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RESEARCH ARTICLE

Managing Genu Varum in Adolescents to Reduce Risks of Progression to Knee Osteoarthrosis

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ABSTRACT

Introduction: Genu varum is not uncommon in adolescents. Managing the condition to reduce its progression may decrease the prevalence of incident knee osteoarthrosis in adulthood. The present review examines studies on risk factors contributing to the progression of genu varum and associated with the degeneration of the medial tibiofemoral joint. We proposed approaches to decrease the magnitude of genu varum and external knee adduction moment, to reduce the incidence of knee osteoarthrosis in the aged population.

Methods and Materials: Literature searches were conducted in Pubmed, Embase, and Cochrane Systematic Reviews, using keywords individually and in combinations. We excluded papers on pathological genu varum, tibia vara, Blount disease, nutritional rickets, imaging, and surgery and included only articles on genu varum involving children and young adults. Reference lists of the included papers were also screened manually for additional references.

Results and Discussion: Search results showed that many children with physiologic genu varum are deficient or insufficient in vitamin D. High-impact exercises in late children and adolescents promote genu varum. In contrast, therapeutic exercises reduce the magnitude of genu varum in young adults with postural bowlegs. Lateral wedge insoles decrease the external knee adduction moment.

We proposed to check the serum vitamin D level of children and adolescents with genu varum. Growing children with genu varum should be advised to reduce the frequency of performing high-impact exercises. Adolescents with genu varum should strengthen the external hip rotators and use lateral wedged insoles.

Keywords: Genu varum, external knee adduction moment, medial tibiofemoral osteoarthrosis, vitamin D, lateral wedged insoles.

Introduction

Genu varum, defined as an intercondylar distance of more than 3 cm, is prevalent in adolescents and young adults.[1] A large epidemiology study in Israel of new military recruits showed that the rates of genu varum were 11.4%, with males having a higher prevalence than females.[1]

Many studies have shown that genu varum is a risk factor for tibiofemoral osteoarthrosis.[2] Genu varum shifts the weight-bearing line medially away from the knee joint centre and increases the external knee adduction moment (EKAM), which is a product of the ground reaction force and its distance from the centre of the knee (figure 1), resulting in an increase in load on the medial knee compartment,[2] contributing to medial tibiofemoral osteoarthrosis.

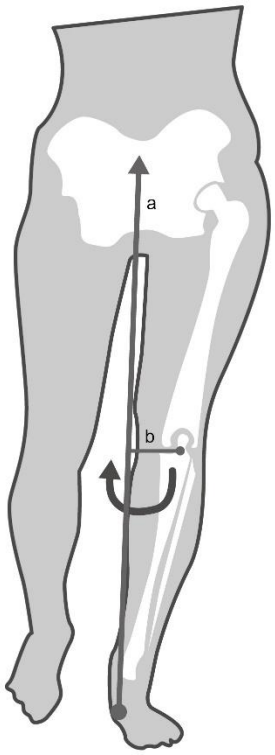

Figure 1: External knee adduction moment (EKAM) is the product of the ground reaction force (a) times the distance between the line of force and the centre of the knee joint (b), and is a measure of the varus deforming moment. The greater the genu varum, the greater the value of b, and thus the EKAM. Conversely, a decrease in genu varum reduces the b value and, therefore, the EKAM.

Knee osteoarthrosis (OA) can affect a single joint, two or even three compartments.[3] Of them, isolated medial tibiofemoral OA, isolated patellofemoral OA, and combined medial tibiofemoral and patellofemoral OA were reported to be more common than the tri-compartmental disease,[3] with isolated medial tibiofemoral OA having the highest prevalence afflicting 27% of OA subjects surveyed.[3] A study in Korea reported the prevalence of symptomatic knee OA and radiographic knee OA in patients aged 50 and over is 37.3% and 24.2%, respectively,[4] suggesting a high prevalence in the elderly patient population.

