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Characteristics of adolescent athletes with pain during sports activities: Evaluation of flexibility using ultrasound elastography

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Abstract

Medical checkups for adolescent athletes aim to prevent or detect sports injuries and manage them before they hamper future sports activities and daily life. However, effective items for evaluation, as well as the areas of intervention to prevent sports injuries, remain unclear. We aimed to clarify the checkup items and intervention areas to prevent sports injuries in adolescent athletes. This is a cross-sectional observational study that investigated the presence or absence of pain in adolescent athletes and the associated factors at the time of checkup. We examined 301 junior high school athletes; joint laxity, range of motion, finger-floor distance, heel–buttock distance, straight leg raising angle, too many toes sign, and presence or absence of low back pain during lumbar extension were investigated. Additionally, after confirming the developmental stage of the tibial tuberosity using ultrasonography, ultrasound elastography was used to quantify the elasticity of the quadriceps femoris; items related to pain during sports activities were extracted. Items related to pain included the too many toes sign, low back pain during lumbar extension, and elasticity of the quadriceps femoris. Athletes with a positive 'too many toes' sign are less likely to experience pain; conversely, the harder the quadriceps femoris, the more likely they were to experience pain. Medical checkups focusing on these items are effective for adolescent athletes who are prone to knee pain.

Keywords: Ultrasound elastography; pain; adolescent athlete; flexibility

スポーツ時痛を訴える成長期アスリートの特徴
－超音波エラストグラフィーを用いた柔軟性の評価－

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成長期アスリートのメディカルチェックでは、スポーツ障害を予防・発見し、将来のスポーツ活動や日常生活に支障をきたす前に対応することが目的である。しかし、スポーツ障害を予防するための効果的な評価項目や介入領域は明らかでない。 そこで本研究では成長期アスリートにおいて有効な検診項目と介入領域を明らかにすることを目的として、中学生アスリート 301 名を対象に、関節弛緩性、関節可動域、指床間距離、踵臀間距離、straight leg raising 角度、too many toes sign の有無、腰椎伸展時腰痛の有無について調査した。また、超音波検査で脛骨結節の発達段階を確認したうえ、超音波エラストグラフィーで大腿四頭筋の弾性を定量化し、スポーツ時の痛みに関連する項目を抽出した。その結果、痛みの有無に有意に関与する項目は、too many toes sign、腰椎伸展時の腰痛、大腿四頭筋の弾性であった。too many toes sign が大きいほど、成長期アスリートは痛みがある割合が少なく、逆に大腿四頭筋が硬いほど、痛みがある割合が多かった。膝痛を起こしやすい成長期アスリートには、これらの項目に着目したメディカルチェックが有効である。

1 Background

The purpose of annual general checkups for adolescent athletes is to prevent or detect sports-related injuries at an early stage and manage them before they hamper future sports activities and daily life *1–3*; however, effective items for evaluation, as well as the areas of intervention to prevent sports injuries, remain unclear *4, 5*. Therefore, the purpose of this study was to clarify these items and those areas of intervention that are required to prevent sports injuries in adolescent athletes.

The main problem in sports injuries is pain at the injury site. The goal is to detect and manage the injury before an individual experiences any pain; however, if adolescent athletes are already aware of pain somewhere in their body during sporting activities, it is predicted that they are likely to already have some form of injury *6, 7*. Furthermore, it is common for the cause of pain or the site of injury to exist at a location that is different from the site of pain; for example, upper limb pain is often affected by the tightness of the lower limbs or trunk *8*. Adolescent athletes who are experiencing a growth spurt, are particularly vulnerable to pain and disability at the site of muscle-tendon insertion because of unequal rates of muscle-tendon and bone elongation, consequently, muscle-tendon becomes relatively stiff. Osgood-Schlatter disease in the knee extension mechanism is particularly well known *9, 10*. In other words, it is significant to measure the elasticity of muscle / tendon as one of the most important factors related to pain in adolescent athletes. However, few studies have examined the association between pain and medical checkup parameters such as muscle-tendon stiffness in adolescent athletes using ultrasound elastography.

