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Normal lower limb variants in children

Andrea Yeo, Kyle James, Manoj Ramachandran

The Royal London & Barts and The London Children's Hospitals, Barts Health NHS Trust, London E1 1BB, UK
Correspondence to: A Yeo
andreayeo@doctors.org.uk

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Bow legs, knock knees, flat feet, intoeing, and out-toeing gaits in children are common but often cause undue parental anxiety, prompting frequent visits to general practice.[1-5] A substantial proportion of referrals to paediatric orthopaedic clinics consist of normal physiological variants in growing children. Our review aims to assist general clinicians in recognising normal physiological variants in the lower limbs of children and to identify abnormal features that require specialist attention.

Why are normal limb variants important?

Musculoskeletal symptoms are one of the leading causes of visits to primary care doctors and such visits are on the increase.[1] One in eight children each year visits a doctor for a musculoskeletal disorder.[2] Normal variants form an important proportion of secondary care referrals. Many parents seek medical attention for the appearance of their child's lower limbs, or with concerns that their child's condition may lead to degenerative musculoskeletal problems or a reduction in their sporting ability.[5] In most cases the problem is a variation of normal development, which follows a benign and predictable course.[6-8] Rarely does the problem persist into adolescence or require treatment.

A Cochrane review of interventions to improve outpatient referrals from primary to secondary care suggested that passive dissemination of referral guidelines was ineffective.[13] An effective strategy may be to combine educational activities championed by consultant specialists (in this case, paediatric orthopaedic surgeons or rheumatologists) in combination with structured referral guidelines.[13]

SOURCES AND SELECTION CRITERIA

We searched PubMed and Google Scholar using the terms "p(a)ediatric", "lower limb variants", "intoeing", "out-toeing", "pes planus", "flat foot", "genu varum", "genu valgum", "vitamin D deficiency", "obesity", and "sporting activity". The search was conducted from inception of databases to March 2015. Wherever possible we used evidence from randomised controlled trials, systematic reviews (including Cochrane reviews), and expert review articles published in the past 10 years. Current relevant Department of Health policies were also included.

Normal variants and abnormal conditions according to age

Normal variants	Conditions
Newborn to toddler:	
Out-toeing	Developmental dysplasia of the hip; neuromuscular (for example, myelodysplasia, poliomyelitis)
Intoeing—metatarsus adductus with or without internal tibial torsion	Congenital talipes equinovarus (clubfoot); neuromuscular (for example, cerebral palsy)
Flexible flat foot	Rigid flat foot—congenital vertical talus
Genu varum (bow legs)	Infantile Blount's disease
Preschool age (2-4 years):	
Intoeing—internal tibial torsion with or without metatarsus adductus	
Genu valgum	Fracture (for example, consequence of proximal tibia metaphyseal fracture, also known as Cozen's fracture); genu varum—infantile Blount's disease
School age (4-10 years):	
Intoeing—femoral anteversion with or without internal tibial torsion	Perthes' disease (can present as intoeing or out-toeing)
Genu valgum	Cozen's fracture
Intoeing—residual femoral anteversion with or without internal tibial torsion	
Out-toeing—lateral tibial torsion; femoral retroversion	Slipped capital femoral epiphysis; genu varum—adolescent Blount's disease
Flexible flat foot	Rigid flat foot: tarsal coalition

In all age groups, other differential causes should be considered, such as vitamin D deficiency (rickets) and obesity, which can cause both genu valgum and genu varum.

THE BOTTOM LINE

- Musculoskeletal symptoms are one of the leading reasons for visits to general practitioners, with over 10% of children presenting for medical attention each year
- Common reasons for referral include intoeing, flat feet, knock knees, and bow legs—all normal variants in growing children
- Additionally, vitamin D deficiency and obesity in children are on the increase, with well documented associations with musculoskeletal disorders ranging from chronic conditions such as rickets with resultant bow legs or knock knees, to more acute conditions such as slipped capital femoral epiphysis
- Recognising developmental norms and differentiating them from disease may help allay parental anxiety, ease referrals to primary and secondary care, and prompt appropriate timely referrals for abnormal conditions

How are normal variants assessed?