Treatment of isolated medial tibiofemoral osteoarthrosis generally involves non-steroidal anti-inflammatory drugs, physiotherapy, hyaluronate injection, nutritional supplements, and bracing.[4] The management approaches address the pain of the condition. Recently, biological therapies have been used.[6] The cell-based treatment options involving the bone marrow mesenchymal stem cells and autologous micro-fragmented adipose tissue containing stromal vascular fraction increase the cartilage quality in OA patients.[6] The methods, however, do not modify the clinical course of the disease. Knee OA has no cure; effective treatment generally involves total knee arthroplasty when the condition is symptomatic and at the end stage. The surgical treatment, however, has shortcomings. The prosthesis has a limited lifespan, rendering surgical intervention before age 65-70 not clinically indicated. Also, the functional outcome may be poor; the treatment poses a financial burden on the health system, which is between 1% and 2.5% of the gross domestic product in high-income countries.[7]

Preventive strategies as an alternative management approach should be considered. Genu varum and the related external knee adduction moment (EKAM) are independent medial tibiofemoral OA risk factors.[2] Genu varum shifts the weight-bearing line medially away from the knee joint centre and increases EKAM, resulting in an increase in load on the medial compartment of the knees.[2] Strategies to decrease genu varum and the EKAM in early life and adolescents may slow down the medial compartment knee degeneration rate and thus reduce the prevalence of incident knee OA in adults.

We reviewed the literature to identify the risk factors associated with atypical genu varum beyond two years and in adolescents, to identify methods to reduce the progression of genu varum and the magnitude of EKAM in children and adolescents, and thus to decrease incident tibiofemoral osteoarthrosis rates in later life.

Methods and Materials

We searched the Pubmed, Embase, and Cochrane Systematic Reviews databases for published studies up to 31 May 2023, using the following terms individually and in different combinations: "Genu varum," "Knee varum," "Bowlegs," "Adolescents," "Child/Children," "Sports," "Vitamin D," "Vitamin A" "Growth plates," "Epiphysis," "Osteoarthrosis," "Conservative treatment." Papers on pathological genu varum, tibia vara, nutritional rickets, imaging, and surgery were excluded. Other articles were then screened, and relevant articles were identified. Their reference lists were checked manually for additional references and again screened for relevancy. Finally, only studies on genu varum involving children and young adults were included in the present review.

Results and Discussion

A literature search showed a lack of studies on managing genu varum in children and adolescents. The lack of investigations is likely related to the benign nature of the condition in children and adolescents. Physiologic genu varum in children resolves spontaneously with no intervention, and genu varum in adolescents does not present with symptoms.

Yet, we have identified some risk factors related to the progression of genu varum. Managing these factors may reduce the progression of bowing of legs, which in turn may reduce the incident knee OA rates in adults, as genu varum is an independent risk factor of tibiofemoral osteoarthrosis.

The prevention approaches differ in patients with different age groups.

PHYSIOLOGIC GENU VARUM IN TODDLERS

Dettling et al. (2017) showed that children with marked physiologic genu varum usually ambulate earlier than the healthy controls. They generally walk at ten months instead of 12-15 months.[8] Thus, parents should be counselled not to allow their children with bow legs to bear weight earlier than they should; also walk-aids should be prohibited.

MANAGING PHYSIOLOGIC GENU VARUM IN CHILDREN AND ADOLESCENTS

Over 95% of the physiologic genu varum in children resolves before two years of age.[8] In a separate study, Lee et al. (2021) reported that 100% of the children had their genu varum resolved by the mean age of 3.2 years, despite excessive tibiofemoral angulation.[9] So, there is a difference in the timing of achieving knee neutrality for different patients. In a retrospective study, Dettling et al. (2018) showed that the age of varus angulation correction and resolution varies with the age of genu varum presentation.[8] Generally, varus angulation decreases and resolves 5 and 7.2 months after presentation.[8] Thus, children under two would preferably be followed-up six months after their presentation, and their parents be reassured that the condition would spontaneously resolve.

