LANDING BIOMECHANICAL CHARACTERISTICS OF ADOLESCENT ATHLETES WITH ANTERIOR KNEE PAIN COMPARED TO HEALTHY CONTROLS

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Anterior knee pain (AKP) is defined as chronic peripatellar pain. It may be caused by repetitive the knee extensor mechanism, which may predispose adolescent athletes to AKP. To reduce risk of AKP, we should understand landing biomechanics in adolescent athletes with AKP. Therefore, we aimed to identify landing biomechanical characteristics of the AKP group compared to the control group. We collected data on joint angles, moments, and powers, ground reaction forces, and vertical stiffness during landing. We used Mann-Whitney *U* test and ensemble curve analyses to compare outcome variables between the AKP and control groups. The AKP group showed the knee-dominant landing strategy and greater ground reaction forces data. Based on our findings, interventions to prevent AKP should be implemented in adolescent athletes.

KEYWORDS: kinematics, kinetics, knee dominant landing strategy, patellofemoral pain syndrome, patellar tendinopathy, quadriceps tendinopathy.

INTRODUCTION: Anterior knee pain (AKP) is defined as the term for musculoskeletal conditions including patellofemoral pain syndrome (PFPS), patellar tendinopathy (PT), quadriceps tendinopathy (QT), and other injuries causing chronic peripatellar pain (Calmbach & Hutchens, 2003; Seeley et al., 2021). AKP results from the repetitive or abnormal knee extensor mechanism (Werner, 2014), which is associated with extensor torques using the quadriceps femoris, patella, patellar tendon, and tibial tuberosity.
Adolescents experience a period of rapid growth known as the growth spurt. As a result, their soft tissues and bones are stressed by the different growth speed (Krabak, Snitily, & Milani, 2016). Therefore, adolescent athletes are predisposed to musculoskeletal injuries (Van Der Sluis et al., 2014). Due to incomplete maturation of soft tissues and bones, many adolescent athletes suffered from AKP caused by the knee extensor mechanism, which is responsible for shock absorption and power generation during sports activities (Harris et al., 2021; Werner, 2014). AKP is common in adolescents aged between 10 and 17 (Coetsee & Phillips, 2007). According to a previous study, approximately 40% of adolescent athletes reported symptoms of AKP (Harris et al., 2021). AKP is one of the most common musculoskeletal injuries in adolescent athletes, which can have negative effects on athletic performance and career.
To reduce the injury risk of AKP, landing biomechanical characteristics of adolescent athletes with AKP should be revealed because a landing task needs knee extensor mechanism for shock absorption during the descending phase. Based on the reasons, many researchers have conducted biomechanical research on AKP using the task with the knee extensor mechanism. This included jump-landing biomechanics in adults (Seeley et al., 2021) and running biomechanics in adults (Greuel et al., 2019). However, there are few studies on landing biomechanical research in adolescent athletes with AKP. Therefore, we aimed to identify biomechanical characteristics of adolescent athletes with AKP compared to healthy controls during landing.

METHODS: Ethical approval from an institutional review board was approved. We complied to the principles set forth in the Helsinki Declaration. Ten adolescent athletes with AKP (6 females, 4 males; age = 14.00±0.82 years; height = 167.58±8.57 cm; body mass = 61.35±10.85 kg; career = 4.36±2.02 years; lower extremity functional scale [LEFS] = 70.80±6.84 score; numerical rating scale [NRS] = 4.90±1.37 scale) and 10 healthy controls (6 females, 4 males; age = 14.30±0.82 years; height = 167.69±6.70 cm; body mass = 57.54±6.10 kg; career =