It is crucial to elucidate the reason for consultation and identify parental concerns—for example, pain, long term disability, cosmesis, awkward walking or running, frequent trips or falls. Occasionally, rotational or angular malalignment are the presenting symptoms of underlying disorders (table); for example, children with mild spastic hemiparesis (cerebral palsy) may present with unilateral intoeing.

To manage the problem effectively, it is essential to determine the level of the deformity, as it may occur anywhere between the foot and the hip. Two or more deformities may be additive or compensate for each other. Examination of children's rotational and angular profiles should therefore proceed in a sequential fashion (box 1).

What are the different normal variants seen in clinical practice?

Lower limb variants can be broadly divided into rotational (intoeing and out-toeing gait) and angular (genu valgum and genu varum) deformities.

Rotational deformities

The child's rotational profile is a composite of measurements of the lower limbs—that is, rotational range of the hips and rotational alignment of the tibia and foot. The most obvious manifestation is the position of the feet—commonly referred to as "intoeing" or "out-toeing." Figure 1 on thebmj.com shows the normal range of rotational motion.

Box 1 | Musculoskeletal examination of a typical child

- Weight
- Height

Rotational profile (especially if a child has an intoeing or out-toeing gait)

- Observe gait and foot-progression angle (angle the axis of the child's foot makes with the direction in which he or she is walking)
- Observe child standing (squinting patella of femoral anteversion; flat foot), sitting ("W" position), running (running accentuates the problem), and lying down
- Shape of foot (heel bisector line—normal between second and third toes)
- Tibial rotation (thigh-foot angle)—prone position with knees flexed to 90° and measure the angle the foot makes with the thigh
- Femoral rotation—prone position with knees flexed to 90°; hip rotation is generally symmetrical in internal and external rotation
- Hypermobility (Beighton score)

Angular profile (especially in the presence of knocked knees or bow legs)

- Distance between knees while standing and lying with the ankles together (normal intercondylar distance <6 cm)
- Distance between ankles while standing and lying with the knees together (normal intermalleolar distance <8 cm)

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- Dementia: timely diagnosis and early intervention (*BMJ* 2015;350:h3029)
- Sepsis in children (*BMJ* 2015;350:h3017)
- The diagnosis and management of hypocalcaemia (*BMJ* 2015;350:h2723)
- Management of the unstable shoulder (*BMJ* 2015;350:h2537)
- Childhood attention-deficit/hyperactivity disorder (*BMJ* 2015;350:h2168)

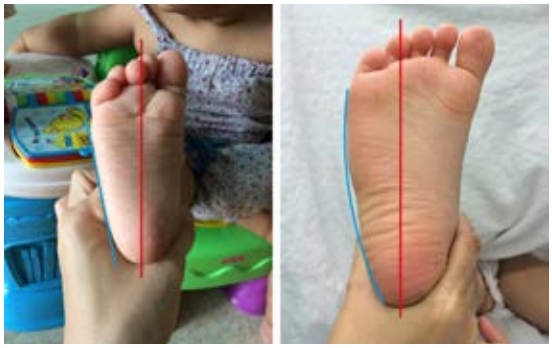

Fig 2 | Vertical line (heel bisector line) drawn through centre of heel. The severity of deformity is determined by where this line meets the forefoot. (Left) Normal foot morphology in child, with heel bisector line crossing second webspace (between second and third toes; red line) and straight lateral border of foot (blue line). (Right) Child with moderate metatarsus adductus, with heel bisector line crossing third webspace (between third and fourth toes; red line), and a curved lateral border of foot (blue line)

