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Retrospective Study

Assessment of Functional Prognosis of Anterior Cruciate Ligament Reconstruction in Athletes based on A body Shape Index

Yunjun Wang, Junchang Zhang, Yuze Zhang, Yinghai Liu

Abstract

BACKGROUND

A healthy body shape is essential to maintain athletes' sports level. At present, there is little known about the effect of athletes' body shape on anterior cruciate ligament reconstruction (ACLR). Moreover, the relationship between body shape and variables such as knee joint function after operation and return to the field has not yet been well studied.

AIM

The aim of this study was to verify the relationship between a body shape index (ABSI) and the functional prognosis of the knee after ACLR in athletes with anterior cruciate ligament (ACL) injuries.

METHODS

We reviewed 76 athletes with unilateral ACL ruptures who underwent ACLR surgery in the First Hospital of Shanxi Medical University between 2017 and 2020, with a follow-up period of more than 24 mo. First, all populations were divided into the High-ABSI group (ABSI > 0.835, n = 38) and the Low-ABSI group (ABSI < 0.835, n = 38) based on the arithmetic median (0.835) of ABSI values. The primary exposure factor was ABSI, and the outcome indicators were knee function scores as well as postoperative complications. The correlation between ABSI and postoperative knee function scores and postoperative complications after ACLR were analyzed using multifactorial logistic regression.

RESULTS

The preoperative knee function scores of the two groups were similar, and with the surgery and postoperative rehabilitation exercises, the Range of motion (ROM) compliance rate, Lysholm score, and KOOS (Knee Injury and Osteoarthritis Outcome Score) of the two groups gradually increased, whereas the quadriceps atrophy index gradually decreased. The knee function scores were higher in the Low-ABSI group than in the High-ABSI group at the 24-month postoperative follow-up ($P < 0.05$). In multifactorial logistic regression, ABSI was the risk factor of low knee joint function score after surgery, specifically Low-ROM scores [OR=1.31, 95%CI (1.10-1.44), $P<0.001$], Low-Quadriceps atrophy index [OR=1.11, 95%CI(0.97-1.29), $P<0.05$], Low-Lysholm scores [OR=2.34, 95%CI(1.78-2.94), $P<0.001$], Low-Symptoms[OR=1.14, 95%CI(1.02-1.34), $P<0.05$], Low-ADL[OR=1.34, 95%CI(1.18-1.65), $P<0.05$], Low-Sports [OR=2.47, 95%CI (1.78-2.84), $P<0.001$] and Low-QOL [OR=3.34, 95%CI (2.88-3.94), $P<0.001$]. Besides, ABSI was also a risk factor for deep vein thrombosis of lower limb [OR=2.14, 95%CI (1.88-2.36), $P<0.05$] and ACL current corruption [OR=1.24, 95%CI (0.98-1.44), $P<0.05$] after ACLR.

CONCLUSION

ABSI is a risk factor for the poor prognosis of knee function in ACL athletes after ACLR, and the risk of poor knee function after ACLR, deep vein thrombosis of lower limb, and ACL recurrent rupture gradually increases with the rise of ABSI.

INTRODUCTION

Athletes are at high risk of anterior cruciate ligament (ACL) ruptures, often combined with meniscal and cartilage injuries, which can lead to knee instability and osteoarthritis (OA) if not treated promptly[[1] Due to the high demand for knee function in athletes, anterior cruciate ligament reconstruction (ACLR) is generally recommended as early as possible to obtain knee stability after an ACL rupture in athletes.[2] Given that good post-operative knee function is the foundation of an athlete's performance on the field,[3] it is important to identify the factors that influence an athlete's post-ACLR knee function.

It is commonly recognized that a proper body shape plays a central role in athletic performance, and the increasing obesity has a negative impact on athletes' physical performance, such as increased lower limb loading and slower movement speed.[4] As a result of it, it is important to regularly monitor the obesity of the athletes to ensure that the mandatory physical obesity level is kept at a low level.[5] Obesity and overweight had previously been identified as high-risk variables for poor function following ACLR, and higher body mass index (BMI) tends to predict higher knee loading and OA risk in ACLR patients, especially when BMI reaches 25 kg/m^2.[6, 7] Besides, high BMI can also alter post-ACLR gait biomechanics, and increase knee compression and shear forces, as well as patellofemoral pressure and knee extensor moment, which can lead to knee instability.[8] Furthermore, high BMI can also change post-ACLR gait biomechanics, and increase knee compression and shear forces, as well as patellofemoral pressure and knee extensor moments, which can lead to knee instability.[9] Therefore, an increasing number of athletes of all sizes or weights are in need of ACLR, and it of great importance to identify risk factors that influence the outcomes and complications of ACLR in athletes.

