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Normal Development of the Tibiofemoral Angle in Saudi Children from 2 to 12 Years of Age

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Abstract: The objectives of this study were to determine the normal chronological changes of the tibiofemoral (TF) angle in Saudi children and to compare between boys and girls regarding the development of the TF angle. Three hundred normal Saudi children with age range of 2-12 years participated in the study. They were selected from both sexes from nurseries and schools of five different areas in Riyadh. The subjects were divided according to their age into ten age groups. The TF angle was measured by plastic goniometers of different sizes. The results revealed a tendency of knock knees that decreased towards normal lower extremity alignment with age increment. There was no significant difference between boys and girls regarding the development of the TF angle ($p=0.605$). It was concluded that the normal Saudi children with age range of 2-12 years exhibit a valgus alignment of the lower extremities that decreases with age increment with no significant difference between boys and girls.

Key words: Children · Tibiofemoral angle · Bowlegs · Genu varum · Knock-knees · Genu varum

INTRODUCTION

Tibiofemoral (TF) angle or knee angle is the angle defined by the mechanical axis of the femur intersecting the mechanical axis of the tibia [1]. The TF angle reduces the energy required in walking by allowing feet to be closer together than the hips. A reduction of this angle is known as genu varum (bowlegs) and an exaggeration of this angle is known as genu valgum (knock-knees) [2].

Development of the TF angle from bowlegs (varus) in the infant to knock-knees (valgus) in early childhood as a part of normal and physiological development is well known [3-6]. This physiological variation in the TF angle often causes apprehension amongst the parents [3,7-9].

Salenius and Vankka [4] reported various factors that may cause physiological bowlegs and knock-knees such as inherited factors, intrauterine position, sleeping positions, bad posture, ligamentous laxity and torsional mal-alignment.

The assessment of bowlegs and knock-knees is performed by measuring the TF angle, intercondylar distance and intermalleolar distance by the use of either non-invasive or invasive techniques [3,4]. The non-invasive techniques include clinical examination as well as photographic analysis [3]. The invasive technique includes mainly the use of radiography [4].

The clinical examination of bowlegs and knock-knees by measuring the TF angle is easily applicable, reliable and reproducible [2,5,8-10]. Photographic method was widely used [2,3,6,11] but unfortunately its use for research purpose is restricted in Saudi culture. Sometimes it is unreasonable to expose children to unnecessary radiation. Additionally, limb mal-rotation during radiography may significantly affect the measurement of the TF angle [7].

The normal development of the TF angle may be affected by racial factor. The American children who are less than one year had genu varum, which spontaneously corrected during the second year of life.

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There was a maximal mean valgus of 6-7° at 3 years of age, followed by constant valgus of 4-5° between 5 and 12 years of age [3]. European children showed a valgus angle of 5.61° to 5.53° from 10 to 16 years of age [8]. In recent study on American children, the TF angle peaked at a mean of 9° of valgus at 6 years and remained between 5° and 7° of valgus from 7 to 18 years of age [12].

The bowlegs and knock-knees are frequently encountered in pediatric orthopedic clinics. Misunderstandings of the physiologic ranges and changes in knee alignment might initiate costly and time-consuming therapeutic measures such as unnecessary bracing [13].

Many researchers investigated the effect of gender on the development of TF angle. Some of them revealed no significant difference between boys and girls [3-5,11,14]. However, others revealed a significant difference regarding gender [2,6,8,13,15].

The purposes of this study were to; (1) determine mean values and normal limits of the TF angle in normal Saudi children aged from 2-12 years in Riyadh city, (2) compare between boys and girls aged from 2-12 years in Riyadh city regarding the development of the TF angle.

Two hypotheses were stated: (1) there will be a valgus pattern in the development of the TF angle that will decrease towards the plateau with age increment from 2-12 years, (2) there will be a significant difference in the development of the TF angle between Saudi boys and girls aged from 2-12 years.

MATERIALS AND METHODS

Subjects: Three hundred children participated in this study. Their age ranged from 2 to 12 years. They were selected from both sexes of equal number. They were classified into ten age specific groups [8] (Table 1). Each age group contained 30 children (15 girls and 15 boys).

