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# Tarsus and knee setting in children at the final stage of early childhood taking into account the six-month age ranges

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*Purpose*: The study aimed to analyze the tarsus and knee setting in 3-year-old girls and boys, taking into account the six-month age ranges. *Methods*: The study involved 800 children (400 girls, 400 boys) recruited from randomly selected preschools in the in the Podkarpackie voivodeship. Study group was divided into two age ranges: 1st group (children aged 3.00–3.49 years) and 2nd group (children aged 3.50–3.99 years). Baseline goniometer (Fei Fabrication, Ltd., USA) was used as primary research tool. The data were analyzed based on Mann–Whitney *U*-test and Student's *t*-test for independent samples. *Results*: Sex differences concern only the tibio-calcaneal angle in children in the 2nd age group (right: $p < 0.001$) and left $p < 0.001$). Statistically significant differences in both girls (right lower limb: $p = 0.003$; left lower limb: $p = 0.002$), and boys (right lower limb: $p = 0.001$; left lower limb: $p = 0.001$) were found. *Conclusions*: Boys were characterized by greater valgus of the tarsus of the right and left foot than girls. Knees of girls and boys in the 1st age group were characterized by greater valgus, compared to children from the 2nd age group.

*Key words*: *tibio-calcaneal angle, tibio-femoral angle, girls, boys*

## 1. Introduction

The ankle and knee joints are crucial elements of the kinematic chain of the human lower limb. Biomechanical relationships within these parts of the musculoskeletal system determine the way foot positioning and loading, as well as locomotion [7], [11], [14], [23], [25], [29], [30]. The tarsus and knees setting in children has evoked controversies and discussions for years. Orthopaedists and physiotherapists believe that the valgus setting of the tarsus is a stage of the natural biological development and is a characteristic feature of the growing foot. The analysis of the extensive literature devoted to the issues of lower limb variability in ontogenesis indicates that a lot of attention has been devoted to these issues, although there are few studies devoted to these issues in children in early childhood. Most of the authors focused on analyzing selected features in older children, more advanced in ontogenetic development [5], [12], [24], [28]. Prętkiewicz-Abacjew and Opanowska [25], as a result of studies on 394 children aged 5 to 7 years, found correct tarsus setting in half of the studied population. There were no cases of varus tarsus, but valgus was more common in boys, especially in the 6-year-old category. Prętkiewicz-Abacjew [24] observed the intensification of the symptoms of valgus tarsus during locomotion in 6-year-old children. Lincoln and Suen [18] pointed out that the majority of healthy, normally developing children have a tendency to place their valgus feet during locomotion. This kind of gait might be a result of a large antetorsion of the femoral neck or increased tibial torsion. These are developmental elements that fall within the limits of the physiology of the development of the skeletal system.

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The knee joint also plays an important role in transferring body weight to the foot. Kutzner-Kozińska [16] noted that varus knees and flexion position of the hip and knee joints is a physiological feature in newborns, which, on the one hand, is a remnant of the intrauterine arrangement, while on the other, it results from the dominance of the flexors over the extensors. The varus setting of the knees lasts until about 3 years of age, after which it turns into physiological valgus. The correct structure of the lower limbs is observed in children around 6–7 years of age. Prętkiewicz-Abacjew and Opanowska [25], taking into account children in the preschool period, pointed to frequent disturbances in the course of the loading (mechanical) line of the lower limb in relation to the anatomical axis, which in normal conditions corresponds to the long axis of femoral and tibial shafts and coincides with the axis of the calcaneus.

The above considerations show that the development of the lower limbs is a complex process and proceeds differently at different stages of ontogenesis. The view on the current state of research prompted the authors to undertake the subject of the study, the aim of which was to analyze the tarsus and knees setting in girls and boys in the final stage of early childhood, taking into account the half-yearly age ranges. The following research questions were meant to be addressed:

1. Do 3-year-old children, in each of the separated six-month age ranges, demonstrate sexual dimorphism of the features determining the setting of the tarsus and knees?
2. Are there any differences in the values of features determining the setting of the tarsus and knees between children classified into age groups taking into account the six-month age ranges?

