

早稲田大学審査学位論文
博士（スポーツ科学）
概要書

Structure of foot and ankle
-biomechanical risk factor of Sever's disease-

足部の構造
-Sever 病の力学的リスク要因-

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早稲田大学大学院 スポーツ科学研究科

橋詰 賢

Hashizume, Satoru

研究指導教員： 矢内 利政 教授

【Background and purpose】

Sever's disease is a traction epiphysitis occurring at immature attachment site of the Achilles tendon (and the calcaneal epiphysis). This injury comprises 2% to 16.3% of children's and adolescent's musculoskeletal injuries at sports medical clinics. The mechanism of Sever's disease has been proposed as follows; the great tensile force is repeatedly applied to the immature attachment site of the Achilles tendon where the hyaline cartilage is present, and this induces repetitive microtrauma accompanied with inflammation.

Epidemiological studies reported that Sever's disease occurs frequently in individuals of active and overweight males of particular age group. Theoretically, the first two factors affect directly the magnitude of ground reaction force (GRF) that would act on the foot during weight-bearing physical activities, and the increased GRF and its moment around the talocrural joint axis may cause a great demand on the triceps surae, which, in turn, increases the tensile stress at the attachment site of the Achilles tendon. The third and fourth factors may be related to physical and social developments of children and adolescents. Sever's disease occurs frequently in boys aged 10-13 who are, in general, undergoing a growth spurt and whose physical activity is higher than corresponding aged girls and younger boys and girls aged 10-13. The large body mass and physical activity for boys aged 10-13, therefore, may account for the age-specific and the sex differences in the incidence of Sever's disease to certain extent.

Mechanically, the tensile stress at the attachment site of the Achilles tendon is not determined completely by the GRF alone. The cross-sectional area (CSA) of the attachment site of the Achilles tendon and the mechanical advantage are the additional structural parameters of foot and ankle determining the tensile stress at the attachment site of the Achilles tendon. The age-related difference and the sex difference in the structural parameters of foot and ankle should be examined to clarify the risk factors that account for the age-specific and the sex differences in the incidence of Sever's disease. The general purpose of this thesis, therefore, was to examine the age-related difference and sex difference in the structural parameters of foot and ankle that influence the tensile stress at the attachment site of the Achilles tendon. The four steps of experiments were conducted in this thesis as follows; 1) develop a three-dimensional method to determine the Achilles tendon moment arm in three-dimensions for accurately determining the structural parameter of the mechanical advantage (Section 1 of Chapter 2), examine the influence of the muscle contraction on the Achilles tendon moment arm in three-dimension (Section 2 of Chapter 2), 3) examine the age-related differences in the structural parameters of foot and ankle by using the developed method in Chapter 2 (Chapter 3), and 4) examine the sex differences in the structural parameters of foot and ankle (Chapter 4).

【Contents and main findings】

• Chapter 2

The three-dimensional method was developed to determine the Achilles tendon moment arm accurately (Section 1). This method was found to be highly reliable (trial-to-trial, day-to-day and inter-examiner). The good agreement of the orientation of the talocrural joint axis between present and some previous results validated this method. The three-dimensional method, therefore, can determine the Achilles tendon moment arm accurately as compared with the traditional two-dimensional method.

Sever's disease occurs under the weight-bearing condition, and therefore the influence of muscle contraction on the Achilles tendon moment arm should be examined in three-dimension (Section 2). The results showed that the Achilles tendon moment arm determined in muscle contraction condition was greater by 18% than that determined in the rest condition and a significant correlation ($r = 0.968$) was found between the Achilles tendon moment arms determined in the rest and muscle contraction conditions. The Achilles tendon moment arm determined in the rest condition underestimates, but corresponds well to, that determined in the muscle contraction condition, suggesting that the Achilles

tendon moment arm determined in the rest condition can be used to examine the difference in the Achilles tendon moment arm between different groups.

• Chapter 3

The higher incidence of Sever's disease was reported for boys aged 10-13 than boys under the age of 10. In Chapter 3, the age-related differences in the structural parameters of foot and ankle that influence the magnitude of the tensile stress at the attachment site of the Achilles tendon were examined. The index that represents the magnitude of the tensile stress at the attachment site of the Achilles tendon for a given physical activity was found to be significantly greater in boys aged 10-13 than in boys aged 7-9. The mechanical advantage was not different among the groups. Body mass was significantly greater in older groups than in younger groups. The CSA of the Achilles tendon insertion was not different between boy's groups and was greater in young adult males than in the boy's groups. These results suggest that the onset of growth spurt for the CSA of the Achilles tendon insertion does not coincide with that for body mass, and this gap might result in the significantly large value in the index for boys aged 10-13. The delayed onset of growth spurt for the CSA of the Achilles tendon insertion may be an additional biomechanical risk factor that account for the age-specificity in the incidence of Sever's disease.

• Chapter 4

The higher incidence of Sever's disease was reported for boys than girls. Particularly, the notable sex difference in the incidence was observed for boys and girls aged 10-13 but for those aged 7-9. These suggest that the sex difference in the incidence of Sever's disease is age-specific. In general, the onset of the growth spurt of body dimensions is earlier for girls than boys. The onset of growth spurt of foot and ankle dimensions should, therefore, be earlier for girls than boys and this results in sex difference in the parameters determining the index of the tensile stress for children and adolescents. In Chapter 4, the sex differences in the structural parameters of foot and ankle that influence the magnitude of the tensile stress at the attachment site of the Achilles tendon were examined for selected age groups. As a result, no sex differences in the mechanical advantage, the CSA of the Achilles tendon insertion and the index of the tensile stress were observed for each age group. These results suggest that the tensile stress at the attachment site of the Achilles tendon was similar between boys and girls if the physical activity level was the same and there is no structural parameter of foot and ankle that account for the age-specific sex difference in the incidence of Sever's disease.

【Conclusions】

The general purpose of this thesis was to examine the age-related difference and sex difference in the structural parameters of foot and ankle that influence the tensile stress at the attachment site of the Achilles tendon, and the four steps of experiments were conducted. The main findings of each step were as follows; 1) the newly developed three-dimensional method for determining the Achilles tendon moment arm was found to be highly reliable and to be validated, 2) the Achilles tendon moment arm determined in the rest condition underestimates, but corresponds well to that determined in the muscle contraction condition, 3) the onset of growth spurt for the CSA of the Achilles tendon insertion does not coincide with that for body mass, and this gap might result in the significantly large value in the index of the tensile stress for boys aged 10-13, 4) there are no sex differences in body mass and the structural parameters of foot and ankle, and this results in no sex difference in the index of the tensile stress for 7-9 and 10-13 years old groups. The presence of the hyaline cartilage at the injured site has been known to be the primary factor of the age-specificity and sex difference in the incidence of Sever's disease. The age-related difference in body mass and the age-related and sex differences in physical activity were also known to be the factors of these specificities of the incidence. Present thesis found that the delayed onset of growth spurt for the CSA of the Achilles tendon insertion may be an additional biomechanical risk factor that accounts for the age-specificity in the incidence of Sever's disease.