Recent studies have shown that physiologic genu varum in children may not be idiopathic. Instead, it may be a bone metabolic disease; children with the condition generally have higher serum alkaline phosphatase and lower serum vitamin D than the healthy controls.[10,11,12] Voloc et al. (2010) evaluated the prevalence of genu varum in 226 healthy children aged 7-16 years and assessed their vitamin D status.[10] Results showed that prepubertal children with serum 25(OH)D level ≤ 30nmol/L have higher alkaline phosphatase levels than those with normal serum vitamin D levels.[10] Thirty-six percent of the cohort with low serum vitamin D levels (≤ 30nmol/L) had lower limb deformities, suggesting that low vitamin D status possibly contributes to the genesis of the lower limb deformities.[10]

The study by Sakamoto et al. (2018) had similar findings. Children with uncorrected physiologic genu varum were found to have an increase in serum alkaline phosphatase.[11] Another study of toddlers aged 17-18 months by the same research group[12] showed that those with genu varum had a significantly lower serum 25(OH)D (24.8 ng/ml) as compared to the control subjects (33.6 ng/ml). Also, the frequency of vitamin D insufficiency/deficiency (<20 ng/ml) of the subjects with genu varum (39%) was significantly higher than that of the control (14%), suggesting physiologic genu varum may be a mineralization disorder.[12] The condition may be related to nutritional rickets and express different severity of a mineralization disorder.[12]

Thus, for children with a delay in knee varus resolution, we propose to assess the serum vitamin D level (Figure 2). For children with serum vitamin D <30 nmol/L, we suggest supplementing 400 IU vitamin D3 daily and following up 5-6 months later, measuring the serum 25[OH]D again. The supplementation should continue until serum 25[OH]D reaches the normal range. Yet, we are not aware of any study on the benefit of vitamin D supplements on physiologic genu varum, Tomasz et al. (2019) reported that supplementation of a high dose of vitamin D3 to toddlers and children aged 1 – 2.5 years with Blount disease together with weight-bearing abstinence for 2-3 months, improves the tibia vara.[13]

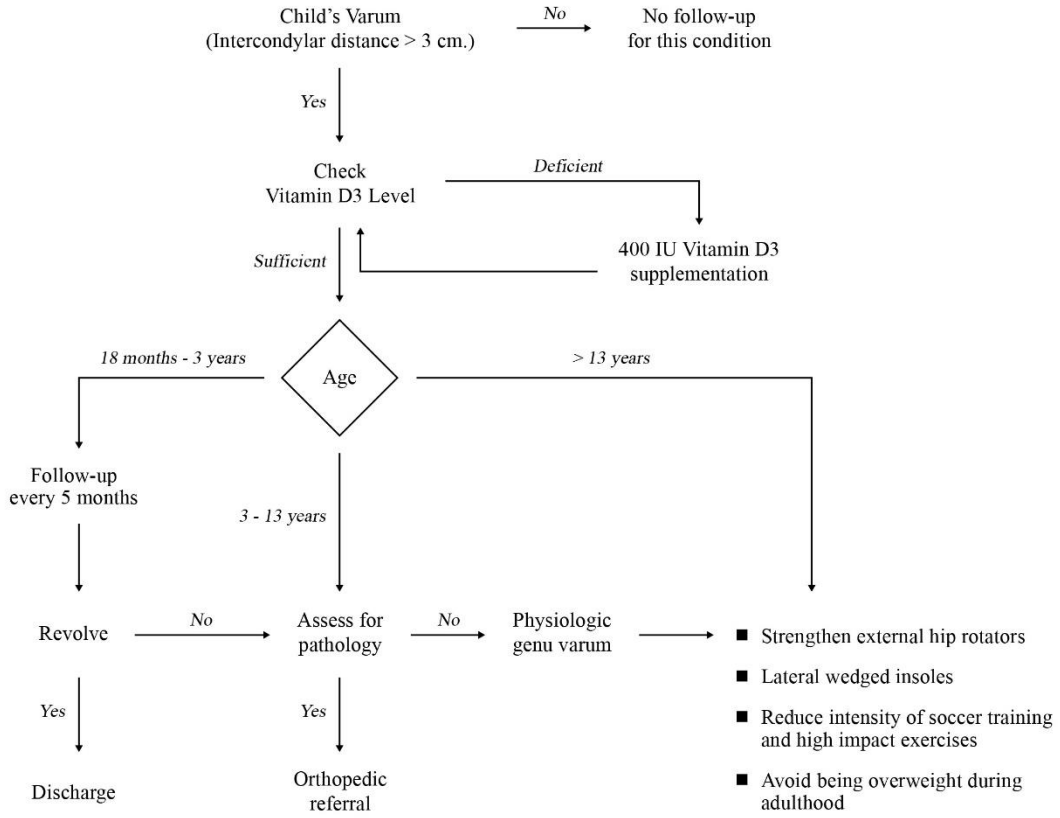

Figure 2: The proposed conservative management of genu varum in children and adolescents.

