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Evaluation of aerobic and anaerobic capacity in pubertal karate athletes: performance analysis and development strategies

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Abstract

Background This study investigated the effects of gender's foot arch structure (normal arch vs. pes planus) on aerobic and anaerobic performance in pubertal karate athletes.

Method Children with chronic cardiovascular and musculoskeletal diseases were excluded from the study. Participants included boys with normal foot arches (B-nfa, $n = 7$), boys with pes planus (B-pp, $n = 11$), girls with normal foot arches (G-nfa, $n = 16$), and girls with pes planus (G-pp, $n = 11$). Aerobic capacity was evaluated using the 6-Minute Walk Test, while anaerobic performance was assessed through the Vertical Jump Test and sprint tests (10 m and 30 m). The height of the foot arch was measured using the Navicular Drop test. Nonparametric data were analyzed using the Kruskal–Wallis test and Dunn's post-hoc test to identify significant differences. Parametric data were analyzed using one-way ANOVA and Tukey's post hoc test. Pearson's test was used for parametric correlation, while Spearman's test was used for nonparametric correlation. The significance threshold was set at $p < 0.05$.

Results Individuals in the G-nfa group exhibited higher anaerobic power than those in the G-pp group ($p = 0.0452$). There was a strong negative correlation between arch pes planus and Spear equations ($r = 0.63$, $p = 0.0004$). B-nfa participants performed faster than both B-pp ($p = 0.0015$) and G-pp ($p = 0.0015$). The G-nfa completed the 10 m sprint test faster than both B-pp and G-pp ($p = 0.0052$). B-nfa outperformed G-pp in the 30 m sprint ($p = 0.036$) and covered greater distances in the six-minute walk test compared to B-pp ($p = 0.034$) and G-pp ($p = 0.002$).

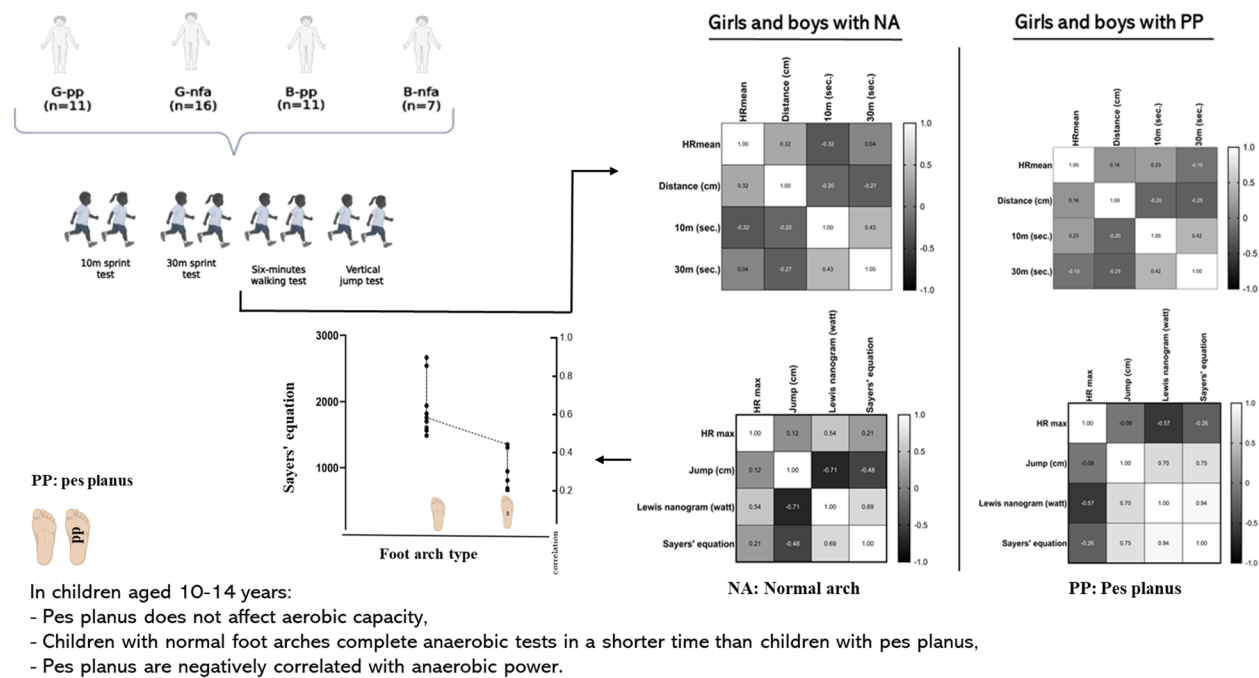
Conclusion In this study, we concluded that flat feet do not negatively affect the development of aerobic capacity in prepubertal children undergoing professional karate training. Still, they may significantly impact the growth of anaerobic power.