# 2. Materials and methods

## 2.1. Participants

The study involved 800 children (400 girls, 400 boys) recruited from randomly selected preschools in the in the Podkarpackie voivodeship in South-Eastern Poland.

The following inclusion criteria were applied: calendar age in the range of 3.00–3.99, written consent of parents/legal guardians for participation in research.

Children from preterm delivery and those with deformation of the lower limbs, neurological disorders and diseases and/or injuries of the musculoskeletal system, including lower limbs were duly excluded from the study.

The group of 3-year-olds covered children between 3.00 and 3.99 years of age. The mean of the group was 3.5 years. The calendar age in a decimals was calculated as the difference between the date of the study and the date of birth [15]. Next, children were qualified in the age categories, based on the half-year ranges, semi-annual division was made. Finally, then study group was divided into two age ranges:

– age range I (1st group): children aged 3.00–3.49 years: 200 girls ($\bar{x}$ = 3.25 ± 0.17 years) and 200 boys: ($\bar{x}$ = 3.25 ± 0.14 years);
– age range II (2nd group): children aged 3.50–3.99 years: 200 girls ($\bar{x}$ =3.75 ± 0.15 years) and 200 boys ($\bar{x}$ = 3.73 ± 0.15).

In the case of girls classified into the 1st and 2nd age group, the mean values of somatic features were respectively: body mass: $\bar{x}$ = 15.58 ± 2.13 kg and $\bar{x}$ = 16.73 ± 2.25 kg; body height: $\bar{x}$ = 96.71 ± 4.15 cm

Table 1. Somatic characteristics of the study subjects

| Group | Girls | | | Boys | | | Statistics |
|---|---|---|---|---|---|---|---|
| | $\bar{x}$ ± SD | max–min | | $\bar{x}$ ±SD | max–min | | |
| Body mass [kg] | | | | | | | |
| 1st | 15.58 ± 2.13 | 24.50–11.00 | 15.00 | 16.26 ± 2.37 | 25.00–11.50 | 16.00 | $Z$ = –0.03; $p$ = 0.973 |
| 2nd | 16.73 ± 2.25 | 22.00–12.00 | 16.25 | 17.07 ± 2.13 | 24.50–12.50 | 17.00 | $Z$ = –1.60; $p$ = 0.110 |
| Body height [cm] | | | | | | | |
| 1st | 96.71 ± 4.15 | 109.00–85.50 | 96.50 | 98.21 ± 4.28 | 107.50–83.50 | 98.50 | $t$ = 3.55; $p$ = 0.696 |
| 2nd | 100.87 ± 4.05 | 114.50–91.50 | 100.50 | 101.09 ± 3.97 | 113.00–86.50 | 101.00 | $Z$ = –0.70; $p$ = 0.484 |
| BMI | | | | | | | |
| 1st | 16.59 ± 1.73 | 22.60–12.06 | 16.45 | 16.82 ± 1.88 | 29.54–13.16 | 16.65 | $Z$ = –0.99; $p$ = 0.324 |
| 2nd | 16.39 ± 1.55 | 22.68–12.50 | 16.32 | 16.68 ± 1.61 | 21.11–12.98 | 16.57 | $Z$ = –1.68; $p$ = 0.092 |

Abbreviations: $Z$ – value of the Mann–Whitney $U$-test statistic; $t$ – value of the Student's $t$-test for independent samples statistics; $p$ – probability value.

and $\bar{x}$ = 100.87 ± 4.05 cm; BMI: $\bar{x}$ = 16.59 ± 1.73 and $\bar{x}$ = 16.39 ± 1.55. In turn, in the case of boys, the average body mass: $\bar{x}$ = 16.26 ± 2.37 kg and $\bar{x}$ = 17.07 ± 2.13 kg; the average body height: $\bar{x}$ = 98.21 ± 4.28 cm and $\bar{x}$ = 101.09 ± 3.97 cm, and average BMI: $\bar{x}$ = 16.82 ± 1.88 and $\bar{x}$ = 16.68 ± 1.61. Body mass, body height and BMI values did not significantly differentiate girls and boys (Table 1).