The Sakamoto et al. (2020) study reported that 61% of the toddlers with genu varum were vitamin D sufficient[12] but did not explain the relationship between vitamin D sufficiency and genu varum. We speculated that it may be related to the serum vitamin A level. Soeta et al. (1999) showed that a high vitamin A dose disturbed calcified cartilage matrix development within the epiphyseal growth plate in rats.[14] Kodaka et al. (1998) experimentally showed that the disappearance of growth plates in rats varies with the gradually increased vitamin A dosage.[15] The epiphyseal growth plate's focal disappearance appeared in the tibia's stressed proximal regions.[15] Rohde et al. (1999) evaluated the influence of vitamin A and vitamin D intake on the growth plate of rats.[16] They showed that by ingesting 258 ng of vitamin D2 daily, retinyl acetate supplementation significantly increased the epiphyseal plate width.[16] The results were more dramatic as vitamin D2 administration was diminished.[16] Johansson et al. (2001) showed similar findings in humans; they found that an intake of vitamin A corresponding to about one serving of liver antagonizes the rapid intestinal calcium response to physiological vitamin D levels.[17]

We cannot find any papers on the role of serum vitamin A in the pathology of genu varum in humans. Our proposal of evaluating serum vitamin A levels in patients with atypical genu varum and who are 25[OH]D sufficient is purely speculative. However, as high serum vitamin A has been shown to retard and even stop epiphyseal growth,[15,16] its role in genu varum may need exploring.

The literature search has also shown that high-impact sports activities[18] and intensive soccer participation[19] are associated with a significantly greater magnitude of genu varum in adolescents from 13 to 15. Yaniv et al. (2006) compared the knee alignment of child/adolescent soccer players with age-matched tennis players.[20] They found that the prevalence of knee varus is significantly higher among soccer players than among tennis players.[20] The difference in intercondylar distance was statistically significant after 13 years of age.[20] A retrospective cohort study by Witvrouw et al. (2009) yielded similar findings. They found that the soccer players had genu valgum until 12-13. When they are 14-15 years, the knees become varum. The changes similarly occurred in nonsoccer players, including those engaging in basketball, tennis, volleyball, and handball.[21] However, at 16-18, a significantly higher degree of genu varum was observed in the soccer players than nonsoccer players.[21] The authors concluded that intense soccer participation increases the degree of genu varum in males aged 16.[21] A similar study by the same group

showed that boys (from 7 to 18 years) who participated in high-impact sports had a significantly higher genu varum magnitude than their sedentary counterparts from 13 to 15 years of age, which corresponded to the growth spurt of the male adolescents.[18]

High-impact sports activities can promote genu varum in the prepubertal phase of rapid growth.[18,19] Adolescents should therefore be advised to reduce the frequency of participating in high-impact sports, including volleyball, basketball, tennis, and soccer (Figure 2), but to participate in leisure sports activities.

Intervention, including lower extremity exercises[22,23] and lateral wedged insole (LWI), has also been reported to reduce genu varum and EKAM in young adults. Strengthening the external hip rotators has been reported to reduce the magnitude of postural genu varum in young adults.[22,24] The lateral wedged insole also reduces the EKAM, which may or may not be clinically significant.[25]

The studies of the effect of exercises on the magnitude of genu varum were mainly from Korea. Seo et al. (2001) first proposed strengthening the external hip rotators to reduce the intercondylar distance in young adult female patients with postural bow legs.[22] In normal subjects, the patellae should be directed anteriorly. Flexion and extension of the knee should occur in the coronal plane. In the presence of lower extremity rotation, knee hyperextension would cause postural genu varum.[26] The lower extremity rotation alters the knee axis, which becomes oblique to the coronal plane. Knee flexion will occur in an anteromedial direction, and knee extension or hyperextension will be in a postero-lateral direction. As a result, there will be apparent bowing of the legs or postural genu varum when the knees hyperextend.[26]