Keywords Flat feet, Pes planus, Youth sports, Biomechanics, Karate, Anaerobic power

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Graphical Abstract



Introduction

Puberty is a crucial period during which physical activity and sports habits are developed. If the sports habits acquired during puberty are maintained, children will be protected from the adverse effects of a sedentary lifestyle in adulthood. Therefore, participation in sports at an early age is essential [1].

The basic physical fitness indicator in childhood and adolescence is accepted as aerobic endurance. Adolescents continue to develop their abilities, including speed, strength, balance, and coordination, which are influenced by their aerobic endurance [2]. However, in some sports, anaerobic capacity is as vital as aerobic capacity. This is more important in sports branches that require sudden, high, and intense power generation, such as karate. For this reason, according to some researchers, anaerobic power and capacity are key determinants of performance in sports that require sudden changes of direction, rapid acceleration, jumping, or sprinting [3]. In evaluating physical performance, in addition to various performance tests, the six-minute walk test is a cost-effective and easy-to-administer test with unique exercise durations. It can be used widely at different points, including children. This test is a crucial indicator of an individual's aerobic endurance [4, 5]. Since the primary criterion for aerobic capacity is maximum oxygen uptake, in addition

to skeletal muscle structure, the cardiopulmonary system is also challenged during exercise. These systems, which facilitate maximum oxygen uptake, work in tandem during exercise. This way, aerobic capacity is activated by exceeding the anaerobic threshold [6]. Doing a job at maximum speed demonstrates anaerobic power. The anaerobic energy system consists of alactic and lactic components, which describe the processes of breaking down stored phosphagens, ATP, and phosphocreatine (PCr), as well as the non-aerobic breakdown of carbohydrates into lactic acid through glycolysis [7]. A strong support structure is necessary during exercises that require sudden, explosive power, such as karate, which relies on anaerobic power.

Although the foot is often perceived as a static and rigid structure, it serves as a good shock absorber. It plays an active role in movement and weight support structures. It has a flexible structure that enables it to adapt to changes in the external environment [8, 9]. Foot arches are fundamental to the motor functions of the foot, which is a dynamic structure. In a standard foot that adapts to the ground structure, contact with the ground occurs with the calcaneal tubercle, first metatarsal head, and fifth metatarsal head. In the triangle formed by these points, there are three arches of the foot: the medial longitudinal arch (MLA), the lateral longitudinal arch (LLA), and the

transverse arch. The MLA consists of the first metatarsal, medial cuneiform, navicular, talus, and calcaneus and is a weight-bearing and shock-absorbing structure [10, 11]. Analyzing the body structure of athletes in karate sports can provide specific details about the athlete's functionality [12]. In karate, proper foot biomechanics are essential for executing sudden, fast, and constantly changing movements, including jumps [13]. The foot carries the body's weight and acts as a shock absorber against the body's dynamic movements [9]. It has been reported that a problem in any of these structures can affect foot biomechanics [14]. The arch structure of the foot may be congenitally defective or may subsequently deteriorate [15]. Pes planus (flat feet), one of the foot arch types, is a general term used for the decrease in the height of the MLA or its complete flattening during loading [16]. It has been reported that people with pes planus expend more energy due to their imbalance and increased muscle tension [17]. Recent studies have demonstrated that assessment tools, such as tensiomyography, can offer valuable insights into muscle function and aid in talent identification [18]. These methods can complement traditional anthropometric data when assessing the link between foot structure and athletic performance.

This study aims to investigate the effects of regular karate exercise on the physical performance and energy efficiency of boys and girls with pes planus during the pubertal period, with the goal of enhancing their aerobic and anaerobic capacities.