Subjects were randomly selected from different nurseries and schools that are located in five sections of Riyadh city (central, north, south, west and east). They were included if they 1) are healthy Saudi children, 2) aged from 2 to12 years and 3) had normal weight according to the Children's body mass index (BMI)-percentile-for-age. The children were excluded if they 1) had one or more of the following disorders: musculoskeletal disorders, neurological disorders, neuromuscular disorders, foot deformities, metabolic disease, orthopedic disorders and/or tibial torsion, 2) underwent operations on the legs, 3) had leg length discrepancy and/or 4) were underweight, overweight or obese.

Study Design: Cross-sectional study of the TF angle in normal Saudi children residing in Riyadh city.

Materials: Plastic goniometers of different sizes, markers and rulers were used to measure the TF angle. Digital weight/height scale and Children's BMI-percentile-for-age Calculator [16] were used to calculate BMI-percentile-for-age.

Procedures: Approval from the Ministry of Education in Riyadh city was obtained and the consent forms were distributed to the parents after a detailed explanation of the procedures. The signed consent forms were obtained. Two therapists (one male and one female) were involved in the measuring process. Therefore, the inter-rater reliability of the therapists was measured before starting the study. The first male therapist took the measurements for 10 boys and 10 girls and then the second female therapist took the measurements for the same children. The correlation coefficient was 0.946 at p=0.01. Afterward, the first therapist applied all the measurements for the rest of boys and the second therapist applied all the measurements for the rest of girls. While children from 2 to 4 years of age were measured, an assistant helped keep them in a stable standing position.

The following procedures were applied systematically with each child:

Each child was examined medically by the nursery and/or school physician. Then the child was selected according to the inclusion and exclusion criteria mentioned above. 2) The selected child was then entered a room in his school prepared for the examination where weight in kilograms and standing height in centimeters were measured respectively by the digital weight/height scale. The height was then converted into meters.

Table 1: Age specific groups (in years) for boys and girls [8]

Number	1	2	3	4	5	6	7	8	9	10
Age Groups	2:<3	3:<4	4:<5	5:<6	6:<7	7:<8	8:<9	9:<10	10:<11	11: 12

3) Children's BMI-percentile-for-age Calculator was used for each child to calculate the BMI-percentile-for-age. The child participated in the study when the BMI-percentile-for-age was between 5th to less than the 85th percentiles [17]. 4) Each participated child was then asked to expose the lower limbs and the pelvic area to locate the anterior superior iliac spine (ASIS), the center of patella and the midpoint of the ankle joint for each lower extremity. 5) The child was asked to be in the standing position. The hips and knees were in full extension with the patellae straight ahead. 6) Skin marks were placed as dots over the ASIS, the center of patella (midpoint of maximum mediolateral width measured by tape measure) and the midpoint of the ankle joint (midpoint between the medial and lateral malleoli measured by tape measure) [15]. Afterward, two longitudinal lines were drawn using the marker and the ruler; one connecting ASIS and the center of patella (femoral axis) and the other connecting the center of patella and the midpoint of the ankle joint (tibial axis). 7) The therapist then measured the TF angle by using the goniometer. The fulcrum of the goniometer was placed on the center of patella, the stationary arm was placed on the femoral longitudinal axis and the movable arm was placed on tibial longitudinal axis. The medial angle between them was measured [10].

Both lower limbs were measured three times for each subject and a mean TF angle was calculated for each child and designated as positive or negative value for varus or valgus, respectively [18].

Statistical Analysis: Statistical analyses were conducted using statistical package for the social sciences (SPSS) version 16 for Windows. Means and standard deviations of the TF angle for the children in each age group were calculated to determine the sequence of the TF angle development.

Comparative studies were conducted between the mean differences of the TF angle in the ten age groups by using one-way ANOVA test to show the statistical significance among as well as within the age groups. In case of significance, the least significant difference (LSD) test as a post hoc multiple comparison test was performed to detect pairs of age groups, significantly different at the 0.05 level of probability.

Finally, independent samples t-test was performed to test the significance difference between boys and girls regarding the development of the TF angle. In all statistical tests, the alternative hypothesis was accepted at 5% level of probability ($\alpha \leq 0.05$).

RESULTS

The general demographic statistics of the participants are represented in Table (2). A valgus alignment (valgus knee angle) was observed in all children with a maximum mean valgus of 9.46°±0.85° at 3 to less than 4 years. The TF angle was decreased with age increment (Figure 1).

