groups (P value > 0.05 for comparison at 1cm and 2cm from the Achilles attachment); there was a statistically significant difference in the thickness of the Achilles tendon at 2cm from the Achilles attachment on the right side (P value <0.05); and there was no statistically significant difference in the thickness of the Achilles tendon at 1cm from the Achilles attachment (P value > 0.05).See Table 1 below for details.

Table 1: Comparison of thickness of ipsilateral Achilles tendon

GROUP	THICKNESS AT 1CM		THICKNESS AT 2CM	
	Left	Right	Left	Right
YOUTH CONTROL GROUP	3.50±0.26	3.52±0.37	4.41±0.28	4.30±0.31
ATHLETE GROUP	3.42±0.29	3.40±0.25	4.44±0.23	4.23±0.26
P VALUE	＞0.05	＞0.05	＞0.05	＜0.05

3.2 Comparison of 2D images of Achilles tendon

The Achilles tendon in the youth control and professional youth athlete groups was gradually thickened using high-frequency ultrasound sweeps, with the gradual confluence of the flounder and gastrocnemius muscles visible in the upper section of the Achilles tendon, which was difficult to define the starting point of the Achilles tendon from ultrasound, and was swept downward from the upper to the lower part of the Achilles tendon. The transverse section changes gradually from a crescent shape to an oval shape. The Achilles tendon itself has no tendon sheath, but the peritendinous tissue makes the Achilles tendon distinctly demarcated from the surrounding tissues on ultrasound. The two sides of the demarcation are basically parallel at the mid-section and continue to gradually become thinner and thinner downward, and the lateral envelope forms a curvature, with the medial side adhering to the Achilles bone and following the lateral course, with the medial side of the lateral side confluent and attached to the Achilles node. Longitudinally the Achilles tendon as a whole is a tapering at both ends, parallel in the middle, with a morphology close to that of a spindle. This scan of the Achilles tendon did not reveal any grossly indistinct edges of the Achilles tendon.

Normal Achilles tendon can be seen inside the same direction with the direction of the Achilles tendon fiber echoes, arranged in an orderly and regular, clear boundary between each other, shaped like a feather, in the middle section, the fiber echoes are parallel to each other, the upper and lower segments, especially the lower section, the fibers converge with each other, and the fibers are clearly demarcated from each other. In the group of young professional athletes, of the 108 Achilles tendons examined, about 50 internal Achilles tendons showed varying degrees of disorganization and thickening of the texture, but none of them were obvious, accounting for about 46% of the total. Hypoechoic nodules were found in 20 Achilles tendons, and no strong echogenic calcification foci were detected in the middle and lower Achilles tendons, with a predominance of the lower Achilles tendon. In addition, the volume of the Achilles tendon was increased and the thickness exceeded the normal value in 2 cases. Among the 50 Achilles tendons with disorders, one Achilles tendon had a bilateral loss of parallelism of the perichondrium.

In the youth control group, about 12 of the 78 Achilles tendons examined were disorganized to varying degrees with thickened texture, accounting for about 15% of the total, which was much smaller than the proportion of athlete volunteers. Moreover, only five cases of strongly echogenic nodules in the Achilles tendon were detected in the sweep, and again, no obvious foci of calcification were found. No Achilles tendons with thicknesses significantly exceeding the normal range were found either. In addition, no other positive ultrasound manifestations such as other foci of paratendinous redundant ossification, paratendinous bursitis, synovial thickening, significant effusion, and swelling of the surrounding soft tissues were observed in the Achilles tendons of the volunteers in either group.

3.3 Comparison of Achilles Tendon Blood Flow

The Achilles tendon in both the youth control group and the professional youth athlete group showed a tissue state with a lack of blood supply. In color Doppler, the scale of color Doppler was adjusted to the lowest level, and no significant blood flow was seen in the Achilles tendon of both groups. After switching to energy Doppler and adjusting the scale, no significant energy Doppler signals were seen in the Achilles tendon, and no significant difference in signal volume was found between the two groups.