BMI, calculated based on their weight and height, is a measurement of a person's weight and height; it is being used to determine a person's fat proportion and is also a common clinical indicator for assessing overweight and obesity.[10] BMI does not directly measure the body’s fat composition, but is defined as a positive correlation between weight and obesity at a specific height.[11] Currently, statistics on obesity are mostly based on BMI, which ranges from 18.5-24.9 in a healthy person, 25-29.9 in an overweight person, and 30+ in an obese person. However, the median distribution of "normal" BMI (~22) differs considerably from the mean BMI of the current population. In addition, the correlation between BMI and the risk of various diseases is not linear.[12] Put another way, a higher BMI does not always reflect an increase in fat, as being overweight may be due to an increase in muscle tissue, especially in athletes with higher levels of musculoskeletal development.[13] ABSI was first proposed by researchers at the City University of New York in 2012.[14] ABSI is calculated from height, weight, and waist circumference (WC), and it standardizes waist circumference with body shape (weight and height), similar to body BMI.[15] ABSI corrects the effect of height and/or body mass to better assesses abdominal fat.[16]

There is a paucity of research regarding the association between ABSI and postoperative knee function and complications in athletes with ACLR. Therefore, it of great significance to identify risk factors associated with poorer postoperative knee function or complications in athletes with ACLR and to emphasize early intervention and guided rehabilitation so as to allow them to return to competition as soon as possible.

MATERIALS AND METHODS

Research subjects

Patients included in this retrospective cross-sectional study were professional athletes with ACL injuries who underwent arthroscopic ACLR between December 2017 and December 2020 at the department of Orthopedics in First Hospital of Shanxi Medical University, and all patients agreed to participate in this study. According to the Helsinki Declaration, the study was approved by the Ethics Committee of First Hospital of Shanxi Medical University, and the informed consent of patients was obtained. Because of the retrospective nature of our study, no additional clinical trial registration was required.

Inclusion criteria: (i) Active professional athletes aged 18 to 40 years old. (ii) First-time knee arthroscopy, within 6 mo after ACL injury. (iii) Intraoperative definite diagnosis of unilateral ACL rupture (may be combined with meniscal or articular cartilage injury). (iii) Patients has no contraindications to surgery and agree to undergo arthroscopic ACLR surgery and participate in this study.

Exclusion criteria: (i) Presence of lower extremity fractures or combined injuries such as medial or lateral collateral ligament or posterior cruciate ligament (PCL). (ii) Previous knee meniscal injury or osteoarthritis. (iii) History of previous knee surgery.

Ultimately, a total of 76 ACLR athletes were included in this study through screening.

General case information

Demographic information was collected through the medical record system and questionnaires, including gender, age, type of exercise, smoking and alcohol history, preoperative physical examination (height, weight, BMI, and abdominal circumference), comorbidities (hypertension, diabetes, cancer, meniscal injury *etc.*), ACL injury, site of injury, and surgical status (duration of surgery, duration of tourniquet, femoral and tibial fixation).

ABSI calculation

The exposure variable in this study was ABSI, and it was calculated as follows: BMI = weight/height^2, and ABSI =WC/ (BMI$^{2/3}$ × height$^{1/2}$).[17]

Grouping

First, the ABSI of all ACLR patients was calculated, and then the population was divided into the High-ABSI group (ABSI > 0.835, n = 38) and the Low-ABSI group (ABSI < 0.835, n = 38) according to their arithmetic median (0.835), respectively. All patients were followed up for more than 24 mo.

ACLR surgical technique

As previously described,[18] all ACLR procedures were performed on ACL patients by the same orthopedic professor under general or combined lumbar and rigid anesthesia using autologous hamstring tendons (semitendinosus and thin femoral muscles). All patients had a thigh tourniquet. Also, all patients had a standard anteromedial femoral and tibial tunnel drilled, with a final fixation of the proximal tendon bundled to the femur with an Endobutton (Smith and Nephew, USA) or RCI screw (Smith & Nephew, UK) and the proximal tendon bundled to the tibia with an RCI screw (Smith & Nephew, UK) or washer (Smith & Nephew, UK). Postoperatively, all patients followed a standard rehabilitation program for rehabilitation.