One-way ANOVA test revealed significant differences among means of the TF angle regarding to the age variable ($p=0.0001$) at ($\alpha \leq 0.05$) (Table 3a). The LSD test was then conducted and revealed that the significant difference of the means of TF angle was observed between certain age groups as seen in Table (3b) with the highest mean value at 3 to 4 years and the lowest mean value at 11 to 12 years (9.46° and 3.47° respectively).

Table 2: Means and standard deviations of the demographics of all children

Age Groups (Years) No.=30 in each	Age (Years)	Weight (Kg)	Height (m)	BMI Percentile
2:<3	2.54±0.30	12.89±1.04	0.90±0.04	41.48±21.79
3:<4	3.43±0.31	15.65±1.27	1.01±0.03	37.68±21.28
4:<5	4.38±0.25	16.22±1.41	1.03±0.05	47.68±18.22
5:<6	5.59±0.32	18.76±1.59	1.12±0.05	38.74±19.90
6:<7	6.43±0.26	20.46±1.69	1.16±0.05	43.56±21.10
7:<8	7.40±0.30	21.48±2.50	1.18±0.06	42.79±18.12
8:<9	8.38±0.23	24.27±3.46	1.24±0.06	42.41±23.05
9:<10	9.38±0.29	27.42±3.11	1.31±0.05	40.84±19.28
10:<11	10.36±0.31	29.53±3.62	1.35±0.06	30.00±13.33
11: 12	11.47±0.25	34.46±3.65	1.43±0.06	41.29±18.66
No.: Number of children.	Kg: Kilogram.	m: Meter.	BMI: Body mass index.	

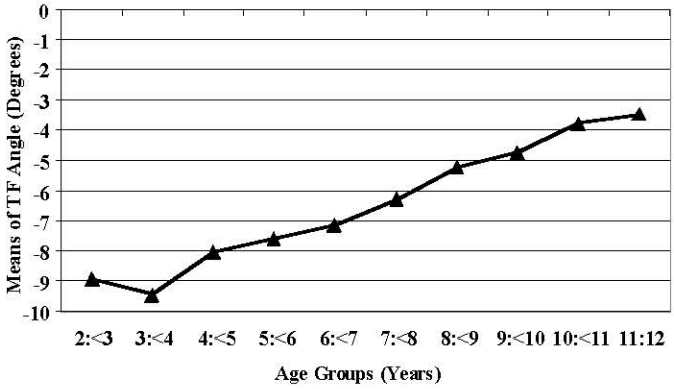

Fig. 1: Development of the tibiofemoral (TF) angle in Saudi children

Table 3a: ANOVA test for the tibiofemoral angle in all children

Source	DF	SS	MS	F. ratio	P. value
Between groups	9	1197.81	133.09	79.227	0.0001
Within groups	290	487.16	1.68		
Total	299	1684.97			

DF: Degree of freedom. SS: Sum of squares. MS: Mean of squares. P: Probability value.

Table 3b: Post hoc multiple comparison test (LSD) for the tibiofemoral angle

Means	Age Groups	2:<3	3:<4	4:<5	5:<6	6:<7	7:<8	8:<9	9:<10	10:<11	11:12
8.97	2:<3			*	*	*	*	*	*	*	*
9.46	3:<4			*	*	*	*	*	*	*	*
8.04	4:<5					*	*	*	*	*	*
7.61	5:<6						*	*	*	*	*
7.14	6:<7						*	*	*	*	*
6.31	7:<8							*	*	*	*
5.24	8:<9									*	*
4.73	9:<10									*	*
3.82	10:<11										
3.47	11:12										

*: Donates pairs of age groups significantly different at $\alpha \leq 0.05$.

Table 4: Comparison between boys and girls regarding the normal values of the tibiofemoral angle at each age group

		Girls	Boys		
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Age Groups	No.	Mean±SD	Mean±SD	t- value	P.value
2:<3	15	8.87±1.36	9.07±1.03	- 0.455	0.653
3:<4	15	9.39±0.87	9.52±0.83	-0.428	0.670
4:<5	15	8.40±1.01	7.68±1.12	1.858	0.070
5:<6	15	7.98±0.84	7.24±0.79	2.450	0.020*
6:<7	15	7.37±2.01	6.91±2.12	0.605	0.550
7:<8	15	6.88±1.90	5.74±1.41	1.856	0.070
8:<9	15	4.94±1.20	5.54±1.66	-1.136	0.260
9:<10	15	4.70±0.97	4.77±1.76	-0.129	0.890
10:<11	15	3.74±0.71	3.89±0.73	-0.548	0.580
11:12	15	3.23±0.76	3.71±1.10	-1.389	0.170

No.: Number of the children. P: Probability value. * Significant at $\alpha \leq 0.05$.