## 2.2. Design

*Tarsal setting measurements*

The setting of the tarsus in relation to the shin was examined in a standing position, taking into account the frontal plane. During the measurement, a child was placed on a platform 25 cm high turned back to the examiner. The heels were pushed to the edge of the platform. Using the BASELINE goniometer (Fei Fabrication, Ltd., USA), the angle of inclination of the calcaneal axis in relation to the vertical was measured (tibiocalcaneal angle). The axis of the calcaneus was a straight line running through the centers of horizontal lines, one of which connected the ankle joints: lateral and medial, and the other: extreme points at the base of the calcaneous. The point of application of the goniometer axis was marked with a dermograph on the child's skin, at the intersection of the line connecting the lateral and medial malleoli with the line drawn along the Achilles tendon. During the measurement, one arm of the goniometer was placed along the lower leg and aimed at the center of the knee joint, and the other arm was positioned towards the center of the base of the heel. The angle between the vertical line and the axis of the calcaneus was taken into account. The tarsus was found to be valgus when the calcaneus axis was inclined lateral to the vertical, and varus when the calcaneus axis was inclined medially to the vertical. The results were determined with an accuracy of 1°. Valgus heel data were recorded as positive values, while varus data were reported as negative values [3], [17].

*Knee setting measurements*

Knee measurements were taken in a standing position. The child was positioned facing the examiner. The hip and knee joints were in a neutral position. The child attempted to bring the medial surfaces of the knees and the medial ankles together. Measurements were made using a BASELINE goniometer (Fei Fabrication, Ltd., USA). Before the measurement, the following points were marked on the child's skin with a dermograph: the anterior superior iliac spine, the center of the patella and the center of the articular surface of the talus trochlea. The point of application of the goniometer axis was determined by the contour of the patella, and then the determination of the center in the center of the contour. During the measurement, the axis of the goniometer was in the center of the patella. One goniometer arm aimed at the anterior superior iliac spine and the other was positioned towards the center of the articular surface of the talus trochlea. In this way, the measurement of the tibio-femoral angle was performed [2], [9], [14], [19], [27]. Valgus knee was found when the circumferential section, i.e., the lower leg, was abducted in relation to the axis of the lower limb. In turn, varus was pronounced when the lower leg was in adduction. The results were determined with an accuracy of 1°. Valgus knee data were recorded as positive values, while varus knee data were recorded as negative values [2], [9], [14], [19], [27].

The choice of a research tool was dictated by a relatively high quality and low price. Arazi et al. [1], Mathew and Madhuri [19] recommend clinical method of measurement with goniometer due to its reliability, repeatability, non-invasiveness, affordability and ease of use. According to Mathew and Madhuri [19] that measurements characterized by minimal intra-observer variability and high inter-observer reliability. Mohd-Karim et al. [21] found a high inter-observer reliability with intraclass correlation coefficient (ICC) of 0.87.

*Somatic features measurements*

Measurements of the body mass (using a OMRON BF500635 medical scale, manufactured by Omron, Ltd., Japan) and body height (using a GPM anthropometer, manufactured by Vitako, Ltd., Switzerland), were taken. The obtained data were used to calculate the Body Mass Index (BMI).

The research was carried out in line with the Declaration of Helsinki, in kindergartens, in gyms and play areas. The child educators were present on examination. All tests were conducted in the morning, by means of the same measurement tools so as the principles of research integrity are met. The subjects were in underwear and barefooted. The study was approved by the Bioethics Review Committee of the University of Rzeszow, Poland (protocol code 2/2/2017). Parents or carers were informed about the aim of the research, its main assumptions and the right to discontinue the study at any stage.