Standard rehabilitation training

All patients received standard lower extremity nerve-muscle function training, including quadriceps (anterior thigh muscle group) isometric exercise. They also practiced thigh muscle tensing and relaxation, without significant pain, more than 500 times/day, and had posterior thigh muscle group isometric exercise more than 500 times/day. Furthermore, they had pump exercises, such as forceful, slow, full-range flexion and extension of the ankle joints, more than 500 times/day. Patients were clinically reviewed by the surgeon at 3 mo and 12 and 24 mo postoperatively.

Functional assessment of the knee joint

All patients completed a 24-month postoperative follow-up to assess the functional recovery of the knees after surgeries.

Range of motion (ROM) compliance rate

ROM is the arc of motion through which the joint moves, and is the most basic method for assessing the motor function of the extremities.[19] Normal knee mobility should be between 140° and 150°, and active knee flexion of 120° or more after surgery is defined as compliance.

Quadriceps Atrophy Index

The quadriceps muscle is not only important for the overall health of the knee joint, but it also plays a key role in ensuring the knee joint's continued stability.[20] The quadriceps atrophy index is calculated as: atrophy index = (healthy thigh circumference - affected thigh circumference) / healthy thigh circumference × 100%. The smaller the value, the smaller the reduction in quadriceps strength and the better the recovery of muscle strength will be.

Knee Lysholm Scale

The Lysholm Scale is a condition-specific scale for evaluating ligamentous injuries of the knee, and also a subjective rating system in the form of a percentage questionnaire.[21] The scale consists of 8 items, including claudication (5 points), support (5 points), strangulation (15 points), instability (25 points), pain (25 points), swelling (10 points), stair climbing and descending (10 points) and squatting (5 points). A higher score indicates better function.

KOOS (Knee Injury and Osteoarthritis Outcome Score)

KOOS is an assessment of the short-term and long-term outcomes of treatment after a knee injury.[22] It consists of five patient-related components, such as symptoms, pain, activities of daily living (ADL), sports, and knee-related quality of life (QOL). A score of 0 means very poor function of that part of the joint, and a score of 100 means perfectly normal function of that part of the joint.

Return to sport (RTS)

According to previous studies,[18] "RTS" was defined as an exercise that was considered to return to the same or higher level of return to pre-injury during the follow-up period.

Postoperative complications

During the follow-up period, patients in both groups were counted for complications, including knee infection, deep vein thrombosis, internal fixation failure, and ACL re-rupture. The patients were analyzed for specific complications, and given symptomatic treatment.

Statistical analysis

IBM SPSS 27.10 software and Graphpad Prism 9 software were used for statistical analysis. The measurement data were expressed as mean ± standard deviation, and one-way ANOVA was used for the comparison between groups. The statistical data were expressed as frequencies (percentages), and the chi-square test was used for the comparison between groups. The median method was used to divide all patients with ACLR into High-ASBI and Low-ASBI groups. The relationship between ABSI and postoperative knee function scores and complications after ACLR was evaluated by multifactorial logistic regression analysis. The difference was considered statistically significant if $P<0.05$ in all analyses.

RESULTS

General Information

First, survey data were collected from a total of 93 athletes, and 76 ACLR athletes were included in the final analysis after excluding those patients who lacked outcomes, exposure, or did not complete follow-up (Figure 1).

As shown in Table 1, there was no significant difference in age between the High-ABSI group (ABSI > 0.835) and the Low-ABS group (ABSI < 0.835) in the preliminary analysis [(25.9 ± 6.3) vs. (26.4 ± 7.1), P = 0.7463]. There were 57 male athletes and 19 female athletes, respectively, and there was no significant difference in gender composition between the two groups (males: 71.05% vs. 78.95%, P=0.5970), both with a high percentage of males. In terms of types of athletes, soccer players had the most with 37, followed by basketball players with 28 and other athletes with 9. Besides, there were no significant differences between the High-ABSI and Low-ABS groups in terms of BMI

(24.3 ± 2.2 vs. 23.9 ± 2.1), percentage of smoking (10.53% vs. 7.895%), and percentage of alcohol consumption (21.05% vs. 18.42%) for individuals (all $P > 0.05$). In terms of surgery, although the High-ABSI group had a lower operative time than the Low-ABSI group, there was no significant difference between them [(88.3 ± 15.7) *vs* (93.4 ± 16.2), $P = 0.1676$].