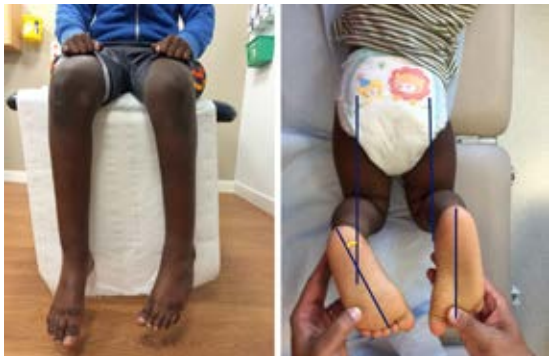

Fig 3 | (Left) Both patellas point forwards (neutral position), but left foot turns inwards suggesting internal tibial torsion. Right foot rests in normal slightly externally rotated position. Left leg is smaller overall as a result of congenital talipes equinovarus (clubfoot), which was successfully treated in infancy. (Right) Toddler in prone position with knees at 90°, axes drawn through thigh and foot show an increased thigh-foot angle on left, indicating internal tibial torsion; compare this with parallel axes on right

Intoeing gait ("pigeon-toed" gait)

There are three main causes of an intoeing gait: metatarsus adductus, internal tibial torsion, and increased femoral anteversion.

Metatarsus adductus

Metatarsus adductus is the most common congenital foot deformity, occurring in 1 in 1000 births.[14] It is defined as an internal angulation of the forefoot (or metatarsals) on a neutral or flexible hindfoot. Clinically, the foot has a curved border and an abnormal heel bisector line (fig 2).[15] In a study of 379 children with metatarsus adductus, nearly 90% required no treatment.[16] No study has proved the effectiveness of passive stretching or corrective shoes for the flexible, benign forms; therefore, these may be allowed to resolve naturally.[15 16] For the rigid type, and cases that do not resolve by age 6-9 months, serial casting may be of value.[14]

Internal tibial torsion

Internal tibial torsion is the most common cause of intoeing.[14] It is defined by the angular difference between the transmalleolar axis of the ankle and the bicondylar axis of the knee. Clinically, the feet are internally rotated while the patella remains in neutral position (fig 3). Internal tibial torsion is most apparent when infants first begin to walk, and parents may mention that their child trips frequently and appears clumsy. The condition affects both sexes equally, is bilateral in two thirds of affected infants, and is associated with metatarsus adductus in about one third.[14] Varus at the knee, either physiological or disease related (such as in Blount's disease), is often associated with internal tibial torsion.

The clinical course is of spontaneous resolution—the transmalleolar axis rotates laterally from 2-4° at birth to 10-20° in adulthood.[7] Resolution is most rapid in infancy. Treatment with orthotic devices is unnecessary and ineffective.[14] In severe cases that cause functional disability, such as frequent trips and falls, tibial rotational osteotomy may be considered in older children (>10 years).[14]

Femoral anteversion

Femoral anteversion is defined as the angular difference between the axis of the femoral neck and the transcondylar axis of the knee. The natural femoral anteversion has been well documented in a 20 year follow-up study of 1148 hips.[19] On average, femoral anteversion is 40° at birth, decreasing throughout growth to 16° in adulthood.[19]

Femoral anteversion is most pronounced between 4 and 6 years of age. It is twice as common in girls and is nearly always symmetrical. It is also often familial. Children sit with their limbs in the "W" position (fig 4), walk with an intoeing gait with the patella pointing inwards ("squinting patella"), and run in an awkward pattern ("eggbeater" pattern, with inward rotation of the thighs and outward rotation of the legs and feet). Intoeing typically becomes more pronounced when children are tired. Tripping as a result of crossing feet may occur.

Femoral anteversion spontaneously resolves in more than 80% of affected children by late childhood.[9 14]

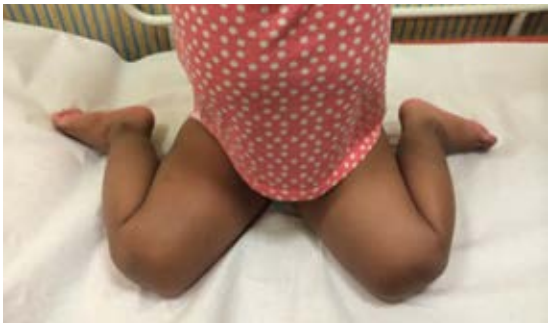

Fig 4 | Two year old sitting in "W" position, typical of femoral anteversion

Various orthotics have been used in the past but none have shown efficacy.[19] In the rare adolescent who has major cosmetic deformity secondary to anteversion, rotational osteotomy of the femur may be considered, although the rate of complications is high.[22]

Out-toeing gait

In early infancy out-toeing is normal and usually resolves by 18-24 months of age.[14] Out-toeing in older children is usually due to external tibial torsion and occasionally femoral retroversion; the latter is more commonly seen in obese adolescents. However, more serious conditions such as Perthes' disease and slipped capital femoral epiphysis should always be considered in older children, especially if unilateral.