3.4 Comparison of Achilles tendon SWV values in youth control group

The right upper, middle, and lower Achilles tendon SWV values in the youth control volunteers were (9.81±0.10) m/s, (9.51±0.25) m/s, and (9.34±0.36) m/s, respectively; The left upper, middle, and lower Achilles tendon SWV values were (9.74±0.15) m/s, (9.41±0.26) m/s, and (9.10±0.29) m/s, respectively.

Comparisons between different segments on the left side were statistically different (p-value <0.01); comparisons between different segments on the right side were also statistically different (p-value <0.01). Moreover, the upper Achilles tendon had the highest SWV value, the lower Achilles tendon had the lowest SWV value, and the middle Achilles tendon had the middle SWV value.

The SWV values of the same segment of the Achilles tendon on the left and right sides were statistically significant when the lower segment was compared with the lower segment (P value <0.01), and the remaining middle and upper segments were not statistically significant when compared with the upper segment (P value >0.05). See Table 2 below.

Table 2: Comparison of SWV values of right and left Achilles tendons in the Youth control group

	UPPER ACHILLES TENDON SWV VALUES	MIDDLE ACHILLES TENDON SWV VALUES	LOWER ACHILLES TENDON SWV VALUES
LEFT	9.74±0.15	9.41±0.26	9.10±0.29
RIGHT	9.81±0.10	9.51±0.25	9.34±0.36
P VALUE	＞0.05	＞0.05	＜0.01

3.5 Comparison of Achilles Tendon SWV in Athlete Groups

The right upper, middle, and lower Achilles tendon SWV values for volunteers in the professional young athlete group were (9.80±0.10) m/s, (9.75±0.12) m/s, and (9.75±0.16) m/s, respectively; SWV values for the left upper, middle, and lower Achilles tendons were (9.81±0.09) m/s, (9.63±0.10) m/s, and (9.42±0.45) m/s, respectively. The different segment pairs on the left side were the same as in normal volunteers, with SWV values from high to low for the upper, middle, and lower segments. The two pairs of different segments on the right side were not statistically different from each other (p-value > 0.05). The SWV values of the same segments of the Achilles tendon on the left and right sides were statistically significant when the lower segments were compared, with the right side being larger than the left side (P value <0.01), and the remaining middle and upper segments were not statistically significant when compared (P value >0.05), as shown in Table 3 below.

Table 3: Comparison of SWV values of the left and right Achilles tendon in the athlete group

	UPPER ACHILLES TENDON SWV VALUES	MIDDLE ACHILLES TENDON SWV VALUES	LOWER ACHILLES TENDON SWV VALUES
LEFT	9.81±0.09	9.62±0.10	9.42±0.25
RIGHT	9.80±0.14	9.75±0.12	9.75±0.16
P VALUE	＞0.05	＞0.05	＜0.01

3.6 Comparison of ipsilateral segmental Achilles tendon SWVs

Comparison of the same segments of the Achilles tendon on the same side between professional athletes and healthy volunteers revealed no statistically significant difference between the volunteers and the professional athletes except for the right upper Achilles tendon (P value > 0.05).

The SWV values of athletes with middle and lower Achilles tendons were higher than those of healthy volunteers and were statistically significant (P value <0.01). See Table 4 for details.