Seo et al. (2001) attributed postural bowlegs to the sitting postures of the Koreans sitting on the floor with their legs crossed. Contractures of the iliofemoral and pubofemoral ligaments in the anterior hip joint induce internal hip rotation and contribute to the bow legs.[22] The hypothesis concurs with the findings by Mozafaripour et al. (2018), who showed that young subjects aged 18 to 26 with genu varum deformity have an internal hip and knee hyperextension rotation.[27]

Strengthening the external hip rotators using a device with calibrated resistance reduces the internal rotation of the femur. It decreases the coronal distance between the centre of the femoral head and that of the knee (Figure 3),[24] with a resultant reduction in EKAM. The strengthening exercises improve the postural bowlegs in three months.[27]

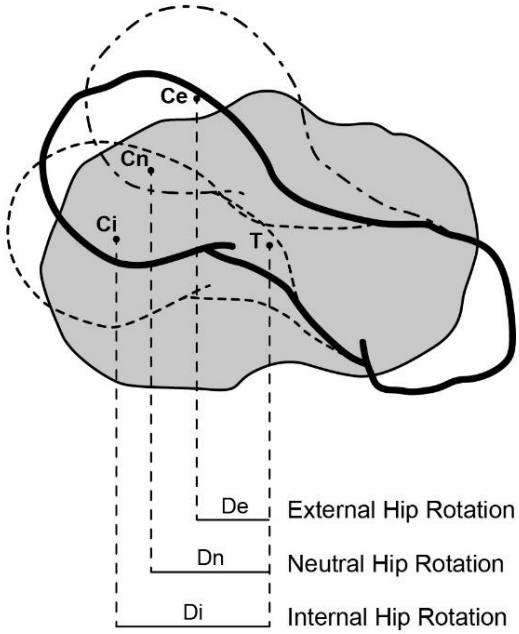

Figure 3: The influence of the external hip rotation on the hip adduction moment. T is the tibial eminence of the knee; here, it represents its centre. Cn is the centre of the femoral head when the hip is in a neutral position, with Ci and Ce representing the centres of the femoral head in internal and external rotation, respectively. The diagram shows that when the hip is in external rotation, the distance (De) between Ce and T reduces compared to Dn and Di, representing the distances between Cn and T and Ci and T, respectively. Thus external hip rotation reduces the knee adduction moment.

Similarly, Park et al. (2017) showed that strengthening the hip external rotators using a device that provides standardized resistance to external rotation of the lower extremities in a weight-bearing position reduces the intercondylar distance.[24] Twenty-five females (aged 15-61) with an intercondylar distance of more than 5 cm. exercised for 30 minutes daily during the weekday for three months. Results showed that the intercondylar distance between the knees reduced from a mean of 7.3 cm. pre-treatment to 5.7 cm post-intervention.[24] Also, the tibiofemoral angle improved from 5.2 degrees pre-intervention to 3.7 degrees after the exercises.[24]

Moon et al. (2023) similarly reported that neuromuscular training together with hip and knee strengthening exercises for three months reduced the intercondylar distance between the knees in middle age women with genu varum and knee pain,

from 6.48 cm before intervention to 5.47 cm post exercises.[28]
Han et al. (2018) and Lee et al. (2020) evaluated the influence of different exercises on the magnitude of genu varum. They used squatting as a therapeutic intervention. Han et al. (2018) compared the immediate and short-term effects of squatting with knees in proximity versus deep squats in patients with an intercondylar distance exceeding 5 cm.[29] They found that the former reduces the intercondylar space immediately after the exercises as opposed to deep squat exercises.[29] Lee et al. (2020) compared the effects of half squatting with a gym ball placed between the knees as opposed to squatting with knees apart the width of the shoulders. Similarly, they found that squat exercises using a gym ball between the knees can reduce the intercondylar distance after three sets of exercises three times a week for six weeks.[30]