At birth, calcaneovalgus may present as out-toeing, with the foot being able to dorsiflex nearly to the shin. This condition may be confused with congenital vertical talus, and a lateral radiograph of the plantar flexed foot usually differentiates the two conditions (fig 5). Calcaneovalgus generally responds quickly to passive plantar flexion stretching exercises, whereas congenital vertical talus typically requires serial casting or surgical correction.

External tibial torsion can cause disability—for example, increased prevalence of patellofemoral instability and patellofemoral pain.[14] It is also thought to develop in compensation for femoral anteversion, which may lead to the "miserable malalignment syndrome."

Flexible pes planus (flat feet)

The foot is the most common region prompting medical attention for musculoskeletal problems in children,[24] with 90% of concerns related to flat feet.[25] The prevalence of flat feet inversely correlates with age—about 45% in children aged 3-6 years,[26] decreasing to 2-16% in older children.[26 27]

Neonates and toddlers universally have "flat feet" owing to the presence of a fat pad beneath the medial longitudinal arch. Additionally, intrinsic laxity and the lack of neuromuscular control in children starting to mobilise result in flattening of the foot when weight bearing.[6 26] This typically resolves between the ages of 4 and 8 years.[25 26]

Clinically, the heel is in valgus, with sagging of the medial arch (fig 6). A careful assessment should be made to differentiate a flexible flat foot from a rigid one, with the latter encompassing <1% of children,[28] which is usually painful and caused either by tarsal coalitions (presentation is typically in adolescence), congenital vertical talus, or inflammatory disorders (pes planus is a common feature of juvenile idiopathic arthritis).[29] The medial arch of a flexible flat foot reconstitutes on tiptoeing (fig 6) or when the foot is dependent. Children rarely have symptoms, with parental concern mainly related to cosmesis or the misconstrued belief that the condition could lead to pain or functional problems in later life.[29] Risk factors include hyperlaxity, obesity, and a positive family history. Examination may reveal the flat foot to be severe and causing the shoe to become deformed.

Most flexible flat feet are physiological, asymptomatic, and require no treatment, although other neurological (cerebral palsy), muscular (muscular dystrophy), syndromic (trisomy 21), or connective tissue (Marfan's and Ehlers-Danlos syndromes) disorders should be actively sought. Some cases of flexible flat feet may be painful, with more specific problems after activity.

The treatment of paediatric flat foot has been controversial and debate is still ongoing with no current ideal intervention.[23] Historically, various devices (for example, high top shoes) were used to correct and prevent such deformities.[14] The consensus now is that the asymptomatic flexible flat foot is benign.

