Clinical Knee Alignment among Adolescents and Association with Body Mass Index: A Large Prevalence Study

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ABSTRACT:
Background: Children and adolescents are commonly referred to an orthopedic surgeon to assess knee malalignment.
Objectives: To assess the prevalence of genu varum and valgum among adolescents, and to identify correlates of these conditions.
Methods: A medical database of 47,588 candidates for military service presenting to the northern recruitment center during an 11 year period was analyzed to identify clinical knee alignment. Based on the standing skin surface intercondylar distance (ICD) or intermalleolar distance (IMD), the prevalence rates of genu varum (ICD ≥ 3 cm) and genu valgum (IMD ≥ 4 cm) were calculated. The association of gender, body mass index (BMI), and place of residence to knee alignment was studied.
Results: The rates of genu varum and valgum were 11.4% (5427) and 5.6% (2639), respectively. Genu varum was significantly more prevalent among males than females (16.2% vs. 4.4%, *P* < 0.001). It was also more prevalent among underweight subjects and less prevalent among overweight and obese subjects (*P* < 0.001). Genu valgum was significantly more prevalent among females than males (9.4% vs. 2.9%) and in overweight and obese subjects compared to those with normal BMI, while less prevalent in underweight subjects (*P* < 0.001). Multivariate analysis revealed that genu varum was independently positively associated with male gender, underweight, and living in a rural area. Genu valgum was independently positively associated with female gender, overweight, and obesity.
Conclusions: This study establishes a modern benchmark for the cutoff and prevalence of genu varum and valgum as well as associations with gender and BMI.

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KEY WORDS: genu varum (bow-leggedness), genu valgum (knock-knee), malalignment, body mass index (BMI), adolescents

Genu varum (also called bow-leggedness) and genu valgum (commonly called knock-knee) are angular knee deformities, in which the apex of the deformity points away from or toward the midline, respectively. Lower extremity alignment goes through a predictable progression from varum to valgum over the first 7 years of life and approaches 4 to 7 degrees of physiologic valgum alignment in children aged 5–18 years [1-4].

Knee alignment differences are influenced by gender and pubertal stage [1,3]. Females aged 10–16 years maintain a steady valgum alignment throughout puberty, while males have a slight varum evolution during the last 2 years of puberty. Lately, the effect of obesity on knee alignment has been examined on a pediatric population, and a greater valgum alignment was observed among obese adolescents in late puberty [5,6].

Lower extremity malalignment may cause musculoskeletal dysfunction, including abnormal joint loading and muscle imbalance [7]. Clinical genu valgum has been found to predict patellofemoral pain in military infantry recruits [8] and young adults [9]. Long-term follow-up over a 36 year period reported on children with physiologic genu varum and found that while two-thirds of those children showed no symptoms as adults, one-third reported mild knee pain, stiffness, or both [10]. In adults, malalignment may lead to an amplification of osteoarthritis [11,12].

Although knee malalignment is commonly encountered by primary care providers and constitutes a reason for referral to an orthopedic surgeon, little is known regarding the prevalence, risk factors, and clinical and functional significance of malalignment among adolescents. This study aimed to assess the prevalence of knee malalignment among adolescents and to identify socio-demographic factors and BMI groups associated with these conditions. In light of previous studies, although only fragmented and providing anecdotal evidence, we hypothesized that among basically healthy Israeli adolescents, genu valgum would be associated with female gender and above normal BMI. Associations of genu varum with gender and BMI have not yet been tested or obtained elsewhere.

PATIENTS AND METHODS

DATA SOURCE

Military service is compulsory in Israel, although various minorities are exempt, including religious women. Mandatory

Table 1. Prevalence of genu varum and genu valgum, stratified by severity level and by BMI categories (all *P* values ‹ 0.001)

		BMI category				
		Underweight 1,760	Normal 39,733	Overweight 4,285	Obesity 1,810	Total 47,588
Genu varum severity level*	0 (Normal)	81.93%	87.47%	97.53%	98.62%	88.60%
	1 (3 ≤ ICD > 5)	14.77%	11.10%	2.26%	1.27%	10.06%
	2 (5 ≤ ICD < 10)	3.01%	1.39%	0.21%	0%**	1.29%
	3 (10 ≤ ICD < 15)	0.28%	0.04%	0.00%	0.11%	0.05%
Genu valgum severity level	0 (Normal)	98.47%	96.65%	82.29%	71.16%	94.45%
	1 (4 ≤ IMD ≤ 8)	1.53%	3.19%	15.87%	21.10%	4.95%
	2 (8 < IMD < 12)	0%**	0.16%	1.80%	7.29%	0.57%
	3 (12 ≤ IMD ≤ 15)	0%**	0%**	0.05%	0.39%	0.02%
	4 (15 < IMD)	0%**	0%**	0%**	0.06%	0.002%