Therefore, the first objective of this study was to investigate the factors associated with pain during sports activities in adolescent athletes, regardless of the location of pain. In other words, the primary purpose of our research, after identifying pain in the body during sports as a condition that either causes or is likely to cause injury, was to clarify the factors related to that condition. Our secondary aim was to conduct a survey on knee pain, which is common among adolescent athletes. In other words, we aimed to investigate the characteristics of athletes with knee pain during sports activities, by comparing their data with those of athletes without knee pain. By clarifying these factors and characteristics, the risk of sustaining a sports injury can be evaluated; thus, injuries can be effectively detected and preventive measures can be adopted. Finally, the third objective was to determine the cutoff value of those items for pain during sports activities. In order to achieve the above objectives, the elasticity of muscle / tendon was included among the items to be evaluated. The elasticity of muscle / tendon was measured by ultrasound elastography, which is highly reliable, rather than by palpation, physical examination, or other instruments such as muscle hardness testers, which are subject to interrater variability.

2 Materials and Methods

This is a cross-sectional observational study that investigated the presence or absence of pain in adolescent athletes and the associated factors at the time of checkup.

The subjects were 310 athletes designated for sports enhancement during the fiscal year.

Subjects were excluded from this study if they or their family did not agree to participate in this study or were unable to participate in the actual checkup.

This study was approved (approved number 1703) by the institutional review board of our university (Certified Clinical Research Review Board, Akita University), and informed consent was obtained from the parents/guardians of the subjects prior to their participation in this study.

All the players who had marked 'yes' in the questionnaire were asked to describe the site. In none of the players was the examination limited by pain or disability. These measurements were taken indoors at a public facility in June and November each year and were performed by an orthopedic surgeon or physical therapist using a goniometer or a similar device. Note that the survey was conducted between 2013 and 2016, and athletes were identified strictly by identification number, therefore no athlete has been checked more than twice. A self-administered questionnaire assessing pain felt on the day of survey and increase in the body height within the past year was filled in, followed by an examination of the ranges of motion for the shoulders, elbows, knees, and hip joints along with checking for joint laxity, finger-floor distance, heel–buttock distance, too many toes sign *11–13*, and straight leg raising angle.

Regarding the range of motion of the elbows and knees, extension <0° and flexion <145° were recorded as restricted extension and restricted flexion, respectively. In the subsequent univariate analysis, athletes with restricted extension or restricted flexion on either side were considered to have significant restrictions of extension or flexion.

The general joint laxity test by Whitehead et al. *14* was used to measure joint laxity; this test is a combination of Carter's method *15*, Brighton's method *16*, and laxity evaluation of the shoulder joint, which evaluates the presence (positive) or absence (negative) of laxity in seven major joints of the body (shoulders, elbows, hands, spine, hips, knees, and ankles) through visual inspection with a goniometer. For the too many toes sign *11–13*, the examiner determined and recorded how many toes (toes IV and V) were visible on the outside of the lower leg from behind the athlete in a standing position. Both sides were checked, and the sum of the values of both sides was used in the statistical analysis. For the detection of lumbar spondylolysis, we confirmed and recorded the presence of "low back pain during lumbar extension" as a pain provocation test. It is possible that lumbar spondylolysis does not cause low back pain on extension, however lumbar spondylolysis, which can cause symptoms and should be taken care of, could be detected by this method.

Additionally, after sonographically confirming the stage of development of the tibial tuberosity, we measured the elasticity of the quadriceps femoris muscle–tendon junction using ultrasound elastography (ACUSON S2000, Siemens Medical Solutions USA, Inc., Ultrasound Division, CA USA) that quantifies elasticity by measuring shear wave velocity. Finally, items related to pain were examined using ultrasonography. The growth-developmental stage was then checked at the tibial tuberosity, and a growth spurt was predicted by classifying the growth-developmental stage into six stages *17, 18*.

There are two methods of ultrasound elastography; the first evaluates tissue elasticity at the strain when the tissue is pressed using the ultrasonic probe *19, 20*, while the second evaluates tissue elasticity by measuring the shear wave velocity *21*. The second method has a higher reproducibility *22*; thus, this method was used in our study. Elastographic measurement was performed in the sitting position, with both the hip and knee joints flexed at 90°. During measurement, the subject was instructed to relax the lower limbs as much as possible.

First, a longitudinal image of the muscle–tendon transition area of the quadriceps femoris was depicted on the ultrasonogram. Next, ultrasonic pulse irradiation was performed to visualize the shear wave velocity of the entire area; four 2 mm × 2 mm regions of interest were then randomly selected in the muscle–tendon junction of the quadriceps femoris, and the average value of the shear wave velocities at these four regions was used as the measured value. This method has been confirmed to be reproducible in various locations *22*, and there are reports of measurements at the muscle–tendon junction of the quadriceps femoris *10*. In this study, the elasticity of the quadriceps femoris muscle was only measured on the dominant side, based on the side, perceived as dominant by the player, even though there were no differences in the measurements on both sides examined in the medical checkup conducted prior to this study.