*Statistical analysis*

The normalcy of characteristics distribution was verified by means of the Shapiro–Wilk test. The quantitative parameters were described using basic measurements of descriptive statistics, i.e., mean, standard deviation, minimum, maximum and median. The analysis of the test results was performed using the Mann–Whitney *U*-test, Student's *t*-test for independent samples, assuming $p < 0.05$ as the level of statistical significance. The Statistica application, ver. 13.1 PL (StatSoft, Inc., Tulsa, OK, USA; StatSoft, Krakow, Poland) was used to process the test results.

# 3. Results

The data collected in Table 2 indicate the occurrence of statistically significant sex differences in the tibio-calcaneal angle angle of the right ($p < 0.001$) and left ($p < 0.001$) lower limbs in the 2nd age group. The values of this angle in boys were higher than in girls.

Comparison of tibio-calcaneal angle results in age groups showed statistically significant differences only in girls. In the 2nd age group, the values of this variable were lower than in the 1st age group (right lower limb: $p < 0.001$ and left lower limb: $p < 0.001$) (Table 2).

The data collected in Table 3 indicate no statistically significant gender differences in tibio-femoral angle values.

In turn, the comparison of this feature within a given sex showed statistically significant differences in both girls (right lower limb: $p = 0.003$*; left lower limb: $p = 0.002$), and boys (right lower limb: $p = 0.001$; left lower limb: $p = 0.001$). The values of this indicator in girls

Table 2. Comparison of the tibio-calcaneal angle values of 3-year-old girls and boys, taking into account six-month age ranges

| Group | Girls | | | Boys | | | $Z$ | $p$ |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x} \pm$ SD | max–min | Me | $\bar{x} \pm$ SD | max–min | Me | | |
| Tibio-calcaneal angle of the right lower limb [°] | | | | | | | | |
| 1st | 4.84 ± 3.09 | 13.00–(–1.00) | 5.00 | 4.93 ± 3.41 | 15.00–(–4.00) | 6.00 | –0.29 | 0.769 |
| 2nd | 3.17 ± 2.97 | 12.00–(–5.00) | 3.00 | 4.61 ± 3.26 | 12.00–(–5.00) | 5.00 | –4.54 | <0.001* |
| Girls $_{\text{1st group}}$ – Girls $_{\text{2nd group}}$ $Z = -5.30$; $p < 0.001$* | | | | Boys $_{\text{1st group}}$ – Boys $_{\text{2nd group}}$ $Z = -1.06$; $p = 0.290$ | | | | |
| Tibio-calcaneal angle of the left lower limb [°] | | | | | | | | |
| 1st | 5.40 ± 3.32 | 16.00–(–1.00) | 6.00 | 5.41 ± 3.65 | 15.00–(–5.00) | 6.00 | –0.18 | 0.858 |
| 2nd | 3.55 ± 3.24 | 14.00–(–5.00) | 3.00 | 4.61 ± 3.26 | 12.00–(–5.00) | 5.00 | –4.91 | <0.001* |
| Girls $_{\text{1st group}}$ – Girls $_{\text{2nd group}}$ $Z = -5.61$; $p < 0.001$* | | | | Boys $_{\text{1st group}}$ – Boys $_{\text{2nd group}}$ $Z = -1.02$; $p = 0.309$ | | | | |

Abbreviations: $Z$ – value of the Mann–Whitney *U*-test statistic; $p$ – probability value.
* $p < 0.05$.