*Two additional severity levels were included in the study (4: 15 ≤ ICD ‹ 20; and 5: 20 ≤ ICD), yet no recruits were diagnosed with genu varum at these levels, therefore they were omitted from the table.
**No cases were observed
ICD = Intercondylar distance, IMD = Intermalleolar distance, BMI = body mass index

pre-induction medical examination for all recruits is conducted at regional recruitment centers. The recruits undergo a comprehensive medical interview and a physical examination by medical board physicians and are referred for further investigation as necessary. Based on the findings related to the various body systems, appropriate Functional Classification Codes (FCCs) are assigned. They are graded on a 1 to 7 scale, where "1" implies no impairment and "7" implies a permanent inability to perform military service. The FCC coding is similar to the International Classification of Diseases with an element of occupational medical ranking. Height, weight, and all FCCs are routinely stored in the main Israel Defense Force (IDF) database, which was the source of the data analyzed in this study [13,14]. The medical processes and data are routinely assessed and evaluated by diverse quality control and assurance means [13,15-18]. More detailed information on the medical process and database, as well as characteristics of the population, is reported elsewhere [19].

THE STUDY POPULATION

The study population included all northern district recruits examined at one recruitment center between the years 1987–1997, inclusive. To ensure a uniform medical baseline, we focused on conscripts who completed the medical profiling process at the age of 16 to 19 years. No selection criteria (inclusion or exclusion) were applied. Only the northern recruitment center was chosen, as for many years the medical examinations were performed by a small group of highly trained medical personnel, and consequently this center is characterized by the high quality of its medical processes [15,16]. The study was approved by the IDF's institutional review board, approval number 1199–2012, and was conducted in compliance with the Declaration of Helsinki.

DEFINITIONS

Height and weight were measured to the nearest 1 centimeter and 1 kilogram, respectively.

Knee alignment was measured using a clinical method similar to the methodology introduced by Cheng and colleagues [20]. With the subject standing facing the examiner, hips and knees in full extension, neutral rotation and the legs close together so that the knees or ankles touch each other, the distance between the skin over the medial femoral condyles (intercondylar distance [ICD] or the distance between the medial malleoli (intermalleolar distance [IMD]) were measured with a measuring tape to the nearest 1 cm and stated as positive values (Supplementary Scheme 1). Table 1 describes the FCCs assigned to recruits according to the IMD and ICD distance. ICD ≥ 3 cm was defined as genu varum and IMD ≥ 4 cm was defined as genu valgum based on earlier studies indicating the normal mean IMD–ICD reaches a steady state around 0 cm (range ± 3 cm) by the age of 8 years [1,20,21].

BMI categories were defined according to gender-related percentiles for 17 year olds [19] based on the U.S. Centers for Disease Control and Prevention criteria. The actual definitions were as follows: obesity: above the 95th percentile (> 28.2 kg/m² and > 29.6 kg/m² for males and females, respectively), overweight: 85th–95th percentiles (males: 25.0–28.2 kg/m² and females: 25.2–29.6 kg/m²), and underweight: below the 5th percentile (males: < 17.6 kg/m² and females: < 17.2 kg/m²) [19].

STATISTICAL ANALYSIS

All statistical analyses were executed with IBM SPSS, version 19 (SPSS Institute, Chicago, IL, USA). Descriptive analyses included means, standard deviations (SD), medians and ranges of continuous variables, and distributions of categorical variables. Differences of means were assessed using Student's *t*-test if the variable was normally distributed. Group differences in categorical variables were assessed using the chi-square or Fisher's exact test, where appropriate. Multiple logistic regression analysis was used to identify independent factors associated with genu varum and valgum. The independent variables included gender (female vs. male), BMI (underweight, overweight, and obese vs. normal), and place of residence (rural vs. urban).