Table 4: Comparison of SWV values of the same side of the same segment of Achilles tendon

GROUP	UPPER ACHILLES TENDON SWV VALUES		MIDDLE ACHILLES TENDON SWV VALUES		LOWER ACHILLES TENDON SWV VALUES	
	Left	Right	Left	Right	Left	Right
YOUTH CONTROL GROUP	9.74±0.15	9.81±0.10	9.41±0.26	9.51±0.25	9.10±0.29	9.34±0.36
ATHLETE GROUP	9.81±0.09	9.80±0.14	9.62±0.10	9.75±0.12	9.42±0.25	9.75±0.16
P VALUE	<0.01	>0.05	<0.01	<0.01	<0.01	<0.01

3.7 Comparison of ipsilateral segmental Achilles tendon SWV across programs

The elasticity values of the upper, middle and lower left Achilles tendon in the ball player group were about (9.81±0.09) m/s, (9.37±0.55) m/s, (9.37±0.55) m/s, and the elasticity values of the upper, middle and lower left Achilles tendon in the track and field athlete group were about (9.80±0.08) m/s, (9.48±0.20) m/s, (9.63±0.11), and the elasticity values of the upper, middle and lower left Achilles tendon in the track and field athlete group were about (9.80±0.08) m/s, (9.48±0.20) m/s (9.63±0.11), respectively.

The elasticity values of the upper, middle and lower right Achilles tendon in the ball player group were approximately (9.81±0.09) m/s, (9.77±0.09) m/s, (9.77±0.17), respectively, and the elasticity values of the upper, middle and lower right Achilles tendon in the track and field player group were approximately (9.78±0.11) m/s, (9.72±0.16) m/s, (9.72±0.15) m/s, respectively.

Comparison of the same Achilles tendon segments showed no statistical significance (P value > 0.05) except for the left mid-segment. Because of the small sample size, no separate comparisons were made between men and women. See Table 5 below for details.

Table 5: Comparison of SWV values of same side and same segment of Achilles tendon in different sports

GROUP	UPPER TENDON VALUES	ACHILLES SWV	MIDDLE TENDON VALUES	ACHILLES SWV	LOWER TENDON VALUES	ACHILLES SWV
	Left	Right	Left	Right	Left	Right
BALL SPORTS	9.81±0.09	9.81±0.09	9.37±0.55	9.77±0.09	9.37±0.55	9.77±0.17
TRACK AND FIELD SPORTS	9.80±0.08	9.78±0.11	9.48±0.20	9.72±0.16	9.63±0.11	9.72±0.15
P VALUE	＞0.05	＞0.05	＜0.05	＞0.05	＞0.05	＞0.05

3.8 Comparison of SWV of ipsilateral segmental Achilles tendon by gender

All volunteers were divided into male and female groups according to gender. Comparison of the SWV values of the same segments of the Achilles tendon on the same side showed that there was a statistically significant difference between the right upper and middle Achilles tendons (P value <0.01), while there was no statistically significant difference between the remaining segments (P value >0.05). See Table 6 below for details.

Table 6: Comparison of SWV values of same side and same segment of Achilles tendon in different genders

GROUP	UPPER TENDON VALUES	ACHILLES SWV	MIDDLE TENDON VALUES	ACHILLES SWV	LOWER TENDON VALUES	ACHILLES SWV
	Left	Right	Left	Right	Left	Right
MALE	9.79±0.13	9.82±0.08	9.56±0.21	9.68±0.22	9.25±0.54	9.59±0.31
FEMALE	9.77±0.11	9.32±0.27	9.51±0.21	9.79±0.11	9.32±0.27	9.51±0.35
P VALUE	＞0.05	＜0.01	＞0.05	＜0.01	＞0.05	＞0.05

4. Discussion

From the two-dimensional data of the Achilles tendon of the volunteers in both groups, it can be seen that positive ultrasound characteristics of the Achilles tendon were detected in 67% of the young athletes and in 15% of the young control group. However, it is important to note that the volunteers had no history of Achilles tendon injury and no clinical signs of Achilles tendon discomfort. If we strictly follow the stages of tendinopathy development, we can categorize it into the second stage of decompensation, in which the Achilles tendon damage is not repaired in time and gradually worsens.