Table 3. Comparison of the tibio-femoral angle values of 3-year-old girls and boys, taking into account six-month age ranges

| Group | Girls | | | Boys | | | $Z$ | $p$ |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x} \pm$ SD | max–min | Me | $\bar{x} \pm$ SD | max–min | Me | | |
| Tibio-femoral angle of the right lower limb [°] | | | | | | | | |
| 1st | 3.10 ± 4.77 | 18.00–(–6.00) | 2.00 | 3.62 ± 5.38 | 17.00–(–8.00) | 2.00 | –0.83 | 0.409 |
| 2nd | 1.62 ± 3.35 | 17.00–(–4.00) | 0.00 | 2.16 ± 4.52 | 16.00–(–5.00) | 0.00 | –0.25 | 0.804 |
| Girls $_{\text{1st group}}$ – Girls $_{\text{2nd group}}$ $Z = -2.96$; $p = 0.003$* | | | | Boys $_{\text{1st group}}$ – Boys $_{\text{2nd group}}$ $Z = -3.28$; $p = 0.001$* | | | | |
| Tibio-femoral angle of the left lower limb [°] | | | | | | | | |
| 1st | 3.15 ± 4.76 | 18.00–(–6.00) | 2.00 | 3.62 ± 5.38 | 17.00–(–8.00) | 2.00 | –0.67 | 0.502 |
| 2nd | 1.62 ± 3.35 | 17.00–(–4.00) | 0.00 | 2.16 ± 4.52 | 16.00–(–5.00) | 0.00 | –0.25 | 0.804 |
| Girls $_{\text{1st group}}$ – Girls $_{\text{2nd group}}$ $Z = -3.13$; $p = 0.002$* | | | | Boys $_{\text{1st group}}$ – Boys $_{\text{2nd group}}$ $Z = -3.27$; $p = 0.001$* | | | | |

Abbreviations: $Z$ – value of the Mann–Whitney *U*-test statistic; $p$ – probability value.
* $p < 0.05$

and boys from the 2nd age group were lower than in children from the 1st age group.

## 4. Discussion

Our study showed no statistically significant intergender differences in the values of the tibio-calcaneal angle in children in the 1st age group. The obtained data suggest that the rate of development of this feature in the examined age range is similar in both sexes, and the average values of the tibio-calcaneal angle oscillate around the upper limit of norm, which, according to Kasperczyk [13], ranges from 0 to 5°. Dziak [6] emphasized that the valgus of the tarsus in preschool children may be due to increased flexibility of the ligament-capsular and muscle structures, as well as the less compactness of the foot joints. It seems that valgus hindfoot may be a mechanism to improve balance in the first years of life. The valgus setting of the hindfoot promotes the relaxation of the ankle joint, and thanks to this the foot can adhere to the ground with a larger surface, providing the child with better stability. The sex differences in the tarsus setting found in the 2nd age group, where boys were characterized by its greater valgus, suggest that male development in this respect is slower than that of girls.

In the case of girls, we found that the subjects from the 1st age group were characterized by higher values of the tibio-calcaneal angle than the girls from the 2nd age group. This indicates that valgus tarsus is a physiological condition and is transient. Due to lack of studies in the literature on the subject, it is difficult to relate our results to other studies. According to Matyja and Gogola [20], valgus tarsal may be a compensatory mechanism in response to postural tone deficits. From a neurophysiological point of view, such reasoning is justified. Most children at the beginning of ontogenesis present poor deep muscles capacity in the lumbo-pelvic complex. It mainly concerns the transverse and oblique muscles of the abdomen, as well as the multifidus, pelvic floor and diaphragm. Increased tonus in the distal parts and valgus alignment of the tarsus may improve central stabilization. Only the gradual development of muscles stabilizing the torso allows to improve the functionality of the limbs.