The independent sample t-test showed non-significant differences in the development of the TF angle (p=0.605) between boys and girls except in the age group 5:<6 years (p=0.020), in which the TF angle was higher in girls than boys (7.98±0.84° and 7.24±0.79° respectively) (Table 4).

DISCUSSION

Knowledge of a normal range of the TF angle in children is of paramount clinical importance. This knowledge allows physicians and therapists to determine whether the TF angle in a specific patient represents physiologic development or pathology. Moreover, a relevant and correct understanding of the development of the TF angle and limb alignment would prevent unreasonable apprehension by parents and relatives as well as unnecessary diagnostic measurements such as repeated exposure to radiation and inappropriate application of orthotics or bracing which might hinder natural development [6].

Several methods have been used to measure the TF angle in children [3-6,8,10,12,14,19]. Although the radiographic methods are commonly used, they are time-consuming and have ethnical issues related to unnecessary radiation exposure in healthy children [4,12]. Further, a malrotation of the limb, if not taken care of, might lead to significant errors in the measurement of the TF angle [14,19]. Clinical methods of measuring the knee angles are acceptable and reproducible, with the advantage of being cheap and radiation-free [3,5,6,8,10].

Oginni *et al.* [2] stated that all of the previous studies regarding the measurement of the TF angle of walking children applied the measurements from the standing position. The authors reported that the supine position was only used for the children below 2 and 3 years due to either their normal developmental inability to stand or the difficulty to keep them in a stable standing position. However, Omololu *et al.* [15] found a non-significant difference between the mean values of the TF angle in supine and standing positions of the children aged from 1 to 10 years.

The development of the TF angle could be divided into three phases. First; the knee alignment changes from an infantile physiologic varus to maximum valgus, second; the valgus knee alignment decreases in amount and the third phase, during which the knee alignment remains stationary (the adult pattern of genu valgus) [4]. However, the age ranges at which these phases come in children varied in different ethnic groups [2,5,6,10,13].

In the present study, none of the subjects had a varus knee alignment. The development of the TF angle follows a valgus pattern that decreases with age increment from 2 to 12 years in normal Saudi children resident in Riyadh city. The data reveal a non significant difference between boys and girls regarding the development of the TF angle. Therefore, the results of the present study accepted the first hypothesis and rejected the second stated one.

The primary finding of this study was that the development of the TF angle in Saudi children was in valgus alignment, peaked of 9.46° at 3 to 4 years of age that decreased gradually to reach 3.47° at 11 to 12 years of age.

Even at the age of 2 years, the Saudi children showed valgus alignment. This was contrary to the findings of the largest study carried to date by Cheng *et al.* [5] who showed a mean varus TF angle at the age of 2 years in Chinese children.

The results of this study agree with Shopfner and Coin [20] who stated that in the normal development of the posture of the legs, there is varus phase to the age of 2 years and a valgus phase between 2 and 12 years.

Many studies [2-6,8,10,11,15,21-23] reported valgus position of the lower extremities during early and middle childhood periods (Table 5). They studied the different patterns of knee development for different ethnic groups. However, they differed from each other's and from the results of the present study in the age of maximum valgus alignment and the age at which the lower extremities became in the position seen in adults. These studies were performed on different cultures using different examination techniques.

Engel and Staheli [3] investigated the lower extremity axial alignment with respect to the midlongitudinal axis of the thigh and lower leg in normal Caucasian elementary school children, in pre-school children and in infants and neonates. They found that children of less than one year displayed genu varum averaging 5°, which was spontaneously corrected during the second year of life. However, they reported that the greatest mean values of genu valgum was 4.5° in girls and 4.7° in boys at 2 to 3 years of life with no significant differences regarding the gender.

Salenius and Vankka [4] revealed that during the second and third years; the TF angle is in marked valgus position of about 12° at the age of 3.6 years.