In this study, although pain was not classified based on the site or definite diagnosis, quantitative evaluation of the muscle-tendon elasticity on elastography was performed only on the quadriceps muscle. This was based on the hypothesis that the assessment of stiffness at each site with manual testing would correlate with the quantitative assessment at only one location.

A bias is not expected in studies involving ultrasonic elastography measurements because the sound speed is calculated automatically. In the study, there was no bias as the examiners conducting manual examinations were blinded to the details of the athlete's pain.

The participants were divided into the following two groups: athletes who feel pain while practicing or competing, regardless of the location (n=87); and athletes who feel no pain anywhere during practice or competitions (n=214). A univariate logistic analysis was performed to identify factors that were related to the presence or absence of pain, followed by a multivariate logistic analysis for the items that were found significant in order to detect the factors related to pain during sports activities, as well as to calculate their odds ratios. The factors included in the univariate logistic analysis are listed in Table 1.

[Insert Table 1 here]

Additionally, we divided the adolescent athletes into two groups: those competing while experiencing pain in either knee (n=44) and those who reported that they did not experience any pain in either knee (n=214) during practice or competitions. The factors associated with knee pain were then detected using univariate logistic analysis. Next, multivariate logistic analysis was performed on the items that were shown to be significant in the univariate logistic analysis in order to detect those factors that were related to knee pain during sports activities, and to calculate their odds ratios. The factors included in the univariate logistic analysis are listed in Table 2. Finally, we evaluated the cutoff values of the items related to pain during sports that were obtained via the multivariate analysis. The cutoff values were determined using the Youden index from the receiver operating characteristic curve. The level of significance was set at $P<0.05$. In addition, the listwise deletion method was employed to account for the missing values in this study. In other words, players with an incomplete evaluation were excluded, however complete data was obtained for all study participants.

[Insert Table 2 here]

3 Results

Out of 310 athletes designated for sports enhancement during the fiscal year, only 301 athletes underwent medical checkups. Thus, this study examined 301 junior high school students, with an average age of 14 years (range, 13–15 years; 174 males, 127 females), who had been selected as certified athletes of their prefecture. Athletic events included swimming, track and field, football, kendo, judo, fencing, tennis, table tennis, badminton, wrestling, sumo wrestling, karate, shooting, basketball, rugby football, gymnastics, canoeing, soft ball, handball, skiing, and ice skating. All of them consented to participate in this study, and none were excluded due to pain or other reasons that could not allow examination.

The presence or absence of pain experienced by adolescent athletes during sports activities and their locations are shown in Figure 1. Univariate logistic analysis revealed that five items (too many toes sign, low back pain during lumbar extension, hip external rotation range on the dominant side, hip internal rotation range on the nondominant side, and shear wave velocity of the quadriceps femoris) were significantly associated with pain during sports activities (Table 1). A multivariate logistic analysis of these items revealed that the pain odds ratios for low back pain during lumbar extension, too many toes sign (total increase in the left and right), and shear wave velocity of the quadriceps femoris were 6.16, 0.65, and 2.39, respectively (Table 3); 57.1% of athletes with low back pain during lumbar extension had knee pain during sports activities. Similarly, 25.0%, 10.7%, and 7.1% of athletes who had low back pain during lumbar extension had pain in the lower back, foot, and other sites, respectively, during sports activities. Additionally, athletes with knee pain during sports often experienced pain in the lower back when the lumbar spine is extended.

[Insert Figure 1 here]

[Insert Table 3 here]

The number of athletes with knee pain was 44 out of the 301 subjects (14.6%). The results of the univariate logistic analysis between athletes with knee pain and athletes without pain revealed that four items (too many toes sign, low back pain during lumbar extension, restriction of knee flexion range of motion, and the shear wave velocity of quadriceps femoris) were significantly associated with the presence of knee pain (Table 2). Multivariate logistic analysis of these items showed that the knee pain odds ratios for the too many toes sign, low back pain during lumbar extension, knee flexion range restriction, and the shear wave velocity of the quadriceps femoris were 0.75, 3.60, 2.46, and 2.42, respectively (Table 4).