It is further confirmed that Achilles tendinopathy progresses slowly and is easily overlooked due to its early clinical symptoms that are not obvious. Not only the high-risk groups such as professional athletes who perform heavy load training, but also the general public should be more vigilant in their daily life. In addition, the detection rate of professional athletes is much higher than that of healthy young people, and it can be found that large-load, long-time, high-intensity athletic injuries to the Achilles tendon are unavoidable, and although there are no obvious clinical symptoms for a short period of time, the use of advanced instruments and technology can achieve early detection and early warning.

4.1 Achilles Tendon Thickness

For the thickness measurement of the Achilles tendon, the thickness of the Achilles tendon in the lower part of the Achilles tendon at 1 cm and 2 cm from the heel bone stop was selected for this experiment. Because firstly, the Achilles tendon is long and not clearly demarcated, so it is difficult to measure the Achilles tendon at one location, and determining the location of the Achilles tendon at this location can be a clear point to compare the thickness; secondly, the lower part of the Achilles tendon is the most frequent part of the Achilles tendon for chronic injuries; in addition, there are studies in the literature on the results of the measurements of the Achilles tendon at various locations, and the repeatability of the measurements at this location of the Achilles tendon is relatively high. Exercise is one of the most important factors in the pathogenesis of tendinopathy, but there is no authoritative reference value for the thickness of the Achilles tendon for the time being, and some studies have suggested that the Achilles tendon at the point of insertion of the heel bone should be less than 5.3 mm, and none of the cases in the present experiment were found to significantly exceed this value.

In the current study, it was found that age and various underlying diseases, including diabetes mellitus, can cause the Achilles tendon to thicken compared to healthy people. And patients with acute Achilles tendon injuries such as Achilles tendon rupture develop thickened Achilles tendon edema. So by comparing the difference in the thickness of the Achilles tendon between the two groups of volunteers participating in this experiment in these two places, it can indirectly reflect the athletic injuries to the Achilles tendon. In this experiment, no significant difference was found in the thickness of the Achilles tendon in the volunteers of professional athletes compared with that of healthy youths.

And it may be related to the selection of the measurement site and the younger volunteers, the thickness of the Achilles tendon was obviously thinner than that in previous studies, especially at the 1cm area of the Achilles tendon. This may be related to the shape of the Achilles tendon and the different measurement sites of other researchers. In addition, in a previous study, Rosso et al (Rosso et al., 2012). measured Achilles tendon thickness at 5 cm from the insertion point of the Achilles bone as 0.54 ± 0.62 cm and 0.50 ± 0.60 cm in males and females, respectively. In each age group, Achilles tendon thickness in males was greater than that in females and showed statistically significant differences. However, in the present study, no statistically significant difference was found between the two Achilles tendon thicknesses in different genders.

4.2 SWV values of the Achilles tendon

4.2.1 Achilles tendon segmentation study

The trend of segmentation of the Achilles tendon in normal healthy youth was obvious, and the overall shear wave velocity SWV value, which reflects the stiffness of the Achilles tendon, was the highest in the upper part of the Achilles tendon, the middle part of the tendon was in the center, and the lower part of the tendon was the lowest. However, in the group of professional young athletes, the trend of segmentation was maintained from the data, but the segmentation was no longer obvious, especially the right Achilles tendon of the athletes did not find obvious segmentation. Meanwhile, when comparing the right and left Achilles tendons in the same group of volunteers, the right Achilles tendon was slightly higher than the left Achilles tendon.

The Achilles tendon has different degrees of minor injuries during athletic injuries, including large and small loads, and the repair of Achilles tendon injuries is a dynamic equilibrium, and some researchers have suggested that the distribution and arrangement of collagen fibers inside the Achilles tendon during the repair process are inconsistent with that of the healthy Achilles tendon, which interferes with the propagation speed of shear waves. In the experiments of this paper, it can be understood that the difference in exercise intensity and exercise volume is the reason for this result. That is, the amount of injury to the Achilles tendon increases, and the internal organization of the Achilles tendon undergoes changes that are subtle and not perceived by volunteers on a daily basis, which is reflected in the stiffness, i.e., increased stiffness of the Achilles tendon.