Given most of the studies did not last more than three months, Park et al. (2017) cautioned that the improvement may regress when the exercises are stopped.[24] Patients are thus advised to continue the strengthening exercises as a maintenance regimen, three days a week, 15-30 minutes daily.[24]

The lateral wedged insole may also be of value in managing adolescent genu varum, though there were no studies on its effects on the progression of genu varum. There were studies, however, in using the lateral wedged insole to manage early and moderate medial tibiofemoral compartment osteoarthrosis.[31,32]

Lateral wedged insoles have been found to reduce external knee adduction moment (EKAM).[23] A 5° lateral wedged insole was reported to reduce the EKAM by 4-6%.[25,31] The insoles shift the foot's centre of force pressure (COFP) laterally, reduce the knee-ground reaction force lever arm, and thus reduce the EKAM.[25]

Chapman et al. (2015) and Sawada et al. (2016) showed that not all subjects had a reduction in EKAM when wearing the lateral wedged insoles. Sixty-seven percent of the subjects with decreased EKAM had a greater ankle/subtalar joint eversion moment.[25] Similarly, Sawada et al. (2016) showed that EKAM was reduced in subjects with normal feet but not those with supinated and pronated feet,[31] suggesting that lateral wedged insole is indicated only in patients with feet capable of eversion. A supinated foot cannot evert; a hyper-pronated foot cannot evert further. Thus LWI cannot shift the foot's centre of pressure laterally, rendering it ineffective in decreasing EKAM in these subjects.[31]

Despite the findings, the reduction of EKAM may only be temporary, lasting only six months.[33] Further, the decrease in EKAM may not be clinically meaningful.[33] However, it must be noted that the study targeted patients with mild early medial knee OA. The long-term effects of lateral wedged insole in EKAM and medial tibiofemoral degeneration are unknown.

Adolescents and young adults with genu varum and who are overweight should reduce their body weight. Obesity has been reported to influence longitudinal medial knee cartilage health negatively.[34] Increasing body weight increases the knee-ground reaction force, indirectly raising the EKAM and loading on the medial tibiofemoral joint.[35] Also, obesity is associated with low-grade inflammation.[36] Reducing obesity reduces the load on the medial tibiofemoral joint and may attenuate the low-grade inflammation related to joint degeneration.

A few studies have shown that patients with genu varum have a lowered BMI than healthy subjects and those with genu valgum.[1,37] Shohat et al. (2018) surveyed the genu varum and valgum prevalence in new military recruits. They reported that genu varum is significantly more prevalent among underweight recruits (18.1%) and less prevalent among overweight (2.5%) and obese subjects (1.4%).[1] The BMI of the underweight males and females was < 17.6 kg/m^2 and < 17.2 kg/m^2, respectively.[1] Similarly, Soheilipour et al. (2020) evaluated the relationship between BMI and knee angular deformities in subjects with a mean age of 41. They found that the patients with genu varum tended to have a lower BMI than those without knee varum and those with genu valgum.[37] though their subjects with genu varum were still obese with a BMI of 39 kg/m^2.[37]

Given the findings, adolescents with genu varum who are generally underweight should be counseled on the importance of maintaining proper body weight during adulthood. Increasing body weight would unnecessarily stress the medial tibiofemoral joint and promote low-grade inflammation.

The proposed management approaches have limitations. They are not evidence-based and have not been subjected to rigorous investigations. Long-term studies are required to see if the proposed methods reduce the progression of genu varum and decrease the magnitude of EKAM in adolescents and thus reduce the prevalence of incident knee osteoarthrosis in adults and elderlies.

Conclusion

Treatment of medial tibiofemoral OA is currently palliative. We proposed measures to reduce the risk of genu varum progression and decrease EKAM in early childhood and adolescents to slow down the degeneration of the medial knee joint.

We suggested supplementing vitamin D to children and adolescents who are deficient or insufficient. Also, patients should be educated on the importance of body weight and be advised to maintain proper body weight. They should be counseled to avoid engaging in high-impact exercises. In the presence of postural genu varum, they should regularly strengthen the external hip rotators. Patients with normal feet able to evert should be prescribed lateral wedged insole and replace laterally worn shoes regularly.

Conflict of Interest: The authors have no conflict of interest to declare.