There was no significant difference in the duration of the tourniquet (P=0.1347) or the number of days in the hospital (P=0.3241) between the two groups. Also, there were also no significant differences in the femur (P=0.5558) as well as the tibia (P=0.6422) in terms of fixation method.

Relationship between ASBI levels and prognosis of knee function in athletes after ACLR surgery

Next, the effects of ABSI levels and postoperative knee function were explored. Figure 2 shows the functional recovery of the knee joint after surgery in different ABSI groups. The results showed that the ROM scores of the two groups were similar before surgery (0 mo) and gradually improved with the ongoing of surgery and postoperative rehabilitation exercises (Figure 2a). Besides, the ROM scores in the Low-ABSI group were higher than those in the High-ABSI group ($P < 0.05$, Figure 2a), indicating that High-ABSI predicted poor knee mobility. The quadriceps muscle also influenced the knee flexion and extension function. The results showed that preoperatively (0 mo), both groups had some short-term atrophy of the quadriceps muscle due to a sudden decrease in motion caused by the ACL rupture (Figure 2b). At 3 mo, 12 mo, and 24 mo postoperatively, the quadriceps atrophy index was higher in the High-ABSI group than in the Low-ABSI group (Figure 2b). It indicated that the higher the ABSI, the lower the muscle strength of the quadriceps would be. In addition, the Lysholm score was an excellent indicator of knee function after knee ligament injury surgery. As shown in Figure 2c, before surgery, the scores of both groups were low ($P > 0.05$). With the ongoing of surgery and rehabilitation exercises, the Lysholm scores of both groups gradually increased, and the Lysholm scores of the Low-ABSI group were consistently higher than those of the High-ABSI group ($P < 0.05$, Figure 2c).

The KOOS score is a comprehensive self-rating measure of post-operative knee surgery outcomes that effectively reflects patients' perceptions of their knee health, symptoms, and function. The KOOS score consists of 5 subscales, including symptoms, pain, ADL, sports, and QOL. As shown in Figure 3, the KOOS scores gradually increased with the ongoing of surgery and rehabilitation in each of the 5 self-scales. At 3 mo postoperatively, the scores in both groups improved rapidly, but there was no significant difference in symptoms, pain, or ADL between the two. It might be attributed to the rapid relief of knee symptoms and pain with the implementation of surgery ($P > 0.05$, Figure 3). At the last follow-up (24 mo after surgery), all KOOS scores reached their highest values in both groups, and the Low-ABSI group had higher scores than the High-ABSI group ($P < 0.05$, Figure 3).

High levels of ASBI are a risk factor for poorer functional recovery of the knee after ACLR surgery in athletes

Furthermore, to identify whether a high level of ASBI was a risk factor for poorer postoperative knee function recovery in ACLR athletes, we performed a multifactorial logistic regression analysis with ABSI as the independent variable and each knee function score at the last follow-up as the dependent variable. We turned these continuous variables into dichotomous variables. The median scores of ROM scores, Quadriceps atrophy index, Lysholm scores, and KOOS (Symptoms, Pain, ADL, Sports, and QOL) were taken for all groups, and scores greater than the median value were defined as low knee function, specifically Low-ROM scores (≤82), Low-Quadriceps atrophy index (≥1.2), Low-Lysholm scores (≤83), Low-Symptoms (≤88); Low-Pain (≤83), Low-ADL (≤87), Low-Sports (≤80) and Low-QOL (≤73).