[Insert Table 4 here]

We compared the hip external rotation range between athletes with a total too many toes sign result of ≤3 and those with a result of ≥4; the range was 55° ± 14° and 62° ± 11° in athletes with a too many toes sign of ≤3 and in athletes with a too many toes sign result of ≥4, respectively. In other words, athletes with a positive too many toes sign had a significantly larger range of hip external rotation ($P<0.0001$); however, there was no difference in the other items.

The shear wave velocity cutoff value for pain in adolescent athletes, representing the elasticity of the quadriceps femoris muscle–tendon junction, was 4.94 m/s (sensitivity, 0.63; specificity 0.69; Fig. 2). Conversely, the straight leg raising angle cutoff value for pain was 75° (sensitivity, 0.60; specificity 0.45). The sensitivity and specificity of finger-floor distance >0 cm, for predicting pain were 24% and 79%, respectively, whereas the sensitivity and specificity of heel–buttock distance >0 cm, for predicting pain were 73% and 29%, respectively (Table 5).

[Insert Figure 2 here]

[Insert Table 5 here]

The shear wave velocity cutoff value of the quadriceps femoris muscle–tendon junction for knee pain only in adolescent athletes was 4.94 m/s (sensitivity, 71%; specificity

65%; Fig. 3), whereas the heel–buttock distance cutoff value for knee pain was 3 cm (sensitivity, 52%, specificity, 65%).

[Insert Figure 3 here]

4 Discussion

This study is the first to demonstrate that low back pain during lumbar spine extension, too many toes sign, and elasticity of the quadriceps, quantitatively evaluated using ultrasound elastography, are significantly associated with knee pain in adolescent athletes. Additionally, we clarified that the shear wave velocity cutoff value of the quadriceps that causes knee pain in adolescent athletes was 4.94 m/s; if this is exceeded, pain potentially caused by Osgood–Schlatter disease or patellar tendinitis occurs. However, it was not possible to clearly indicate the cutoff values in the receiver operating characteristic curve analysis as a conclusion of this research, because the area under the curves of the receiver operating characteristic curves generated from the data in this study ranged from 0.69 to 0.72 and these were from low to moderate accuracy. To improve this accuracy further, it may be necessary to investigate in more athletes, as well as technological innovations to improve the accuracy of ultrasound elastography. In particular, athletes with low back pain during lumbar spine extension were 3.6 times more likely to have knee pain; thus, it was speculated that if the lower back could not be sufficiently extended owing to pain, it could cause knee injuries. Furthermore, knee pain may affect the lower back. To show a direct causal relationship between low back pain during lumbar extension and knee pain during sports activities, it is necessary to consider further research with more athletes.

In addition, athletes with a positive too many toes sign, used for flatfoot screening, were less likely to have pain, especially knee pain, during sports activities. However, this does not necessarily indicate that flat feet are advantageous in preventing pain in athletes. It is also possible that the positive too many toes sign results from the perspective of this study's detected factors other than flat feet. In this study, the athlete stood with a "natural" posture. The examiner then observed the toes from behind, confirming whether the toes (IV and V toes) could be seen on the outside of the lower leg; thus, this does not confirm whether this sign is positive only in athletes with flat feet. Additionally, the range of external rotation of the hip joint was significantly larger in athletes with a positive too many toes sign than those in athletes without such a sign; thus, what the examiner perceives as a positive "too many toes sign" may have been the external rotation range of the hip joint in the standing position. In other words, the larger the rotational range of motion of the hip joint, the more advantageous it may be in preventing pain during sports activities, especially knee pain. Nevertheless, if a positive too many toes sign was indicated from the viewpoint used in this study, it was shown to be a factor that prevents pain, especially knee pain, during sports activities.

Another reported factor causing sports injuries is reduced physical flexibility *19*. Until now, it has been impossible to quantitatively evaluate flexibility; thus, this measurement was substituted by range of motion, or various other physical findings. In this study, the flexibility of the muscle–tendon junction could be easily quantified using ultrasound elastography. Previous studies have reported that the hardness of the muscle–tendon junction, measured using ultrasound elastography, was related to pain during sports *10*; this relationship was clarified in the multivariate analysis in our study, confirming that the stiffness of the muscle–tendon junction is independently involved in pain, especially knee pain, during sports activities. We were also able to clarify the shear wave velocity cutoff value for pain, which directly correlates with flexibility.