Moving on to subsequent issues, it should be mentioned that in our material, the differences in the setting of the knees concerned both girls and boys. Children in the 1st age group were characterized by greater knee valgus than in the 2nd age group. This suggests that the mechanical axis of the lower limb gradually approaches the center of the knee joint with age. It is difficult to relate our results to other authors' studies, mainly due to the small number of papers and different approaches to research procedures. The analysis of the literature enables us to claim that in the studies on the setting of the knees, some authors relied on the measurements of the distance between the medial malleoli of the tibia and the medial condyles of the femur [5], [12]. Perhaps this method of measurement was considered relatively uncomplicated. In turn, Saini et al. [26] and Mohd-Karim et al. [21] emphasized the usefulness of tibiofemoral angle measurements in clinical and screening studies, mainly due to such advantages as accuracy, reliability and standardization. According to the authors, a clearly defined measurement procedure allows to minimize errors. However, Baruah et al. [2] pointed out that despite the above-mentioned positives, the different approach of the authors to the research methodology and the lack of compliance with the principle of homogeneity of the studied groups, particularly visible in the grouping of people of different ages and genders, in many cases make it difficult to interpret the data. Kaspiris et al. [14] pointed to racial differences as a factor that may cause the inability to compare the results obtained in different populations. Studies based on measurements of the tibiofemoral angle were conducted by Mathew and Madhuri [19] in a population of children from South India. In the age range from 2 to 3 years of age, the mean angle values were 2.45 ± 0.87° for girls and 1.80 ± 0.65° for boys. The highest valgus was observed in the age group from 5 to 6 years of age and the averages were 7.25 ± 0.64° for girls and 6.70 ± 1.30° for boys. In turn, Baruah et al. [2] recorded the value of this angle at the level of 3.26 ± 1.10° in 3-year-old residents of north-eastern India, in subsequent years they observed its gradual increase to an average value of 8.55 ± 1.06° at the age of 7, with a relatively low standard deviation, and then a gradual decrease in subsequent years, to an average of 3.18 ± 1.18° at the age of 18. The studies of children from Lagos and Ibadan, Nigeria, Omololu et al. [22] found that the difference in tibio-femoral angle values between 1-year-olds and 10-year-olds is about 11°. The authors observed the maximum varus in the subjects from 1 to 3 years of age while in 3-year-olds the most common was valgus, which averaged 14.20 ± 5.60° in the case of the right lower limb and 14.10 ± 5.80° in the left one. In our material, the values of the tibiofemoral angle changed in the following six months from 3.62 ± 5.38° to 1.62° 1.62 ± 3.35° and were definitely lower. Omololu et al. [22] pointed out to racial differences in the setting of the knees, referring to the research by Cheng et al. [4], who in the majority of children between 3 and 11 years of age representing the Chinese population recorded significantly higher values of varus angle of the knee. Also Samia et al., [27] based on the study of children aged 2 to 12 from Saudi Arabia, Heshmatipour and Karimi [10] in the study of residents of Iran aged 8–11, and Arazi et al. [1], who studied children aged 3 to 17 in Turkey, observed the influence of on the development of the tibiofemoral angle. This may be caused by the differences in the structure of the knee joint. Hafez et al. [8] pointed to racial differences in the structure of the proximal end of the tibia and the distal end of the femur. Caucasians had larger knee joint sizes than Chinese. In turn, Arab knee joints were more massive compared to Asians, but smaller than the knees of Caucasians. The authors concluded that this is the result of differences in somatic build, including body height of people representing the above-mentioned populations.

In the light of these observations, the issues raised in the work should be considered valuable. The authors are convinced that the obtained data will be used in the diagnosis and prevention of musculoskeletal deformities. Awareness of physiological developmental deviations allows, on the one hand, to detect abnormalities early enough and undertake immediate correction, while on the other hand, to limit therapeutic activities to cases where they are necessary.

# 5. Conclusions

Sex differences concern only the tibio-calcaneal angle in children in the 2nd age group. These differences indicated that boys were characterized by greater valgus of the tarsus of the right and left foot than girls.

Girls from the 1st age group were characterized by higher values of the tibio-femoral angle than girls from the 2nd age group. This indicates that the knees of girls and boys in the 1st age group were characterized by greater valgus, compared to children from the 2nd age group.

## Competing interests

The authors declares that they have no competing interests.

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