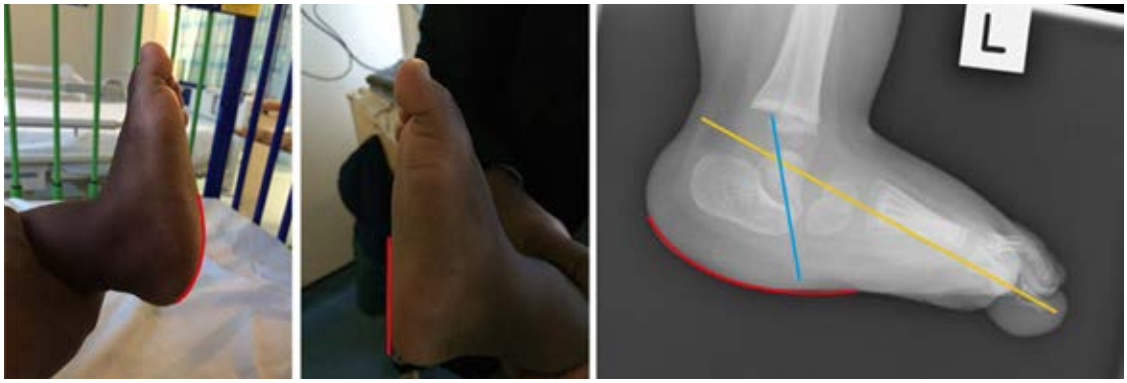

Fig 5 | Congenital vertical talus may be clinically confused with calcaneovalgus deformity or severe flat feet. (Upper left) Rockerbottom deformity of sole of left foot (curved red outline); whereas right foot (upper right) is normal, with straight outline of sole. Radiograph of child's left foot (bottom) shows talus (blue line) to be in vertical position when it typically should be in line with first metatarsal/big toe (yellow line)—angle formed between these two lines is known as Meary's angle. Note curved soft tissue outline of sole of foot as a result (red line). This condition warrants specialist referral

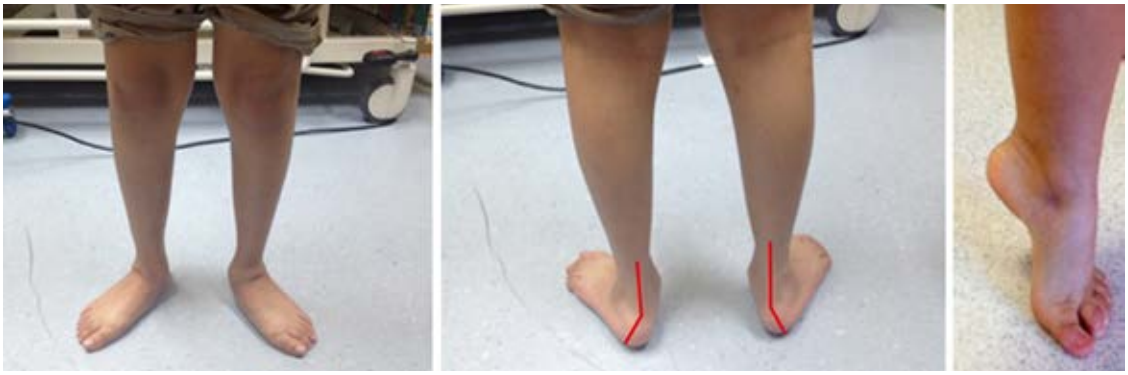

Fig 6 | Child with bilateral flexible flat feet and fallen medial arches, hyperpronation of foot (left) and valgus heels (middle, red line showing outward tilting of both heels) with "too many toes" sign. However, on tiptoe, the medial arch reforms (right)

Treatment is mainly directed towards symptoms of pain and severity of the deformity. A Cochrane review of non-surgical treatment for paediatric flat feet showed a general lack of good quality trials but suggested that bespoke orthoses may improve pain and function in children with juvenile idiopathic arthritis and flat feet; however, in otherwise normal, asymptomatic children, there is no evidence for the efficacy of foot orthoses or any other non-surgical intervention.[24] In children with symptoms, expert opinion favours the use of a well moulded insole, which does not correct the flat foot but alleviates pain and prevents shoe deformation.[24 30]

Angular deformities

Angular alignment refers to the tibiofemoral angle, which can be clinically assessed by the intermalleolar and intercondylar distances (fig 7). Angular deformities (for example, genu varum and genu valgum) tend to be symmetrical and cause no pain. Clinical examination should focus on excluding rotational abnormalities and ligamentous laxity as these can exaggerate the appearance of angular deformities.[31]

Disease should be considered in cases where the deformity is unilateral, asymmetrical, severe, progressive, or accompanied by short stature. Genu varum in children aged more than 3 years or genu valgum in children aged less than 2 years should also raise concern and warrant specialist referral for further investigation, where typically long leg alignment radiographs are taken (fig 8). Box 2 lists the possible causes of both conditions.