As shown in Table 2, the results revealed that High-ABSI was a risk factor for patients with low postoperative knee function scores, specifically Low-ROM scores [OR=1.31, 95%CI(1.10-1.44), $P<0.001$], Low-Quadriceps atrophy index [OR=1.11, 95%CI(0.97- 1.29), *P*<0.05], Low-Lysholm scores [OR=2.34, 95%CI(1.78-2.94), *P*<0.001], Low-Symptoms [OR=1.14, 95%CI(1.02-1.34), P<0.05], Low-ADL [OR=1.34, 95%CI(1.18-1.65), P<0.05], Low-Sports [OR=2.47, 95%CI(1.78-2.84), *P*<0.001] and Low-QOL [OR=3.34, 95%CI(2.88-3.94), *P*<0.001]. Interestingly, while pain scores (higher scores were associated with less pain) were higher in the High-ABSI group than in the Low-ABSI group (*P*<0.05, Figure 2c), multifactorial logistic regression showed that High-ABSI was not a risk factor for pain [OR=1.04, 95%CI (0.78-1.44), *P*=0.06] (Table 2). Ultimately, at the final follow-up, the percentage of RTS was significantly higher in the Low-ABSI group (78.95% vs. 60.53 %, *P*<0.05) than in the High-ABSI group (Figure 2d).

Association between ASBI levels and postoperative complications in ACLR athletes

As shown in Table 3, except that the incidence of venous thrombosis of lower limbs (21.04% *vs* 2.631%, *P*=0.0284) in the High-ABSI group was higher than that in the Low-ABSI group, there was no significant difference in the incidence of knee joint infection (5.262% *vs* 5.262%, *P*>0.9999), internal fixation failure (2.631% *vs* 0.000%, *P*>0.9999) and ACL current failure (7.893% *vs* 2.631%, *P*=0.6148) between the two groups. Further multifactorial logistic regression analysis also showed that ABSI was a risk factor for deep vein thrombosis of the lower limb [OR=2.14, 95%CI (1.88-2.36), *P*<0.05] as well as ACL recurrent rupture [OR=1.24, 95%CI (0.98- 1.44), *P*<0.05] (Table 4).

DISCUSSION

The current standardized treatment for ACL injury is ACLR, which aims to restore the function and stability of the knee joint, thus promoting RTS.[23] Although most ACL reconstructions restored the mechanical stability of the injured knee joint, the incidence of RTS was different. In 85-90% of ACLR patients, the prognosis of knee joint function returned to normal or close to normal within 6 mo after surgery.[24] There are also some research reports that only 63% of the people restored their exercise level before the injury at the last follow-up.[25]

Our study also showed that the knee joint function scores of most patients with ACLR remained stable from 1 to 2 years after surgery. In the last follow-up 24 mo after the operation, the athletes in High-ABSI and Low-ABSI groups had 60.53% (23/38) and 78.95% (30/38) RTS completion rates, respectively. This confirms that ACLR is undoubtedly the standard operation to reconstruct the integrity of the anterior cruciate ligament and restore the function of the knee joint.

Obesity is also a risk factor for poor function after various knee surgeries.[26] Li *et al* found that obesity and medial cartilage injury were strong risk factors for osteoarthritis after the first single-beam ACLR.[27] Another prospective study involving 92 patients with ACLR also pointed out that the incidence of postoperative complications in patients with high BMI (BMI>25 kg/m^2) was slightly higher than that in patients with normal BMI.[21] For obese patients with ACLR with BMI higher than 25 kg/m^2, the score of the International Knee Documentation Committee (IKDC) was lower after the operation.[28] However, there were also some different results. In addition, another study also confirmed that the preoperative BMI of patients had no significant adverse impact on the KOOS and Lysholm scores, and that there was no significant difference in the postoperative clinical results of these patients.[21] Therefore, the relationship between obesity based on BMI content and the postoperative function of ACLR is complex, because BMI may not be able to effectively measure the content of individual fat and identify muscle and obesity. ABSI has a positive correlation with visceral fat and is not affected by muscle. Thus, it can better display content of fat than the traditional BMI.

The study also confirmed that the knee joint function scores of the High-ABSI population were lower than those of the low-ABSI population. The multivariate logistic analysis also demonstrated that High-ABSI was the influencing factor of poor function after ACLR. Like most previous studies,[24] and that there was no significant difference between the two groups in various functional scores (ROM compliance rate, quadriceps femoris atrophy index, Lysholm score, *etc.*) before surgery (P>0.05). With the progress of postoperative rehabilitation, the ROM scores, quadriceps femoris atrophy index, and