4.15±2.03 years; LEFS = 80.00±0 score; NRS = 0±0 scale) voluntarily participated in this study. Inclusion criteria for the AKP group were as follows: 1) within a range of 12–15 years; 2) had participated in the sports activities; 3) suffered from AKP without a contact or non-contact trauma to the knee joint; 4) reported at least 3 scale of NRS (pain). Inclusion criteria for the control group were as follows: 1) within a range of 12–15 years; 2) had participated in the sports activities; 3) without any signs and symptoms related to musculoskeletal injuries of the lower extremities. Exclusion criteria for both groups were 1) had a history of sports injury within 3 months prior to the experiment; 2) had a history of surgery. All participants conducted the warm-up session for 5 minutes, familiarization for a landing task, and three data collections. Landing was defined as a double limb landing after jumping from a 30 cm high jump box. All landing kinematics were recorded by 20 infrared cameras (Oqus700+, Qualisys, Sweden) with a sampling rate of 250 Hz and ground reaction forces (GRF) data were collected by two force plates (Kistler, Sweden) with a sampling rate of 2,500 Hz. We used the Visual 3D marker set to obtain the joint kinematic and kinetic data. After data collection, marker data were low-pass filtered at 6 Hz using a fourth-order low-pass Butterworth filter. Then, we extracted data from initial contact (IC) to maximum knee flexion (MKF) on joint angles, moments, and powers of hip, knee, and ankle joints in the sagittal plane, and center of mass (COM) displacement as well as GRF data including peak vertical GRF (vGRF) and time to vGRF. We calculated the loading rate by dividing peak vGRF by time to peak vGRF. In addition, the vertical stiffness was calculated by dividing peak vGRF by COM vertical displacement. For joint moments, it indicated net joint moment. For joint angles and moments, positive values were defined as dorsiflexion and flexion and negative values as plantar flexion and extension. For joint powers, positive values were defined as power generation and negative values as shock absorption. The Mann-Whitney *U* test was performed to compare peak vGRF, time to peak vGRF, load rate, and vertical stiffness of two groups. The ensemble curve analysis is a statistical analysis method to identify differences in time-series data between groups like statistical parametric mapping. The ensemble curve analyses with mean and 90% confidence intervals (CI) were conducted to compare joint angles, moments, and powers of two groups. Significant differences were identified when CI bands of two groups did not overlap. In addition, the alpha level for Mann-Whitney *U* test was set at 0.05.

RESULTS: For GRF data and vertical stiffness, the results revealed that the AKP group demonstrated significantly greater peak vGRF (p=0.003), shorter time to peak vGRF (p<0.001), and greater loading rate (p<0.001) compared to the control group (Table 1). However, there was a no significant difference in vertical stiffness between two groups (p=0.063) (Table 1). The results of ensemble curve analyses revealed that the AKP group showed less plantar flexion angles (0–2%), less dorsiflexion angles (43–100%), less plantar flexor moments (11–100%), less knee extensor moments (44–45%, 51–89%), greater hip extensor moments (10–11%), less shock absorption of the ankle (17–20%, 23–38%, and 56–59%), greater shock absorption of the knee (14–18%) and hip (97–100%), and greater power generation of the hip (10–12%) compared to the control group (Figure 1).

Table 1: Differences in GRF data and vertical stiffness between the AKP and CON groups.

Variables	AKP (n=10)	CON (n=10)	*U*	*p*
Peak vGRF (N/BW)	3.49 (0.55)	2.35 (0.36)	12.00	0.003**
Time to peak vGRF (sec)	0.03 (0.01)	0.05 (0.03)	2.50	<0.001***
Loading rate (N/BW/sec)	109.83 (48.39)	48.88 (15.84)	2.50	<0.001***
Vertical stiffness (N/BW/m)	13.99 (4.88)	9.79 (4.67)	25.00	0.063

$^{**}p$<0.01, $^{***}p$<0.001.
Values are expressed as median (interquartile range).
Abbreviation: AKP, anterior knee pain; CON, control; GRF, ground reaction forces; vGRF, vertical ground reaction force.

DISCUSSION: The present study was conducted to identify differences in landing biomechanical characteristics between adolescent athletes with and without AKP. Our findings