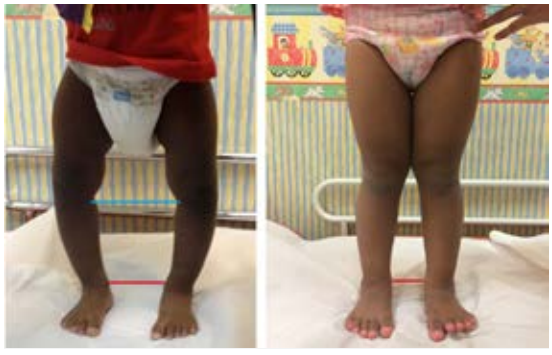

Fig 7 | (Left) Infant with bilateral physiological genu varum (bow legs)—gap between the knees (intercondylar distance, blue line, normal <6 cm) is wider than gap between the ankles (intermalleolar distance, red line). (Right) Older child with genu valgum (knock knees)—there is an appreciable gap between the ankles (red line, normal intermalleolar distance <8 cm) when the knees are together

Genu varum (bow legs)

Physiological genu varum is thought to relate to intrauterine positioning, which leads to the contracture of the medial knee joint capsule.[31] This, in addition to the internal tibial torsion common in this age group, accentuates the deformity when children weight bear. Therefore, referrals for bow legs are common for children aged between 10 and 14 months, the average age at which children start to stand and ambulate. The intercondylar distance is measured with the medial malleoli in contact and should be less than 6 cm.[34]

Some studies suggest that participation in high impact sport may predispose to knee varus.[35-38] It is, however, not clear if the demands for intensive practice on the growing skeleton lead to the varus axis, or that knee varus confers some advantage resulting in natural selection of such individuals.[36] This has important clinical implications as such angular deformities of the knee are associated with

Box 2 | Causes of genu varum and genu valgum

Genu varum

- Blount's disease
- Metabolic (for example, rickets, renal osteodystrophy)
- Post-traumatic
- Post-infection (for example, osteomyelitis)
- Skeletal dysplasias (for example, achondroplasia, osteogenesis imperfecta, metaphyseal chondrodysplasia)
- Tumours

Genu valgum

- Idiopathic
- Metabolic (for example, rickets, renal osteodystrophy)
- Obesity
- Post-traumatic (for example, proximal tibial metaphyseal fracture)
- Post-infection
- Neuromuscular
- Congenital (for example, fibular dysplasia)
- Skeletal dysplasias (for example, pseudoachondroplasia, multiple epiphyseal dysplasia)
- Tumours

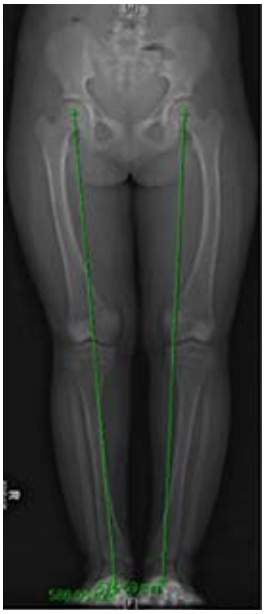

Fig 8| Long leg radiograph of a child with rickets. Both femora bow and there is unilateral overall genu varum of the left leg—the mechanical axis (green line) of the left limb passes medial to the centre of the knee compared with the normal alignment of the right leg

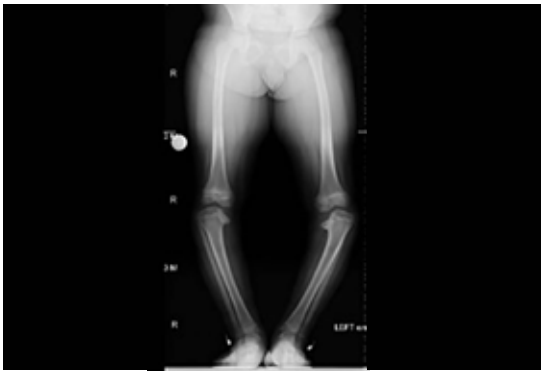

Fig 9|Long leg radiographs of child with bilateral Blount's disease of proximal tibia. Both legs box (worse on left) and space between the knees (intercondylar distance) is wide when the ankles are together

an increased risk of injury[37] and osteoarthritis in later life.[35] Further studies are required to find preventive solutions to this relation. There is currently no specific advice that can be given to such high performance adolescents who present with knee varus. However, those who present with concurrent knee pain should be investigated for alternative injuries—for example, meniscal injury, osteochondritis dessicans, or ligamental injury.