RESULTS

THE STUDY POPULATION

The study population included 47,588 recruits, of them 28,386 (59.6%) were male. BMI distribution among the study population was as follows: 39,733 (83.5%) had a normal BMI, 1760 (3.7%) were underweight, 4285 (9.0%) were overweight and 1810 (3.8%) were obese.

THE PREVALENCE OF GENU VARUM AND VALGUM

The overall prevalence of genu varum among the study population was 11.4% (5427 subjects). Of them, 10.1% (4789 recruits),

1.3% (615 recruits), and 0.05% (23 recruits) were diagnosed with genu varum of severity level 1 ($3 \leq ICD \leq 5$), 2 ($5 \leq ICD < 10$), and 3 ($10 \leq ICD < 15$), respectively. No recruits were diagnosed with genu varum of higher severity levels (i.e., 4: $15 \leq ICD < 20$, and 5: $20 \leq ICD$). The prevalence of genu valgum was 5.5% (2639 subjects). Of them, 4.9% (2357 recruits), 0.6% (273 recruits), 0.02% (9 recruits), and 0.002% (1 recruit) were diagnosed with genu valgum of severity level 1 ($4 \leq IMD \leq 8$), 2 ($8 < IMD < 12$), 3 ($12 \leq IMD \leq 15$), and 4 ($15 < IMD$), respectively.

KNEE ALIGNMENT AND BMI

In both genders, as the BMI increased the prevalence of genu varum declined, whereas the prevalence of genu valgum grew [Figure 1]. In addition, at the lower range of BMI, the prevalence of genu varum was higher among males, whereas at the higher range of BMI the prevalence of genu valgum was higher among females.

Moreover, among underweight subjects (compared to normal BMI subjects) the prevalence of all severity levels of genu varum, and mainly the more severe conditions, was higher [Table 1]. Inversely, among overweight and even more considerably among obese subjects, the prevalence of all severity levels

Figure 1. Prevalence of genu varum and genu valgum in **[A]** males and **[B]** females stratified by body mass index

*A cutoff of minimum 50 subjects within each BMI strata was applied

of genu varum, and mainly the more severe conditions, was lower [Table 1]. The prevalence of genu varum severity levels by BMI categories stood as a mirror image to the prevalence of genu valgum severity levels.

Altogether, these findings indicated an inverse correlation between genu varum and BMI, as well as a positive correlation between genu valgum and BMI.

FACTORS ASSOCIATED WITH GENU VARUM AND VALGUM

Possible correlates between knee alignment conditions and socio-demographic variables were tested by univariate analysis.

Genu varum was significantly more prevalent among males compared to females (16.2% vs. 4.4%, respectively, $P < 0.001$). In contrast, genu valgum was significantly more prevalent among females compared to males (9.4% vs. 2.9%, respectively, $P < 0.001$).
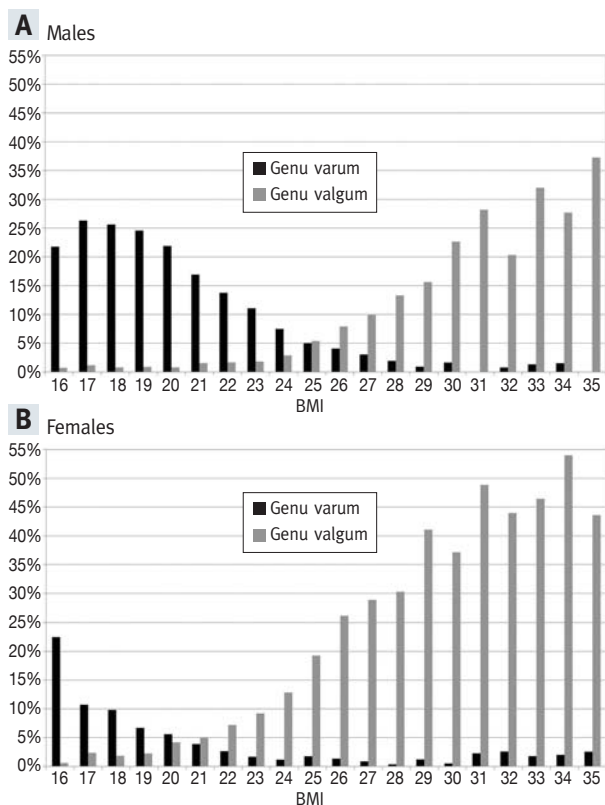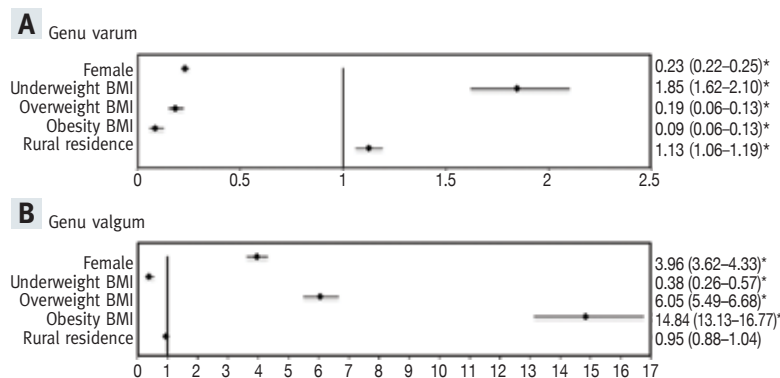
Genu varum was significantly ($P < 0.001$) more prevalent among underweight recruits (18.1%), and less prevalent among overweight (2.5%) and obese subjects (1.4%) compared to normal BMI subjects (12.5%). The mean height and weight of recruits with varum were 172.3 ± 7.6 cm and 59.9 ± 8.4 kg, which are significantly ($P < 0.001$) taller and lighter, respectively, compared to the 169.1 ± 8.7 cm and 72.7 ± 11.5 kg of recruits without varum.