In this study, we also measured muscle tightness parameters that have been utilized for some time, such as the finger-floor distance, heel–buttock distance, and straight leg raising angle. There were concerns regarding the tightness of the muscles and tendons compared with those of general athletes of the same generation; however, there was no significant difference in the muscle tightness test results. The target group comprised elite, designated sports strengthening athletes; for such elite athletes, it is necessary to quantitatively evaluate the hardness of local muscle and tendons using ultrasound elastography.

One of the limitations of this study is that the differences in the results according to the various types of sport could not be investigated. By conducting a larger survey and further investigating whether this same tendency is observed, regardless of the difference in types of sport, we can give more effective advice to adolescent athletes in the future. Another limitation is that the results of the measurements in this study may differ from those of an average sports enthusiast because the study participants were relatively competitive athletes in the same age group.

Furthermore, we only evaluated the elasticity of the muscle–tendon junction of the quadriceps femoris; the elasticity of other regions was not evaluated. Most of the pain sites reported by adolescent athletes were around the knees, and many of these cases were expected to be a result of factors related to the flexibility of the quadriceps femoris, such as Osgood–Schlatter disease. Additionally, in a medical checkup scenario where a large number of athletes are inspected, one of the sites that is easily exposed for applying an ultrasonic probe is the knee; therefore, examination using ultrasound elastography of the muscle–tendon junction of the quadriceps has even been performed in past reports [10]. It has also been reported that athletes with pain other than knee pain have a high shear wave velocity of the quadriceps femoris; i.e., the quadriceps femoris tends to be stiff [10]. Hence, it is possible to estimate the “hardness” of the entire body by evaluating only one area, instead of multiple areas. Still, it is necessary to measure other areas depending on the characteristics of the type of sport, as well as the type of sports injury to be targeted. Future research is required for both the method and site of measurement. In the future, we plan to collect evidence regarding the kind of risks that exist among various sports injuries, as well as the type of sport, by following athletes who have undergone medical checkups; the results should lead to the creation of criteria for sports injury prevention or recovery from injury. An additional limitation is that this study evaluated the association between pain at the time of evaluation and the corresponding measurements; thus, pain-related changes itself may have affected the measurements. Prospective cohort studies are necessary to clarify the factors contributing to the injuries.

In conclusion, this study was the first to analyze the factors that affect the pain in adolescent athletes, including an evaluation of elasticity via shear wave velocity measurement. In adolescent athletes, low back pain during lumbar spine extension, too many toes sign, and quantitative assessment of quadriceps elasticity on ultrasound elastography were significantly associated with pain at all locations during sports activities, especially in the knee. Our results provide useful evidence when considering the selection of medical checkup items for adolescent athletes for better prevention of sports injuries.

Conflict of interest

The authors declare that there are no conflicts of interest.

Contributions

HK, MF and TK conceptualized the study design and protocol, and determined the study institutions. HK and HS collected and assembled the data. HK, MF and MN carried out the analysis and interpretation of data. HK and MN drafted the manuscript. All authors have critically reviewed, revised and approved the manuscript.

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Availability of data and materials

Not applicable.

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Table 1 The results of univariate logistic analysis between the presence and the absence of pain, experienced by adolescent athletes during sports activities

Items	*Odds ratio*	*95% CI min.*	*95% CI max.*	*P-value*
Developmental stage of tibial tuberosity	1.05	0.71	1.54	0.82
Body height grown in 1 year	1.05	0.94	1.16	0.38
Heel-buttock distance	1.01	0.96	1.06	0.67
External rotation range of shoulder (dominant side)	0.99	0.97	1.02	0.69
External rotation range of shoulder (nondominant side)	0.99	0.96	1.01	0.33
Internal rotation range of shoulder (dominant side)	1.00	0.99	1.02	0.69
Internal rotation range of shoulder (nondominant side)	1.01	0.99	1.03	0.47
External rotation range of hip joint (dominant side)	0.98	0.96	1.00	**0.03***
External rotation range of hip joint (nondominant side)	0.99	0.97	1.01	0.31
Internal rotation range of hip joint (dominant side)	0.99	0.97	1.00	0.12