Materials and methods

Individual groups and experimental plan

Approval for this study was obtained from the Inonu University Malatya Clinical Research Ethics Committee (2023/5059). One methodological limitation of the study was the inability to perform a power analysis for one article due to insufficient access to necessary resources. However, using the G*Power program, we determined that assuming a 5% type I error (α), a 20% type II error (β) with a power of 80%, an effect size of 0.4 would require 19 participants per group, totaling 76 participants. As a result, the study's power analysis requirements were not fully met. To address this, a post-hoc power calculation was conducted to provide insights for future research endeavors [19]. Individuals with heart disease, muscle disease, chronic illnesses, obesity, or congenital or acquired long-term conditions were excluded from the study. Healthy children who had been receiving regular karate training at Malatya Çelik Sports Schools for three months, attending classes two days a week, participated in our study voluntarily. Children aged 10 to 14 years with a BMI in the range of 0.5% to 0.85% for both girls and boys took part in the research. Foot arch elevation

was recorded after the children completed the aerobic and anaerobic tests. The study was conducted in a double-masked manner; that is, the children, their parents, and the investigators were unaware of the children's arch structures until the study was completed. Foot measurements were taken from the soles of the feet after aerobic and anaerobic capacity assessments were performed on individuals with appropriate indications.

Group 1: Boy karate players ($N_{\text{boys}}=18$)

- Boys karate players with normal foot arch (B-nfa, $n=7$)
- Boys karate players with pes planus (B-pp, $n=11$)

Group 2: Girl karate players ($N_{\text{Girls}}=27$)

- Girls'karate players with normal foot arch (G-nfa, $n=16$)
- Girls'karate players with pes planus (G-pp, $n=11$)

Six (6) minute walk test

The 6-Minute Walk Test is adapted from the 12-minute Cooper test, developed by Cooper et al. (1960), as recommended by the American Thoracic Society. This test measures the distance participants travel at their walking speed in 6 minutes. During this test, participants were fitted with a smartwatch to evaluate their maximum and average heart rates [20].

Vertical-jump test

Before the test, the players warmed up by performing 2-3 repetitions of submaximal squat jumps. During the actual test, they were instructed to keep their hands on their hips to eliminate the influence of arm movements on their vertical jumps and to prevent any coordination issues that could affect the evaluation of their leg extensors [21].

In the vertical jump test, participants stood in front of a wall marked in centimeters, with their feet shoulder-width apart and their bodies facing the marked wall laterally. Each participant was given three attempts in the same position to measure their maximum height. Anaerobic power was calculated using the Lewis formula and Sayers'equation after determining the distance the participants could reach while standing and the distance they jumped and touched [22, 23].

Sprint tests (10 m and 30 m)

Participants completed three sprint tests, with distances of 10 and 30 meters, sprinting at maximum speed. There was a 3-minute recovery period between the 10-meter

and 30-meter sprints. The shortest time recorded for each distance in the sprint tests was used for the data analysis. Before each sprint test, participants engaged in a warm-up that included 10 minutes of running at 60-70% of their maximum heart rate (HRmax), followed by 5 minutes of short, rapid leg movements, such as jumping distances of 5 to 10 meters. The sprint times were recorded in seconds using a stopwatch [24].

Medial longitudinal arch measurements

To ensure consistent positioning and measurement techniques, all measurements for the Navicular Drop (ND) test were performed by the same physiotherapist following a standard protocol. Participants were seated in a chair with hips and knees flexed at 90° and feet flat on the floor. The ankle joint remained in a neutral position, specifically in the subtalar joint. The navicular tuberosity was identified 2.5 cm anteroinferior to the medial malleolus and marked for visibility. Initial height measurements of the navicular tuberosity were taken while seated, followed by measurements in a standing position with even weight distribution. The height difference was measured using a calibrated caliper; those with a difference greater than 10 mm were diagnosed as having pes planus [25].

Statistical analysis

Statistical analysis was performed using GraphPad Prism 10.4.1 software. When $n > 30$, the Kolmogorov-Smirnov test was applied to evaluate the data distribution. A p -value > 0.05 was interpreted as indicating a parametric distribution, while a p -value < 0.05 indicated a non-parametric distribution. Since age, body mass (kg), HRmean, 10 m, 30 m sprint, and six-minute walk test data showed a parametric distribution, they were statistically evaluated using one-way ANOVA. In the case of significant differences, Tukey's post-hoc test was used for pairwise comparisons. HRmax, vertical jump, and anaerobic power (Lewis Nomogram, Sayers' equation) test results showed a non-parametric distribution. These data were analyzed using the Kruskal-Wallis test. When significant differences were detected, Dunn's post-hoc test was applied for pairwise comparisons. To establish a correlation between individuals, the Pearson test was used for parametric data, including the HR mean, 10 m, 30 m sprint, and 6-minute walk tests. In contrast, the Spearman test was used for non-parametric data, including the HR max, vertical jump, and anaerobic power tests. A p -value below 0.05 ($p < 0.05$) was considered significant.