Genu valgum was significantly ($P < 0.001$) more prevalent among both overweight (17.7%) and obese subjects (28.8%) and less prevalent among normal (3.4%) weight and underweight subjects (1.5%). The mean ($\pm$ SD) height and weight of recruits with genu valgum was 166.5 ± 8.6 cm and 70.4 ± 14.4 kg, which are significantly ($P < 0.001$) shorter and heavier, respectively, compared to the 169.6 ± 8.6 cm and 61.9 ± 10.8 kg of recruits with no valgum.

Genu varum was significantly ($P < 0.001$) more common among those living in rural areas (12.2%) compared to those living in urban areas (10.6%). In contrast, genu valgum was significantly ($P < 0.01$) more common among those living in urban areas (5.8%) compared to those living in rural areas (5.3%).

In the multiple logistic regression analysis genu varum was independently positively associated with male gender and with rural place of residence, positively associated with underweight, while negatively associated with overweight and obesity with a dose-response relationship [Figure 2]. Genu valgum was independently positively associated with female gender and increased BMI while place of residence did not remain a significant factor. A negative association was found with being underweight [Figure 2].

DISCUSSION

Little data are available regarding the risk factors for genu varum and valgum in healthy adolescents and their clinical relevance. Utilizing computerized medical records can enable researchers to describe epidemiological data based on large

Figure 2. Correlates of **[A]** genu varum and **[B]** valgum with socio-demographic variables in the multivariate logistic regression analysis, odds ratios and 95% confidence intervals are provided

A Genu varum

Female	0.23 (0.22–0.25)*
Underweight BMI	1.85 (1.62–2.10)*
Overweight BMI	0.19 (0.06–0.13)*
Obesity BMI	0.09 (0.06–0.13)*
Rural residence	1.13 (1.06–1.19)*

B Genu valgum

Female	3.96 (3.62–4.33)*
Underweight BMI	0.38 (0.26–0.57)*
Overweight BMI	6.05 (5.49–6.68)*
Obesity BMI	14.84 (13.13–16.77)*
Rural residence	0.95 (0.88–1.04)

*P value < 0.001, BMI = body mass index

populations previously not feasible, so long as the inherent limitations are recognized [22]. In the present study, we report the prevalence of genu varum and valgum in a large cohort of healthy adolescents.

Genu varum was positively associated with male gender, being underweight, and living in rural areas, and negatively associated with being overweight and obesity. In contrast, genu valgum was positively associated with female gender, being overweight and obesity, and negatively associated with being underweight.