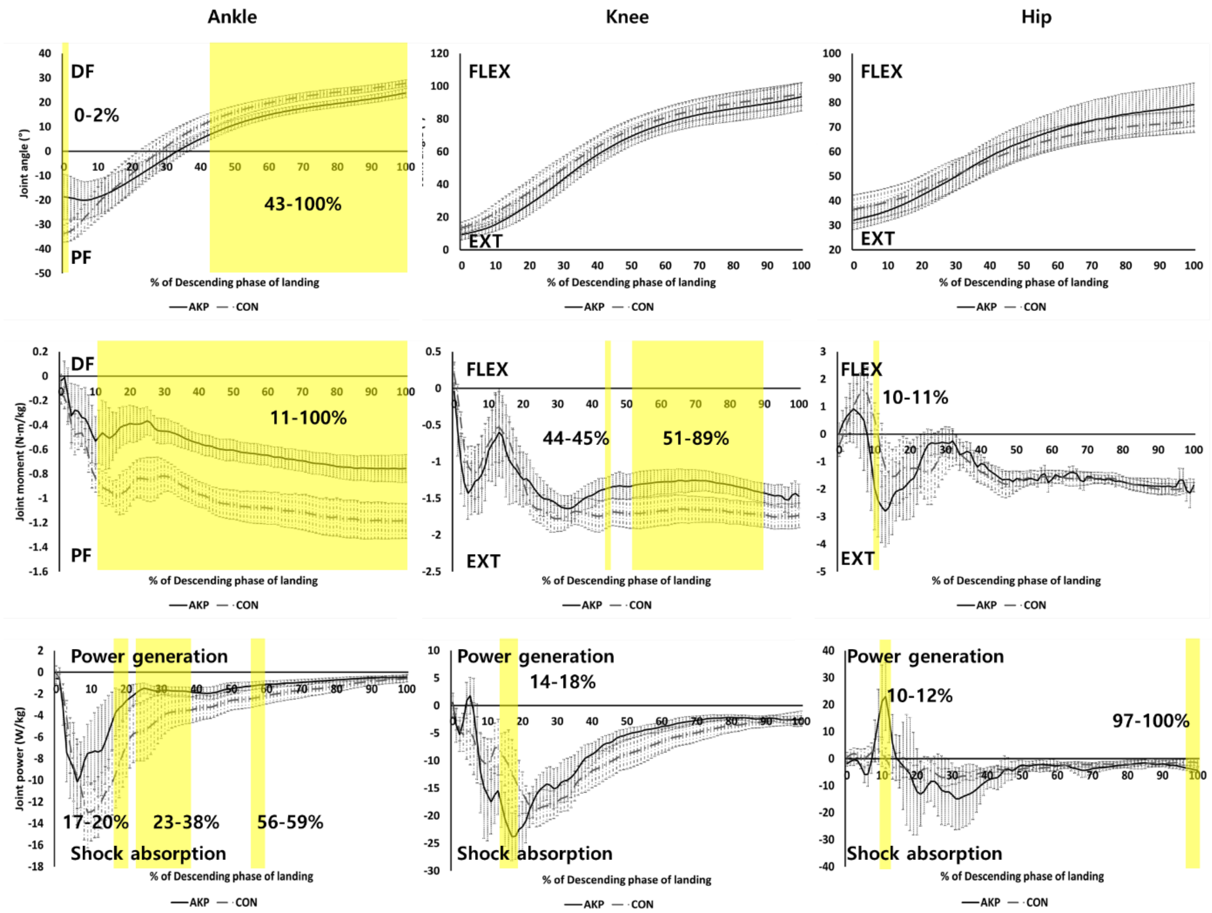

Figure 1: Differences in joint angles (first row), moments (second row), and powers (third row) between the AKP and CON groups. Mean ± 90%CI. Yellow highlights indicate significant differences in each variable between the AKP and CON groups.

revealed that the AKP group demonstrated altered landing biomechanics including the ankle kinematics, ankle, knee, and hip kinetics, and vGRF data compared to the control group.

In this study, the AKP group generated the greater peak vGRF and loading rate as well as the shorter time to peak vGRF than those of the control group. According to previous studies, peak vGRF and loading rate were associated with chronic injuries (Hreljac, Marshall, & Hume, 2000; Pohl, Hamill, & Davis, 2009; Van Der Worp, Vrielink, & Bredewe, 2016). Given the GRF is one of the external forces, it should be controlled by athletes for better performance and injury prevention. As the peak vGRF and loading rate occur during the early phase of landing, landing biomechanical strategies during the phase is important to prevent acute and chronic injuries. Based on our findings, the AKP group was vulnerable to chronic injuries. Although the AKP group needs proper landing biomechanics to absorb GRF, they showed the ankle biomechanical dysfunction and unnecessary hip kinetics during landing.

To absorb GRF, individuals need greater ankle joint excursion, plantar flexor moments, and shock absorption during landing. However, the AKP group landed with less ankle joint excursion, plantar flexor moments, and shock absorption, which may increase knee joint loading associated with AKP. For hip kinetics, the AKP group demonstrated the greater hip extensor moments, power generation for 10–12% of landing, and shock absorption for 97-100% of landing. These kinetic mechanisms may be considered as effective movement strategies to reduce vGRF, but it may not have effects on proper shock absorption during landing. The peak vGRF occurs during the early phase of landing, which may imply that individuals need better abilities to absorb GRF in the phase. Nevertheless, the greater shock absorption of the hip in the AKP group occurred during the late phase of landing. Therefore, the hip kinetics observed in this study were not enough to reduce risk of chronic injuries such as AKP.