Results

No significant difference was noted among HRmax, HRmean, age, body mass, and vertical jump parameters. Individuals in the G-nfa group had higher anaerobic

power than those in the G-pp group, according to Lewis nanograms ($p = 0.038$) and Sayers' equation ($p = 0.0452$). Additionally, individuals in the G-nfa group had higher anaerobic power than those in the B-pp group ($p = 0.034$), according to Lewis's nanogram. Still, no significance was found according to Sayers' equation. Also, negative correlation was observed between foot arch pes planus and Spear equations ($r = 0.63$, $p = 0.0004$). B-nfa individuals finished faster than B-pp ($p = 0.0015$) and G-pp ($p = 0.0015$); G-nfa participants completed the 10 m sprint test faster than B-pp (0.0052) and G-pp (0.0052). Individuals of B-nfa completed the 30 m sprint test faster than G-pp ($p = 0.036$). The six-minute walking test showed greater distances in individuals with B-nfa than in those with B-pp ($p = 0.034$) and G-pp ($p = 0.002$) (Table 1).

Post hoc power analysis

A post hoc power analysis was conducted to assess the adequacy of the sample size obtained. The study revealed that the statistical power to detect medium effect sizes ($d = 0.5$) in the smallest group ($n = 7$) was approximately 0.35, which is well below the acceptable level of 0.8. Future studies should aim for at least 20 participants per group to ensure adequate power.

Discussion

In karate, anaerobic power and capacity are key determinants of successful performance. Anaerobic capacity refers to the maximum amount of energy produced in a short period through the phosphagen and glycolytic energy pathways [26, 27]. Aerobic capacity is essential for high-intensity activities, such as combat sports, which require minimal rest, as well as anaerobic capacity [28]. During karate, physical activity requires high energy levels, reaching values approximately 3.5 times higher than maximum oxygen consumption [29]. Due to disorders in foot biomechanics, the energy spent may increase even further [17]. Increased energy expenditure in individuals with pes planus may be linked to compromised core stability and altered lower limb mechanics. Dello Iacono et al. (2016) have reported that core stability training improves lower limb strength and balance, which could help mitigate performance deficits observed in flat-footed athletes [30].

Strong correlations have been reported between 10 and 30-second sprint tests and maximum lactate production rates [31, 32]. Although the literature on the effects of pes planus on sprint performance primarily focuses on areas such as the 30 m sprint, balance, vertical jump, and general physical performance, no study has been found that shows its relationship with the 10 m sprint test. Physical performance results, such as the 30 m sprint,

Table 1 Descriptive statistics and groups' comparisons of the research (Data are presented as mean, standard deviation, median, minimum, maximum). Cohen's d and 95% Confidence Interval (CI) columns were calculated on the group pair showing the most significant difference for each measurement