Internal rotation range of hip joint (nondominant side)	0.98	0.97	1.00	**0.03***
Straight leg raising angle (dominant side)	1.00	0.98	1.02	0.73
Straight leg raising angle (nondominant side)	1.00	0.98	1.02	0.79
Restricted knee extension	0.42	0.05	3.58	0.43
Restricted knee flexion	1.44	0.73	2.83	0.30
Restricted elbow extension	0.86	0.17	4.36	0.86
Restricted elbow flexion	1.93	0.85	4.38	0.12
Low back pain during lumbar extension	7.47	3.08	18.15	**<0.01***
Too many toes sign	0.37	0.17	0.80	**0.01***
Finger-floor distance	1.19	0.62	2028	0.60
General joint laxity	1.05	0.87	1.28	0.60
Shear wave velocity of quadriceps femoris	2.37	1.65	3.39	**<0.01***

*P<0.05 (significant)

Table 2 The results of the univariate logistic analysis between athletes with knee pain and athletes without pain

Items	*Odds ratio*	*95% CI min.*	*95% CI max.*	*P-value*
Developmental stage of tibial tuberosity	1.19	0.73	1.94	0.48
Body height in 1 year	1.09	0.97	1.22	0.13
Heel–buttock distance	1.05	1.00	1.11	0.07
External rotation range of shoulder (dominant side)	0.98	0.95	1.02	0.31
External rotation range of shoulder (nondominant side)	0.99	0.96	1.03	0.74
Internal rotation range of shoulder (dominant side)	1.01	0.98	1.03	0.59
Internal rotation range of shoulder (nondominant side)	1.00	0.98	1.03	0.89
External rotation range of hip joint (dominant side)	0.99	0.96	1.01	0.27
External rotation range of hip joint (nondominant side)	0.99	0.97	1.01	0.43
Internal rotation range of hip joint (dominant side)	1.00	0.98	1.02	0.91

Internal rotation range of hip joint (nondominant side)	1.00	0.98	1.02	0.71
Straight leg raising angle	1.00	0.99	1.01	0.89
Restricted knee extension	1.99	0.39	10.20	0.41
Restricted knee flexion	2.66	1.27	5.57	**0.01***
Restricted elbow extension	1.000	0.00	Infinite	0.99
Restricted elbow flexion	1.77	0.67	4.68	0.12
Low back pain during lumbar extension	4.21	1.89	9.38	**<0.01***
Too many toes sign	0.80	0.68	0.99	**0.04***
Finger-floor distance	1.54	0.76	3.14	0.24
General joint laxity	0.88	0.70	1.10	0.25
Shear wave velocity of quadriceps femoris	2.61	1.75	3.90	**<0.01***

*$P<0.05$ (significant)

Table 3 The results of multivariate logistic analysis between the presence and the absence of pain, experienced by adolescent athletes during sports activities.

Items	*Odds ratio*	*95% CI min.*	*95% CI max.*	*P-value*
External rotation range of hip joint (dominant side)	1.00	0.98	1.03	0.81
Internal rotation range of hip joint (nondominant side)	0.99	0.97	1.01	0.16
Low back pain during lumbar extension	6.16	2.28	16.61	**<0.01***
Too many toes sign	0.65	0.50	0.83	**<0.01***
Shear wave velocity of quadriceps femoris	2.39	1.50	3.58	**<0.01***

*P<0.05 (significant)

Table 4 The results of the multivariate logistic analysis between athletes with knee pain and athletes without pain.

Items	*Odds ratio*	*95% CI min.*	*95% CI max.*	*P-value*
Restricted knee flexion	2.46	1.03	5.86	**0.04***
Low back pain during lumbar extension	3.60	1.46	8.90	**0.01***
Too many toes sign	0.75	0.58	0.97	**0.02***
Shear wave velocity of quadriceps femoris	2.42	1.59	3.70	**<0.01***

*P<0.05 (significant)

Table 5 Sensitivity and specificity of each cutoff value in a typical check method

Findings	**Sensitivity**	**Specificity**
Shear wave velocity of quadriceps femoris > 4.94 m/s	0.63	0.69
Straight leg raising angle < 75°	0.60	0.45
Finger-floor distance > 0 cm	0.24	0.79
Heel-buttock distance > 0 cm	0.73	0.29

Figure Legends

Fig. 1. Bar diagram showing the relative percentages of athletes with pain in different locations

There were 214 athletes (71.1%) who did not complain of pain during sports activities. Altogether 28.9% athletes participated in sports activities despite pain; the knee was the most frequent affected site. The number of athletes with knee pain was 44/301 (14.6%)