Table 5: Studies highlighting the variations of the tibiofemoral angle in healthy children of different ethnic groups

Title	Authors (year)	Number of Children	Age Range	Method of Measurement	Outcome
The development of the tibiofemoral angle in children	Salenius and Vankka (1975)	1,279 European children (Finland)	Newborn to 16 years	Roentgenographically and clinically from supine position for the newborn till less than 2 years and from standing position for the children from 2 to 16 years of age	Pronounced varus position was recorded before the age of 1 year, which changed into valgus between 18 months and 3 years of age. After that, the valgus corrected spontaneously to about 5–6 years. No gender variation was seen.
Angular and rotational profile of the lower limb in 2,630 Chinese children	Cheng *et al.*, (1991)	2,630 Chinese children	Newborn to 12 years	Clinical measurement with a goniometer from supine position for the newborn till less than 2 years and from standing position for the children from 2 to 12 years of age	Steady decrease in tibiofemoral angle from birth to minimum mean of 8° valgus at age of 3.5 years that reversed to reach plateau of 1° valgus at 8.5 years. No gender difference was reported.
Normal limits of knee angle in white children—genu varum and genu valgum	Heath and Staheli (1993)	196 White European children (Washington)	6 months to 11 years	Photography from supine position for the 6 months till less than 2 years of age and from standing position for the children from 2 to 11 years of age	Maximum bowleg was noted at an age of 6 months, which progressed towards neutral knee angles by the age of 18 months. The greatest mean knock knee of 8° was found at an average age 4 years, followed by a gradual decrease to a mean of 6° at 11 years of age
Development of the clinical tibiofemoral Angle in normal adolescents. A study of 427 normal subjects from 10 to 16 years of age	Cahuzac (1995)	427 European children (France)	10–16 years	Clinical measurement with a goniometer from standing position	Girls had a stable valgus angle from 10 years (5.6 1°) to 16 years of age (5.53°). No significant difference between boys and girls was reported until they were 14 years old. Boys after 14 years of age showed a gradual and significant decrease of the valgus angle to 4.41°. At 16 years old, boys were more bowlegged than girls.
Normal development of the tibiofemoral angle in children: A clinical study of 590 normal subjects from 3 to 17 years of age	Arazi *et al.*, (2001)	590 Turkish children	3–17 years	Clinical measurement with a goniometer from standing position	Children exhibited up to 11° physiologic valgus. Maximal mean valgus angle was 9.6° at 7 years of age for boys and 9.8° at 6 years of age for girls
Normal values of knee angle, intercondylar and intermalleolar distances in Nigerian children	Omololu *et al.*, (2003)	2,166 Nigerian children	1-10 years	Clinical measurement with a goniometer from supine position for children from 1 year to less than 2 years of age and from standing position for the children from 2 to 10 years of age	Bowlegs were recorded at ages 1-3 years that reduced to 0° at age of 5 years in girls and age of 7 years in boys. Both sexes had no bowing after age of 7 years. The valgus angle was found to be constant at about 11 degrees between ages 1-10 years in both sexes

Table 5: Continued

Title	Authors (year)	Number of Children	Age Range	Method of Measurement	Outcome
Knee angles and rickets in Nigerian children	Oginni *et al.*, (2004)	2,036 Nigerian children	Newborn to 12 years	Photography and direct measurement with a goniometer from standing position except for those less than 3 years where the supine position was used.	The majority of the knees were bowed in the first 6 months. At 21–23 months, the distribution of angles became strongly bimodal: about half being varus and half being valgus. After this, the knee angle was found to be valgus in most of the children
Development of tibiofemoral angle in Korean children	Yoo *et al.*, (2008)	452 Korean children	1-15 years	Radiography from standing position	Genu varum was found before 1 year of age, progressing to neutral at 1.5 years of age. This was followed by increasing genu valgum, with a maximum of 7.8° at 4 years, followed by a gradual decrease to approximately 5–6° of genu valgum of at 7–8 years of age
Normal development of the knee angle in healthy Indian children: a clinical study of 215 children	Saini *et al.*, (2010)	215 Indian children (136 boys and 79 girls)	2 to 15 years	Clinically from standing position	Physiological varus rarely persists beyond 2 years of age. A progressive increase in knee valgus occurs after 2 years of age, with peak knee valgus of 8° at 6 years of age. Thereafter, the valgus at the knee decreases and stabilizes to around 4–5° in most of the children after the age of 10 years. Girls show more valgus knees than boys

The valgus position corrected spontaneously in the following years to adopt the adult knee angle pattern at about the age of 5 to 6 years. The results of this study differ from the study of Salenius and Vankka [4] in the peak valgus value and the time of its occurrence.