	B-nfa (n = 7)	B-pp (n = 11)	G-nfa (n = 16)	G-pp (n = 11)	p-value	Effect Size (Cohen's d)	95% CI
mean $\pm$ SD							
Age (year)	11.67 $\pm$ 1.37	10.09 $\pm$ 1.5	10.38 $\pm$ 1.8	10.50 $\pm$ 1.9	> 0.05		
Body mass (kg)	48.14 $\pm$ 6.7	47.7 $\pm$ 12.5	47.15 $\pm$ 12.3	43.6 $\pm$ 6.89	> 0.05		
HR mean (BPM)	108.3 $\pm$ 10.8	101 $\pm$ 13.3	109.1 $\pm$ 17.2	102.2 $\pm$ 15.95	> 0.05		
10 m (seconds)*	2.19 $\pm$ 0.37 ^a	2.9 $\pm$ 0.49 ^b	2.34 $\pm$ 0.3 ^{a,c}	2.9 $\pm$ 0.49 ^{b,d}	0.0001	$\approx$ 2.14 (B-nfa & B-pp)	(1.13–3.14)
30 m (seconds)*	5.4 $\pm$ 0.9 ^a	6 $\pm$ 0.44 ^{a,b}	5.8 $\pm$ 0.9 ^{a,b}	6.8 $\pm$ 0.6 ^b	< 0.0001	$\approx$ 1.89 (G-nfa & G-pp)	(1.05–2.73)
6MWT (m)*	711 $\pm$ 57.9 ^a	612 $\pm$ 81.7 ^b	628 $\pm$ 64 ^{a,b}	577 $\pm$ 34 ^b	0.0046	$\approx$ 1.42 (B-nfa & G-pp)	(0.59–2.24)
median (min–max)							
HR max (BPM)	128.3 $\pm$ 11.9	124 $\pm$ 18.7	120.2 $\pm$ 27.5	129.4 $\pm$ 25.2	> 0.05		
Vertical jump (cm)	29 $\pm$ 9.87	29 $\pm$ 6.9	28.5 $\pm$ 9	27 $\pm$ 8.3	> 0.05		
Lewis nomogram (watt)*	505 (488–596) ^{a,b}	392 (330–456) ^a	630 (550–734) ^b	348 (330–455) ^a	0.0003	$\approx$ 2.67 (G-nfa & G-pp)	(1.62–3.72)
Sayers'equation (watt)*	1653 (1486–1938)	1124 (684–1350)	1819 (1562–2668)	729 (653–805)	0.0007	$\approx$ 10.65 (G-nfa & G-pp)	(8.35–12.95)

* $p < 0.05$; $X \pm SD$ mean $\pm$ standard deviation, CI confidence interval; Effect sizes (Cohen's d) and 95% confidence intervals are reported for significant comparisons.

Superscripts denote significant pairwise differences (post-hoc): a = different from B-pp; b = different from B-nfa; c = different from G-pp; d = different from G-nfa

6MWT 6-min walk test, Kg kilogram, BPM beats per minute, 10 m 10 m sprint test, 30 m 30 m sprint test, m meter, B-nfa boys with normal foot arch, B-pp boys with pes planus, G-nfa girls with normal foot arch, G-pp girls with pes planus

reverse movement jump, and standing balance test, have been reported to decrease in individuals with pes planus in association with foot pain [33]. Febriyanti et al. concluded that levels of pes planus associated with foot pain reduced physical performance outcomes such as the 30 m sprint test [33]. On the other hand, it has been reported that pes planus does not cause a disadvantage in motor performance in vertical jumps, sprints, and static balance [34]. In our study, no difference was observed between boys and girls with normal arches in the 10- and 30-meter sprint tests. This lack of difference in our study may be because children in adolescence have not yet completed their physical development, and their secondary sex characteristics have not yet fully developed. However, in the 10-meter sprint test, boys with normal arches completed the test faster than boys and girls with pes planus, and girls with normal arches completed the test faster than boys with pes planus. Furthermore, boys with normal arches completed the 30-meter sprint test faster than girls with flat feet. These results suggest that while anaerobic development continues concurrently in children with normal arches between the ages of 10 and 14, pes planus may disadvantage both boys and girls.

Çular et al. (2018) validated the 30-second continuous jump test for combat athletes, reporting high reliability (ICC = 0.95) and strong correlations with other anaerobic tests [27]. Physical performance results, such as the reverse movement jump and standing balance test, have been reported to decrease in individuals with pes planus in association with foot pain [33]. Similarly, it

has been reported that athletes with pes planus exhibit worse balance and vertical jump performance, and that individuals with pes planus expend more energy to tolerate imbalances and increased muscle tension [13, 17]. However, a study found no significant difference in vertical jumps between girls and boys with pes planus and those with normal foot arches, indicating that pes planus did not affect the performance of 10 to 12-year-olds [35]. Although the vertical jump test was not affected by flat feet in our study, significant differences were observed in anaerobic capacity and strength tests, suggesting that regular sports activity provides more advantages in performance development for children with normal foot arches compared to children with pes planus.