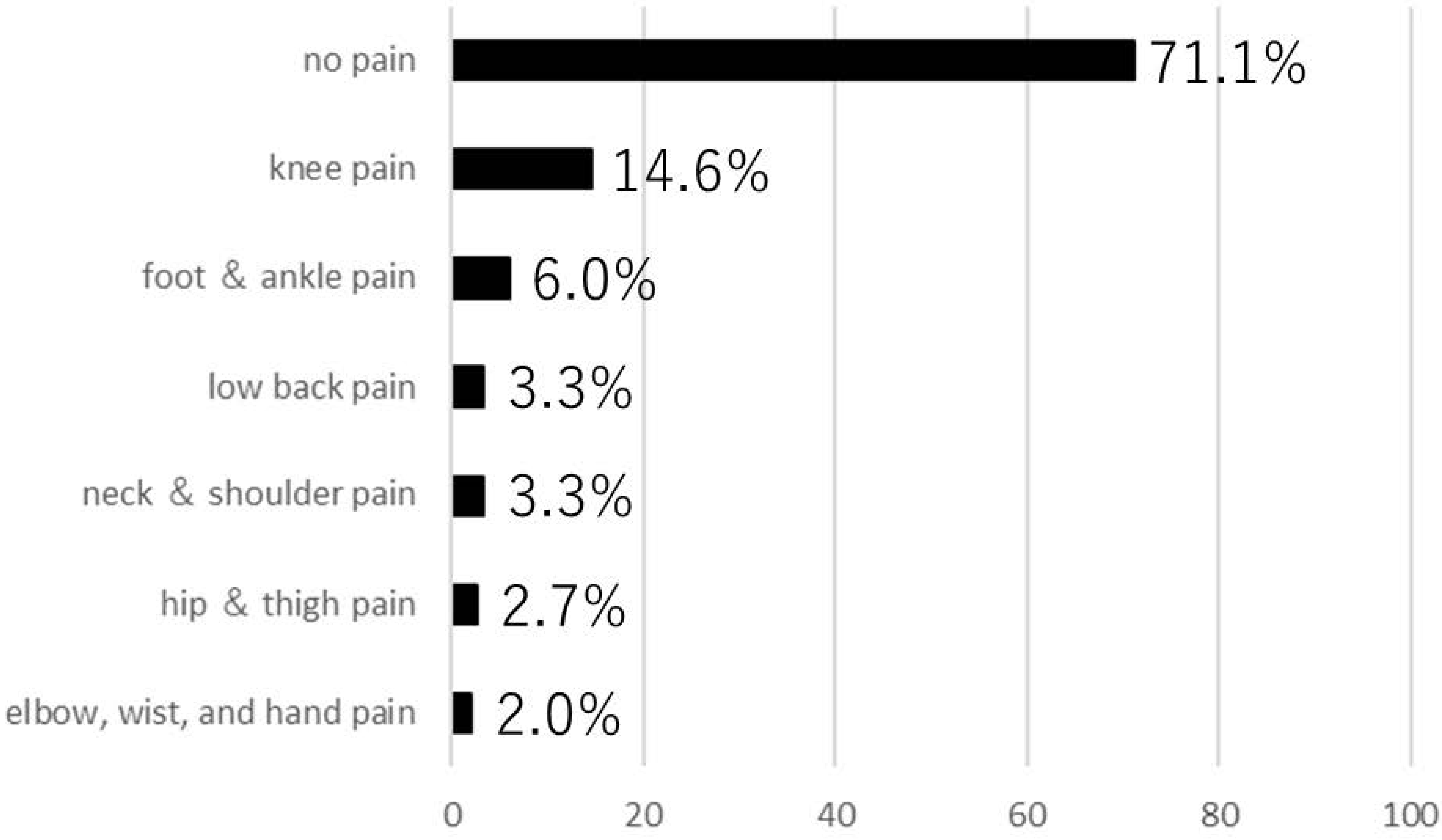
Fig. 2. Receiver operating characteristic curve of shear wave velocity in the quadriceps femoris for pain during sports activities

The shear wave velocity cutoff value of quadriceps femoris for pain during sports activities is 4.94 m/s, with a sensitivity of 0.63 and specificity of 0.69. The area under the curve of this receiver operating characteristic curve was 0.693.