Lysholm score of the two groups were significantly improved compared with those before surgery ($P<0.05$). Subsequently, it was gradually revealed that the knee joint function of the High-ABSI group was still lower than that of the Low-ABSI group. At the 6th month and the 12th month after operation, the knee joint function score of the Low-ABSI group was significantly lower than that of the Low-ABSI group. These results also confirmed the conclusion of previous research[4] that obese people would experience increased load on the lower limbs, thus affecting their recovery of knee joints. Besides, the risk of lower limb deep venous thrombosis after operation in the High-ABSI population is also higher than that in the Low-ABSI population, since obesity is a risk factor for deep venous thrombosis (OR=1.67, 95%CI: 1.16-2.40, P = 0.006), and Mendel randomization has verified the causal relationship between BMI and DVT.[29]

Fat plays an important role in the formation of deep venous thrombosis of lower limbs. Studies have shown that lipid metabolism in adipocytes participates in the process of thrombosis, and adipocytes can promote thrombosis by releasing a variety of thrombogenic factors, such as coagulation factors, platelet activating factors, platelet-derived active substances, *etc.*[30] Therefore, in the process of athletes' rehabilitation, it is necessary to take measures to reduce obesity, thus reducing the incidence rate of deep vein thrombosis.

However, our investigation still has some limitations. This is a retrospective study with a limited number of participants and results that only cover a brief period of time. In addition to that, this study is part of a larger correlation investigation. To investigate the possible causal connection between ABSI and the postoperative function of ACLR in the future, additional randomized controlled trials or Mendelian randomization will be required.

CONCLUSION

ABSI is a risk factor for poor prognosis of knee function in ACL athletes after ACLR, and the risk of poor knee function after ACLR, deep vein thrombosis of the lower limb, and ACL recurrent rupture gradually increases with the rise of ABSI.

ARTICLE HIGHLIGHTS

Research background

At present, the indicators of individual obesity only rely on BMI index, but BMI is often not linearly related to body fat content, which limits the research on the association between obesity and other diseases.

Research motivation

Introducing ABSI - as a body type indicator to replace traditional BMI in order to objectively evaluate the association between athletes' body size/obesity and ACLR.

Research objectives

Explore the relationship between knee joint function in athletes with ABSI and ACL injuries after ACLR.

Research methods

Multiple logistic regression analysis was used to investigate the relationship between knee joint function scores and postoperative complications after ABSI and ACLR surgery. Relation

Research results

The knee joint function score of the low ABSI group was higher than that of the high ABSI group ($P<0.05$). High ABSI is a risk factor for low score of knee joint function after operation, and also a risk factor for deep vein thrombosis of lower limbs.

Research conclusions

ABSI is closely related to the prognosis of knee joint function after ACLR. The rise of ABSI is likely to lead to poor knee function after ACLR and deep vein thrombosis of lower limbs.

Research perspectives

In the future, randomized controlled trials or Mendelian randomization are needed to verify the possible causal relationship between ABSI and postoperative function of ACLR.

ACKNOWLEDGEMENTS

Not Applicable.

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Footnotes

Institutional review board statement: According to the Helsinki Declaration, the study was approved by the Ethics Committee of First Hospital of Shanxi Medical University

Informed consent statement: The data used in this study were not involved in the patients' privacy information, so the informed consent was waived by the Ethics Committee of First Hospital of Shanxi Medical University. All patient data obtained, recorded, and managed only used for this study, and all patient information are strictly confidential, without any harm to the patient.

Conflict-of-interest statement: The authors declare no competing interests.

Data sharing statement: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Grade E (Poor): 0

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Figure Legends

Figure 1. Flow diagram of the screening and selection process in this study.

Figure 2. Comparison of knee joint function between High-ABSI group and the Low-ABSI group after ACLR. (A) ROM scores; (B) Quadriceps atrophy index; (C) Lysholm scores; (D) RTS completion rate. data are represented as mean ± SD, $^{a}P < 0.05$, $^{b}P < 0.01$ *vs* Low-ABSI group. Note. ROM: Range of motion; RTS: Return to sport.

Figure 3. Comparison of knee KOOS scores between High-ABSI group and the Low-ABSI group after ACLR. (A) Symptoms; (B) Pain; (C) ADL; (D) Sports; (E) QOL. data are represented as mean ± SD, $^{a}P < 0.05$, $^{b}P < 0.01$ *vs* Low-ABSI group. Note. ADL: activities of daily living; QOL: quality of life.

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