Reference

1. Shohat N, Machluf Y, Farkash R et al. Clinical Knee Alignment among Adolescents and Association with Body Mass Index: A Large Prevalence Study. *Isr Med Assoc J*. 2018 Feb; 20(2):75-79.
2. Brouwer GM, Tol AWV, Bergink AP, et al.: Association between valgus and varus alignment and the development and progression of radiographic osteoarthritis of the knee. *Arthritis Rheum*. 2007; 56: 1204–11.
3. Stoddart JC, Dandridge O, Garner A et al. The compartmental distribution of knee osteoarthritis - a systematic review and meta-analysis. *Osteoarthritis Cartilage*. 2021 Apr; 29(4):445-455.
4. Kim I, Kim HA, Seo YI et al. The prevalence of knee osteoarthritis in elderly community residents in Korea. *J Korean Med Sci*. 2010 Feb; 25(2):293-8.
5. Lim WB, Al-Dadah O. Conservative treatment of knee osteoarthritis: A review of the literature. *World J Orthop*. 2022 18 March; 13(3):212-229.
6. Primorac D, Molnar V, Rod E et al. Knee Osteoarthritis: A Review of Pathogenesis and State-Of-The-Art Non-Operative Therapeutic Considerations. *Genes (Basel)*. 2020 Jul 26; 11(8):854.
7. GBD 2015 Disease and Injury Incidence and Prevalence Collaborators Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990–2015: A systematic analysis for the Global Burden of Disease Study 2015. *Lancet*. 2016, 388, 1545–1602.
8. Dettling S, Weiner DS. Management of bow legs in children: A primary care protocol. *J Fam Pract*. 2017 May; 66(5):E1-E6.
9. Lee S, Song KS, Lee KJ et al. Natural course of excessive genu varum without underlying pathology in children. *Surg Rehab*. 2021; 5:1-3
10. Voloc A, Esterle L, Nguyen TM et al. High prevalence of genu varum/valgum in European children with low vitamin D status and insufficient dairy products/calcium intakes. *Eur J Endocrinol*. 2010 Nov;163(5):811-7.
11. Sakamoto Y, Ishijima M, Kinoshita M et al. Association between leg bowing and serum alkaline phosphatase level regardless of the presence of a radiographic growth plate abnormality in pediatric patients with genu varum. *J Bone Miner Metab*. 2018 Jul; 36(4):447-453.
12. Sakamoto Y, Ishijima M, Nakano S et al. Physiologic leg bowing is not a physiologic condition but instead is associated with vitamin D disorders in toddlers. *Calcif Tissue Int*. 2020 Feb; 106(2):95-103.
13. Tomasz, K., Jacek, K. and Marian, D. "Syndrome of contractures" according to Prof. Hans Mau; Problems of shanks, knees, hips, pelvis and spine; children, adolescents, adults, diagnosis, treatment. *Surgical Science*. 2019; 10, 24-38
14. Soeta S, Mori R, Kodaka T et al. Histological disorders related to the focal disappearance of the epiphyseal growth plate in rats induced by high dose of vitamin A. *J Vet Med Sci*. 2000 Mar; 62(3):293-9.
15. Kodaka T, Takaki H, Soeta S et al. Local disappearance of epiphyseal growth plates in rats with hypervitaminosis A. *J Vet Med Sci*. 1998 Jul; 60(7):815-21.
16. Rohde CM, Manatt M, Clagett-Dame M et al. Vitamin A antagonizes the action of vitamin D in rats. *J Nutr*. 1999 Dec; 129(12):2246-50.
17. Johansson S, Melhus H. Vitamin A antagonizes calcium response to vitamin D in man. *J Bone Miner Res*. 2001 Oct; 16(10):1899-905.
18. Thijs Y, Bellemans J, Rombaut L et al. Is high-impact sports participation associated with bowlegs in adolescent boys? *Med Sci Sports Exerc*. 2012 Jun; 44(6):993-8.
19. Thaller PH, Fürmetz J, Chen F et al. Bowlegs and intensive football training in children and adolescents. *Dtsch Arztebl Int*. 2018 Jun 15; 115(24):401-408.
20. Yaniv M, Becker T, Goldwirt M et al. Prevalence of bowlegs among child and adolescent soccer players. *Clin J Sport Med*. 2006; 16:392–6.
21. Witvrouw E, Danneels L, Thijs Y et al. Does soccer participation lead to genu varum? *Knee Surg Sports Traumatol Arthrosc*. 2009 Apr; 17(4):422-7.
22. Seo KB, Lee ES, Park YK. Non-operative treatment of adult genu varum: a report of two cases. In: Abstract book from the first world congress of the international society of physical and rehabilitation medicine (ISPRM), Amsterdam, 7–13 July 2001
23. Huang XM, Yuan FZ, Chen YR et al. Physical therapy and orthopaedic equipment-induced reduction in the biomechanical risk factors related to knee osteoarthritis: a systematic review and Bayesian network meta-analysis of randomised controlled trials. *BMJ Open*. 2022 Feb 9;12(2):e051608.
24. Park SH, Lee JW, Kim JH et al. Effectiveness of hip external rotator strengthening exercise in Korean postural bowleg women. *Aesthetic Plast Surg*. 2017 Aug;41(4):887-892.
25. Chapman GJ, Parkes MJ, Forsythe L et al. Ankle motion influences the external knee adduction moment and may predict who will respond to