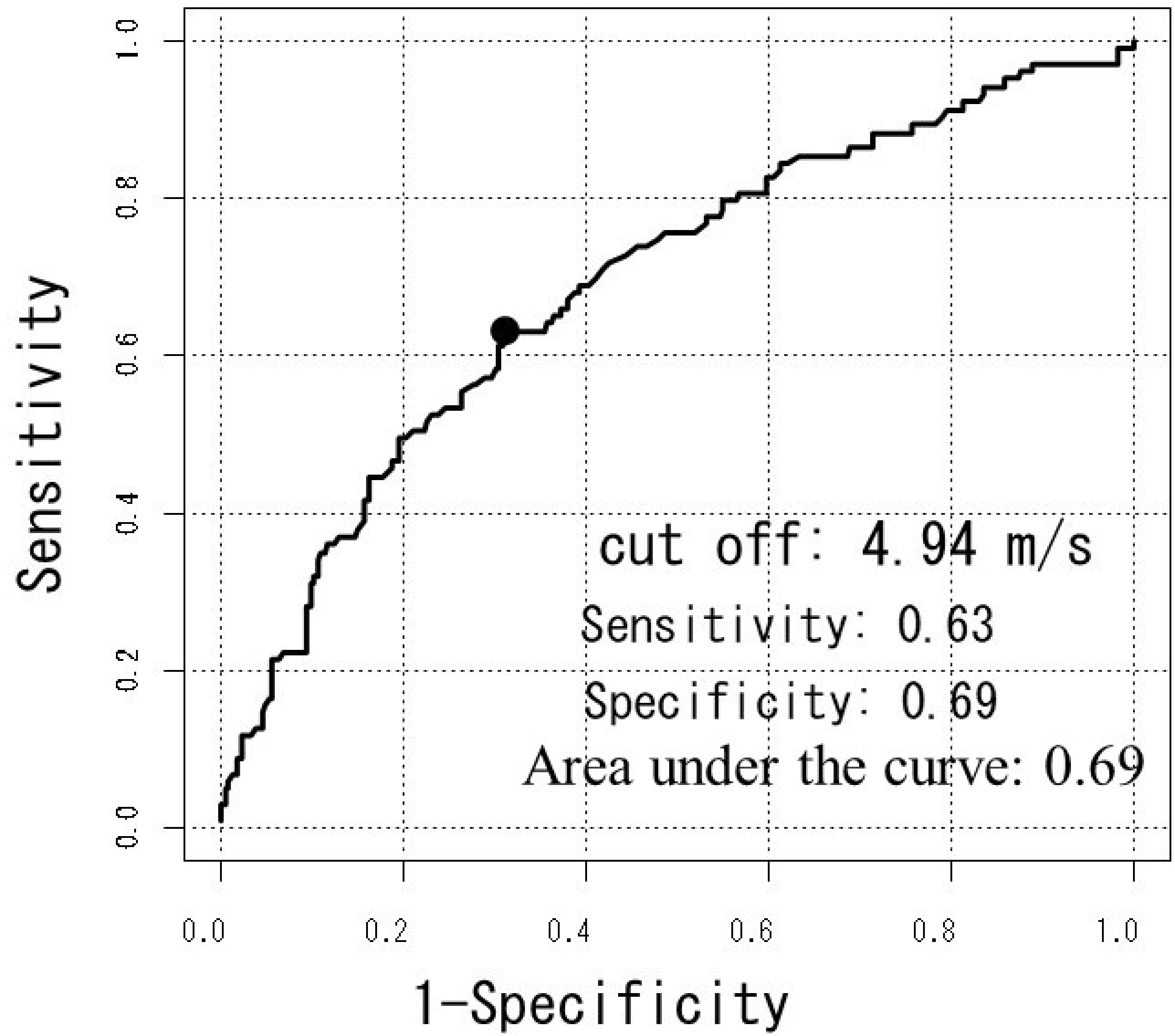
Fig. 3. Receiver operating characteristic curve of shear wave velocity in the quadriceps femoris for knee pain during sports activities

The shear wave velocity cutoff value of quadriceps femoris for knee pain during sports activities is 4.94 m/s, with a sensitivity of 0.71 and specificity of 0.65. The area under the curve of this receiver operating characteristic curve was 0.719.

Presence or absence of pain and its location



Cut-off value for pain of shear wave velocity of the quadriceps femoris



Cut-off value for knee pain of shear wave velocity of the quadriceps femoris