In contrast to the ankle and hip joints, the AKP group showed greater shock absorption of the knee during the early phase of landing. As the greater peak vGRF and loading rate occurred during the phase, landing biomechanics observed in the AKP group may be considered as the knee-dominant landing strategy to reduce GRF. In addition, less knee extensor moments in the AKP group were observed during the late phase of landing. During the phase, the knee joint was continuously flexed. When knee flexion angles increase, the joint compression forces in the patellofemoral joint also increase given the composition of quadriceps femoris and patellar tendon vectors. Therefore, less knee extensor moments observed in the AKP group during the late phase of landing may be a preventive mechanism to reduce joint compression forces in the patellofemoral joint.
In summary, the AKP group showed ankle dysfunction and insufficient hip kinetics as well as the knee-dominant landing strategy. Therefore, ankle and hip conditioning should be performed to improve biomechanical abilities for shock absorption during landing.
This study has some limitations. First, a sample size was small. Second, we did not consider differences in sex, chronological age, and maturation status of participants. However, there were not significantly different between those variables in the previous study (Harris et al., 2021). Third, we cannot establish the causality between the AKP occurrence and landing biomechanics because this study was a retrospective case-control study. Therefore, future studies are needed to perform a prospective cohort study with a large sample size.

CONCLUSION: AKP is one of the most common injuries in adolescents and physically active people. According to our findings, the AKP group demonstrated the knee-dominant landing strategy and greater GRF data such as loading rate. Therefore, adolescent athletes with AKP should try to improve their biomechanical abilities for shock absorption using the ankle and hip joints to prevent AKP instead of the knee-dominant landing strategy.

REFERENCES

Calmbach, W. L. & Hutchens, M. (2003). Evaluation of patients presenting with knee pain: Part II. Differential diagnosis. *American Family Physician*, 68 (5), 917–922.

Coetsee, M. F. & Phillips, J. (2007). Incidence of non-traumatic anterior knee pain among 11-17-years-old. *South African Journal of Sports Medicine*, 19(2), 60–64.

Greuel, H., Herrington, L., Liu, A., & Jones, R. K. (2019). How does acute pain influence biomechanics and quadriceps function in individuals with patellofemoral pain? *The Knee*, 26(2), 330–338.

Harris, M., Edwards, S., Rio, E., Cook, J., Cencini, S., Hannington, M. C., … & Docking, S. (2021). Nearly 40% of adolescent athletes report anterior knee pain regardless of maturation status, age, sex or sport played. *Physical Therapy in Sport*, 51, 29–35.

Hreljac, A., Marshall, R. N., & Hume, P. A. (2000). Evaluation of lower extremity overuse injury potential in runners. *Medicine and Science in Sports and Exercise*, 32(9), 1635–1641.

Krabak, B. J., Snitily, B., Milani, C. J. (2016). Understanding and treating running injuries in the youth athlete. *Current Physical Medicine and Rehabilitation Reports*, 4 (2), 161–169.

Pohl, M. B., Hamill, J., & Davis, I. S. (2009). Biomechanical and anatomic factors associated with a history of plantar fasciitis in female runners. *Clinical Journal of Sport Medicine*, 19(5), 372–376.

Seeley, M. K., Denning, W. M., Park, J., Croft, K., Horton, W. Z., & Hopkins, J. T. (2021). Anterior knee pain independently alters landing and jumping biomechanics. *Clinical Biomechanics*, 89, 105458.

Van Der Sluis, A., Elferink-Gemser, M. T., Coelho-e-Silva, M. J., Nijboer, J. A., Brink, M. S., & Visscher, C. (2014). Sport injuries aligned to peak height velocity in talented pubertal soccer players. *International Journal of Sports Medicine*, 35 (4), 351–355.

Van Der Worp, H., Vrielink, J. W., & Bredewe, S. W. (2016). Do runners who suffer injuries have higher vertical ground reaction forces than those who remain injury-free? A systematic review and meta-analysis. *British Journal of Sports Medicine*, 50(8), 450–457.

Werner, S. (2014). Anterior knee pain: An update of physical therapy. *Knee Surgery, Sports Traumatology, Arthroscopy*, 22, 2286–2294.

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