lateral wedge insoles?: an ancillary analysis from the SILK trial. *Osteoarthritis Cartilage*. 2015 Aug; 23(8):1316-22.

26. Maurisseau, Nerline Varda. A comparative analysis of walking patterns between genu varum and normal subjects. *Western Michigan University Master's Theses*. 2000; 4572
27. Mozafaripour E, Rajabi R, Minoonejad H. Anatomical alignment of lower extremity in subjects with genu valgum and genu varum deformities. *Phys Treatment J*. 2018; 8(1):27-36.
28. Moon HH, Seo YG, Kim WM et al. Effect of combined exercise program on lower extremity alignment and knee pain in patients with genu varum. *Healthcare*. 2023; 11:122.
29. Han SK, Kim TH, Rho JS et al. The immediately effect of narrow squats on the knee joint biomechanics during a gait and distance between the knees of person with genu-varum. *Phys. Ther. Korea*. 2018; 25(3): 19-26.
30. Lee K, Han J, Bae Wonsik. Effects of squat exercise using balls on the gap interval between knees, q-angle, muscle activity in women with genu-varum. *J Korean Society of Integrative Medicine*. 2020; 8(2), 97~107.
31. Sawada T, Tokuda K, Tanimoto K et al. Foot alignments influence the effect of knee adduction moment with lateral wedge insoles during gait. *Gait Posture*. 2016 Sep; 49:451-456.
32. Ferreira V, Simões R, Gonçalves RS et al. The optimal degree of lateral wedge insoles for reducing knee joint load: a systematic review and meta-analysis. Arch Physiother. 2019 Dec; 19;9:18.
33. Duivenvoorden T, van Raaij TM, Horemans HL et al. Do laterally wedged insoles or valgus braces unload the medial compartment of the knee in patients with osteoarthritis? *Clin Orthop Relat Res*. 2015 Jan; 473(1):265-74.
34. Sinclair J, Lynch H, Chockalingam N. Effects of obesity on medial tibiofemoral cartilage mechanics in females—an exploration using musculoskeletal simulation and probabilistic cartilage failure modelling. *Life*. 2023; 13, 270.
35. Sharma L, Lou C, Cahue S et al. The mechanism of the effect of obesity in knee osteoarthritis: The mediating role of malalignment. *Arthritis Rheum. Off. J. Am. Coll. Rheumatol*. 2000; 43, 568–575.
36. Dell'Isola A, Allan R, Smith SL et al. Identification of clinical phenotypes in knee osteoarthritis: A systematic review of the literature. *BMC Musculoskelet. Disord*. 2016; 17, 425.
37. Soheilipour F, Pazouki A, Mazaherinezhad A et al. The prevalence of genu varum and genu valgum in overweight and obese patients: assessing the relationship between body mass index and knee angular deformities. *Acta Biomed*. 2020 Oct 5; 91(4):ahead of print.