Heath and Staheli [6] measured the TF angle to study its development in white children. They recorded maximum bowlegs at the age of 6 months and approximately neutral TF angles (0.0°) by the age of 18 months. They also recorded maximum knock-knees of 8° at 4 years of age, which was followed by a gradual decrease to a mean of <6° at 11 years of age. The authors stated that the existence of bowlegs after the age of 2 years is considered abnormal.

Yoo *et al.* [13] carried out a study on normal healthy Korean children, with full-length anteroposterior view standing radiography. They found that the patterns of the chronological changes in the TF angle were similar to those described previously but the TF angle development was delayed. There reported genu varum before the age of 1 year, neutral TF angle at the age of 1.5 years and a genu valgum with maximum value of 7.8° at the age of 4 years that was followed by a gradual decrease to 5–6° of genu valgum at 7–8 years of age.

When the TF angle was compared between boys and girls, the results revealed non-significant differences between them except at the ages 5 to 6 years at which girls had more knee valgus. These findings come in agreement with Cheng *et al.* [5], Engel and Staheli [3], Fakoor *et al.* [22], Heath and Staheli [6] and Qureshi *et al.* [11] who reported no significant differences in the development of the TF angle due to gender.

On the other hand, others reported significant differences in the development of the TF angle due to gender. Arazi *et al.* [10] reported significant differences between boys and girls in only three age periods (13, 14 and 16 years). Omololu *et al.* [15] found that Nigerian children had maximum bowing at ages 1 to 3 years which reduced to neutral or 0° at age of 5 years in girls and 7 years in boys. Oginni *et al.* [2] reported that the TF angle of girls was more valgus than boys by about 1° at ages from 8 to 12 years. Yoo *et al.* [13] found significant

differences between boys and girls at the age of 12 years. Most recently, Saini *et al.* [23] also reported that the Indian girls had statistically significant more knee valgus than boys.

Although the use of different techniques to estimate the TF angle might be responsible for variations in observations in different studies, it is more likely that these variations are possibly due to the ethnical and racial differences that might exist in different population groups. Oginni *et al.* [2] found a good correlation between the direct measurement using the goniometer and the photographic method attributing the variations in observations to the ethnicity.

Intraexaminer or interexaminer variability may be responsible for some error in the measurement, especially with the clinical method. Thus, we attempted to describe the normal development of the TF angle that could be used as a practical and accurate screening reference, thereby, influencing decisions regarding the necessity for further clinical and/or radiologic assessment in Saudi children. From the present study, we found that physiological varus does not persist beyond 2 years of age in Saudi children. We believe that a varus alignment of the knee in Saudi children after the age of 2 years might be atypical and needs detailed evaluation. The TF angle at the age of 2 years averages around 9° of valgus and is almost the same for both Saudi boys and girls. Thereafter, a progressive decrease in knee valgus occurs, with minimum knee valgus of 3° at 12 years of age.

Salenius and Vankka [4] reported on the cause of physiological bowlegs when children learn to walk. They hypothesized that children tend to hold their feet wide apart to increase their stability. This position probably produces pressure on the outer side of the knees and induces faster growth of the medial part of the epiphyseal plate, resulting in a valgus position of the tibia.

The results of this study revealed that there is a significant difference between boys and girls only at 5 to 6 years of age which may be due to a normal physiological developmental variation as reported by Sass and Hassan [24]. Nguyen and Shultz [25] stated that there are sex differences in lower extremity alignment in which females, on average, have greater anterior pelvic tilt, thigh internal rotation, knee valgus and genu recurvatum.

CONCLUSION

The development of the TF angle follows a linear pattern with a tendency toward physiological knock-knees that decreases with increasing age from 2 to 12 years in 300 typically developing Saudi children resident in Riyadh city. There were no significant gender differences except at 5 to 6 years of age during which time girls had a more knee valgus than boys.

Further research may be required with large number of subjects from various provinces in Saudi Arabia. Racial TF angle differences should be taken into account while performing the corrective osteotomies around the knee or total prosthetic knee replacement to get the optimum result with the Saudi children.

It is obvious now that the role of health education is very important in reassuring families about typical development of the TF angle therefore preventing the emotional and financial cost of unwarranted treatment.

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