The higher anaerobic power in the G-nfa group compared to both the G-pp and B-pp groups suggests the potential contribution of foot arch type to anaerobic performance during regular karate training. Although the Lewis formula provides a practical estimate of anaerobic power, the need for sport-specific validation in power assessments for combat sports is highlighted [36]. It is noteworthy that the significant differences observed according to the Lewis nomogram do not fully align with the Sayers equation (Table 1). This raises the question of the compatibility of different calculation methods in assessing anaerobic power, suggesting the need for further research on the sensitivity of these assessment tools. Furthermore, the negative correlation between pes planus and anaerobic power ($r = -0.63$, $p = 0.0004$) suggests that foot arch structure may influence anaerobic

performance through factors such as power production and ground contact time. This finding is consistent with the hypothesis that biomechanical disadvantages in individuals with pes planus deformity may lead to decreased performance, particularly in short-distance sprint tests that require rapid force production. Performance differences between the normal arch and pes planus groups might be influenced by gait variability. Padulo et al. (2023) reported that training load significantly affects running gait patterns, indicating a complex interaction between foot structure and movement [37].

While anaerobic capacity is essential for karate, aerobic capacity is also crucial to prevent fatigue during recovery [38]. One of the most critical factors determining an athlete's endurance is cardiorespiratory endurance. The athlete's cardiovascular and respiratory systems work together during the performance to carry the body's oxygen demand [39]. The relationship between critical power (CP) and maximal oxygen uptake (VO_2max) suggests that children with pes planus may have lower VO_2max , which may affect their aerobic performance [40]. While the 6MWT is not the only validated tool for assessing fitness in both children and adults, as a sub-maximal exercise test, it does not require excessive effort that overtaxes the cardiovascular system and causes significant changes in heart rate and/or %saturation oxygen. Additionally, the 6MWT is a simple, rapid, and low-cost test, making it easy to administer to a vast population. Thus, it is helpful for reliably measuring exercise capacity before subjects reach the anaerobic threshold [41]. Additionally, more targeted tests (such as VO_2max estimation or shuttle runs) are more appropriate for specific sports. Future studies can compare the results of different tests to demonstrate the advantages and disadvantages of both methods more clearly. This can help determine the most appropriate methods for better assessing the aerobic capacity of athletic young people. According to the 6MWT, although the aerobic capacity of boys with normal arches was higher than that of girls with pes planus, no significant difference was observed between the two groups. Additionally, there was no significant difference between the HRmax and HRmean values of the groups during the six-minute walking test. This is consistent with the participants having similar ages and physical characteristics, which reduces the impact of potential confounding variables in the comparisons.

Our study revealed significant differences between children with normal arches and those with pes planus, specifically that girls and boys with normal arches had higher anaerobic capacity levels than their counterparts with pes planus (Table 1). Furthermore, boys and girls with normal arches demonstrated a significant advantage in short-distance acceleration abilities compared to those

with pes planus. However, no significant difference was observed in aerobic capacity between men and women with normal arches. These findings suggest that foot structure is crucial in determining athletic performance, and that young athletes with pes planus may be at a disadvantage in terms of energy efficiency and performance. Athletes with pes planus need to address the risks associated with karate, an anaerobic sport, to prevent potentially adverse effects on lower extremity alignment and to minimize the likelihood of future complications. Therefore, identifying athletes with pes planus and implementing appropriate corrective exercise strategies is vital for optimizing athletic performance. Future studies should include detailed gait analysis and develop strategies to improve balance problems in individuals with pes planus. Our study's limitations include the need for a more extensive and diverse sample better to assess the effects of pes planus across different sports.

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Authors' contributions

Concept-Conception or design- KK, CA, HD; Acquisition, analysis, or interpretation of data- KK, CA; Drafted the manuscript- KK, HD; Critically revised the manuscript for important intellectual content- KK, HD; Final approval- KK, HD, CA.

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Data availability

The data and materials presented in this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate

Approval for this study was granted by the İnönü University Malatya Clinical Research Ethics Committee under research protocol number 2023/5059. This study, conducted on children who are not yet considered adults, is based on the World Medical Association (WMA) Declaration of Helsinki, which outlines ethical principles for medical research involving humans. The stated statement in the informed consent forms received from the participants/guardians was as follows: "I have read all the explanations and explained them to my child in a way that they can understand. I understand that my child can withdraw from the research at any time, with or without reason. I accept my child's voluntary participation in the research as a mother/father or legal guardian (legal representative) of my own free will, without any pressure or coercion."

Consent for publication

Written informed consent was obtained from the patients to publish this manuscript. Consent for publication means approval to use identifying images or information that may compromise participant anonymity. This does not apply in our case, so we mark it as "not applicable."

Competing interests

The authors declare no competing interests.

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