Possibly due to the effect of exercise volume on the different segments of the Achilles tendon, as well as anatomical and blood supply differences, the experimenters found that the SWV values of the right middle and lower Achilles tendon of professional athletes were higher than those of the left middle and lower Achilles tendon in comparison with ordinary volunteers, and this trend was more pronounced than that of the upper Achilles tendon. We can understand that the different segments of the Achilles tendon are affected by sports due to its anatomy, stress, blood supply and many other factors, resulting in its reflection in the elasticity value is not the same, the overall trend is that the SWV value increases, due to the different segments of the SWV increases differently, the gap between the SWV of different segments of the Achilles tendon is not obvious.

4.2.2 Comparison of SWV values of Achilles tendon in different groups

In the experiment of this paper, the SWV of the Achilles tendon was compared between the youth control group and the athlete group on the same side and at the same segment. Firstly, in terms of SWV values, the athletes had higher values than the healthy volunteers in different segments; further comparisons revealed statistical significance except for the upper segments. Chronic Achilles tendon injuries as well as tendinopathies are most frequent in the middle and lower Achilles tendon, especially in the middle and lower Achilles tendon due to scarce blood supply to the Achilles tendon, which is the most frequent site of Achilles tendon rupture.

In this experiment, the SWV values of the middle and lower Achilles tendon of healthy volunteers were lower than those of athletes, while no significant difference was found in the SWV values of the upper Achilles tendon. This may be related to the fact that athletes have a greater amount of exercise and intensity than ordinary young people: the greater amount of exercise causes subtle injuries and repairs to the Achilles tendon, especially the middle and lower segments, which are more obvious; there may be two reasons why no significant difference in the stiffness of the upper Achilles tendon was found in the experiments of this paper:

(1) The form of collagen cross-linking within the upper Achilles tendon is inconsistent with that of the middle and lower segments, while the upper Achilles tendon has a richer blood supply and is less affected by athletic injuries. (2) The upper Achilles tendon is affected by the limitations of the VTIQ technique, which has a range of 0.5-10m/s, i.e. when measuring the upper Achilles tendon, the range is often exceeded and High is displayed. This means that when measuring the upper Achilles tendon, the range is often exceeded and High is displayed. In application, the notation of High as 10 m/s is more common in the upper Achilles tendon than in the other segments, which further affects Achilles tendon stiffness measurements.

5. Conclusion

Achilles tendon injuries have become more frequent with the increase in the number of people involved in athletic injuries. Whether conservative or surgical treatment is chosen, the evaluation of the later rehabilitation effect is very important. It can provide reference for patients and rehabilitation personnel to correctly recognize the recovery status of the injury, which is helpful for patients to understand their own Achilles tendon recovery as well as help rehabilitation personnel to make adjustments to the rehabilitation program. The following conclusions were drawn from the monitoring of different groups of Achilles tendons by ultrasound images. 1. The Achilles tendon in healthy young people exhibits a high stiffness structure with a more uniform overall stiffness. 2. High-intensity, prolonged exercise causes changes in the internal tissues of the Achilles tendon without clinically symptomatic tissue, which manifests itself in increased stiffness of the Achilles tendon.

There are still some shortcomings in this study. First, the number of volunteers participating in the experiment is relatively small, and in order to minimize the bias caused by the small sample size, the experiment in this paper adopts segmented and multiple values to further reflect the elasticity characteristics of the Achilles tendon more accurately.

However, it is still difficult to avoid the limitation of the data caused by the small sample size. Secondly, the sample of athletes in the experimental study also has limitations. The target of this experimental study is professional athletes, but the level of volunteers is mainly national athlete level 2 and national athlete level 1, and the more professional athletes at the level of general are not included.

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