Genu valgum (knock knees)

Referrals for knock knees are common in children aged between 3 and 4 years. Knock knees can be accentuated by obesity, ligamentous laxity, and flat feet. In addition, torsional deformities such as femoral anteversion with compensatory external tibial torsion may make a physiological genu valgum appear more severe. The intermalleolar distance is measured with the knees in contact and should be less than 8 cm.[34] Treatment of physiological genu varum and valgum involves reassurance and observation.

What else should be considered?

Vitamin D deficiency

There is a resurgence of nutritional rickets secondary to vitamin D deficiency in children from ethnic minority groups and white children in Europe and Australasia.[39-41] Lower limb deformities have been attributed to vitamin D or calcium deficiency, or both. Genu varum is typical of rickets, but genu valgum can also occur.

Vitamin D insufficiency has been a recent focus of the UK Department of Health (the "Healthy Start" supplements and National Institute for Health and Care Excellence guidelines).[42 43] A comprehensive review on the diagnosis and management of vitamin D deficiency can be found elsewhere.[44]

Obesity

Globally, the prevalence of obesity is increasing.[45-47] Current evidence points to a negative effect of obesity on the musculoskeletal health of children.[48-51] An increased body mass index in children has been identified as a predictor for musculoskeletal problems, with knee and foot pain the most commonly reported symptoms.[50-53] Children who are overweight or obese show alterations in standing balance, postural adjustment, and movement efficiency, which has been proposed to contribute to the development of lower limb angular deformities and premature osteoarthritis.[48 49 53] Several studies have found a positive relation between body mass index and genu valgum[51 53] and flat feet.[27 54 55] Similarly, there are positive associations between childhood obesity and conditions such as Blount's disease (fig 9) and slipped capital femoral epiphysis.[51 56 57] Blount's disease is a growth disturbance of the medial portion of the proximal tibial growth plate. It can occur at any age from birth to skeletal maturity. Slipped capital femoral epiphysis, on the other hand, typically occurs during adolescence. It is a disorder of the proximal femoral growth plate (physis), leading to displacement of the femoral neck from the femoral head.

ANSWERS TO ENDGAMES, p 35

For long answers go to the Education channel on thebmj.com

CASE REVIEW

A woman with upper and lower airway symptoms

1 Granulomatosis with polyangiitis (previously known as Wegener's granulomatosis), a small vessel vasculitis that predominantly affects the kidneys and respiratory tract. Other possible differentials (before the positive cytoplasmic antineutrophil cytoplasmic antibody (c-ANCA) result) included atypical pneumonia, a complication of pneumonia, or another diagnosis such as pulmonary embolus or cancer.

2 Systemic features of granulomatosis with polyangiitis include fever, malaise, and anorexia. Focal symptoms tend to present in the ears, nose, respiratory tract, and urine. This patient had ear problems, recent episodes of epistaxis, changes on chest radiography, blood stained sputum, and haematuria on dipstick testing.

3 Biopsy of affected tissue, with identification of the disease process, such as necrotising glomerulonephritis on a renal biopsy, is needed to confirm the diagnosis.

4 Immunosuppression (usually with steroids and either cyclophosphamide or rituximab) and supportive management, which may include haemodialysis. Prevention and management of treatment related complications is also important.

SPOT DIAGNOSIS

An occult cause of dyspnoea

The diagnosis is compressive cervical goitre.
See thebmj.com for extended answer and discussion.

STATISTICAL QUESTION

A comparison of sampling error and standard error

Statements *a*, *b*, and *c* are true, whereas *d* is false.