We used the IMD and ICD as a clinical method to scan for malalignment. Earlier studies examining the IMD–ICD in pediatrics found it to reach a steady state by the age of 7–8 years [21]. Cheng and colleagues [20] studied the angular and rotational profile of the lower limbs in 2630 normal Chinese children from newborn to age 12 years using clinical measurements. The group was subdivided according to age, with 2500 children between ages 2–12. Within that group, the mean IMD–ICD reached a plateau of 0 cm by the age of 8 years with a normal range of ± 3 cm. The ICD and IMD were tightly correlated to the tibiofemoral angle. Cahuzac and colleagues [1] examined the ICD and IMD in 427 normal European children aged 10–16 years. The mean IMD–ICD at age 16 was 2 cm (IMD) in girls and 0.5 cm (ICD) in boys. Similar to these earlier studies, 83% of the general adolescent population had both ICD and IMD lower than 3 cm and 4 cm, respectively.

Based on these values, the prevalence rates of genu varum and genu valgum in the present study were 11.4% and 5.5%, respectively. These findings can serve as a reference for further studies regarding knee malalignment, as to the best of our knowledge, no previous studies referred to the normal distribution of IMD an ICD in the adolescent population. Of importance, we did not find any differences between the application of the clinical examination in our cohort of adolescents compared to these earlier studies on younger patients.

Taylor and colleagues [6] investigated the musculoskeletal consequences of pediatric overweight in a large pediatric cohort of children with a mean age of 11.8–12.6 years. They found a significantly higher prevalence of genu valgum among overweight compared to non-overweight children and adolescents. Bout-Tabaku et al. [5] examined the association between obesity and knee alignment in a cross-sectional study. They measured knee alignment using whole body dual-energy X-ray absorptiometry in 155 healthy weight and 165 obese subjects aged 10.5 ± 4.4 and 11.9 ± 3.3, respectively. They found significantly greater variability in knee alignment among females with higher BMI scores, and greater valgum alignment in obese adolescents in late puberty. Our cohort showed similar results in older adolescents. We strengthen these earlier studies by showing a direct relation and a dose response relationship between BMI categories and the prevalence of malalignment.

The interesting finding that rural living was associated with genu varum could be explained by the difference in life style in these areas [23,24]. Alternatively, it is possible that differences in population origin in rural and urban places of residence can be partly responsible for the observed differences. Rural and urban residences differ in their composition of population, in term of immigrants, ethnic groups, and so forth. Characterizing the genetic, environmental, and life style components related to this finding requires further investigation.

The main limitation of the present study is its cross-sectional design and the fact that alignment was based solely on a clinical examination. Nevertheless, we report on a large cohort of patients undergoing a fast, yet comprehensive and straightforward examination that can easily be performed anywhere in the world. The link between measurement tools, observations, and biomechanical explanations should also be considered. For example, weight gain may result in thickening of the fat layer of lower extremities, mainly around the hips and knees, and may lead to extension of the distance between hips (which may be classified as "pseudo" genu valgum). This in turn can also lead to increased distance between the ankles, and knee malalignment ("real" genu valgum). Properly differentiating between such "pseudo" and "real" malalignments, as described above, would require X-ray imaging, which could adequately determine the degree of genu varum and genu valgum, and provide further information of the validity and reliability of the clinical measurements. However, such imaging was not possible. Other modalities such as magnetic resonance imaging and Tc-MDP bone single photon emission computed tomography, are valuable in imaging knee injuries (although they differ in sensitivity, specificity, and accuracy in evaluating meniscal injuries, for example [25]); however, they were also not applicable for our purposes.

Clinical measurements have specific disadvantages; coronal malalignment may be accentuated by fat thighs, ligamentous laxity, and pes planus. In addition, our clinical examination did

not exclude any rotational abnormalities such as persistent femoral neck anteversion with compensatory external tibial torsion, which could make a genu valgum look more severe. Nevertheless, the associations are strong and were noted in various degrees of genu varum and valgum; therefore, it is plausible that these factors are not a sole reason that can explain those findings.

CONCLUSIONS

Altogether, this work adds to earlier studies showing the association between BMI and malalignment in a large cohort of late adolescence. We present the prevalence of malalignment and help standardize measurements of malalignment. Future cohort studies are necessary for the evaluation of the long-term clinical and functional significance of such malalignment.

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Supplementary Scheme 1. Schematic representation of knee alignment measurements. **[A]** genu varum, commonly known as "bow legs" or "O" legs. Clinical assessment is performed with the patient standing with the ankles touching, and measuring the distance between the most prominent skin over the medial femoral condyles. **[B]** genu valgum, commonly known as "knocked knees" or "X" knees. Standing with knees touching, the distance is measured between the skin over the medial malleoli

A Genu varum

B Genu valgum

Medial femoral condyle

Medial malleolus