Osteogenesis imperfecta is an autosomal-dominant disorder of the connective tissue. It is characterized by bone fragility attributable to low bone mass, which results in an increased risk of fracture. This bone fragility, which can lead to breakage after minimal trauma, has led to adoption of the alternative term brittle bone disease. The condition is caused by the body's response to mutations in type I collagen genes and is the end result of a complex cascade of events initiated by defects in the genetic code, leading to bone fragility. A general relationship exists between collagen mutation and type of osteogenesis imperfecta. In the least severe form of osteogenesis imperfecta, type I, mutations prematurely terminate the message for half of type I collagen synthesis. The remaining collagen is structurally normal, and the phenotype is mild. The classification by Sillence et al initially included four phenotypes (I–IV) involving mutations in COL1A1 and COL1A2. Three new phenotypes have been added, of which one, type VII, is the result of mutations in the cartilage-associated protein (CRTAP) gene. Investigation of recessive forms of osteogenesis imperfecta, which have been reported largely in the South African black population, has revealed mutations involving the CRTAP gene and the leucine proline-enriched proteoglycan 1 (LEPRE1) gene, which are both involved in collagen proline-3 hydroxylation. Classification is also based on the timing of fractures or on multiple clinical, genetic, and radiologic features. According to Roughley et al, the typical clinical features of the seven currently identified types are as follows: type I, nondeforming, normal height; type II, perinatal, lethal; type III, severely deforming, very short; type IV, moderately deforming,

Background: Osteogenesis imperfecta is an autosomal-dominant disorder of the connective tissue. Also known as brittle bone disease, it renders those affected susceptible to fractures after minimal trauma. Therefore, it is important to minimize the risk of falls and subsequent fractures in patients with this disease. In-toeing is a common condition in children that can result from various pathologic entities, including anteversion, internal tibial torsion, and metatarsus adductus. These conditions can result in frequent tripping and other functional problems.

Methods: A descriptive study was undertaken to determine the prevalence of in-toeing gait attributable to tibial or femoral torsion or metatarsus adductus in children with type I osteogenesis imperfecta. The study involved orthopedic and biomechanical examination of 15 children (9 girls and 6 boys) aged 4 to 9 years with confirmed type I osteogenesis imperfecta. Patients who used assistive ambulatory devices, such as canes, crutches, and wheelchairs, were excluded from the study.

Results: Of the 15 children studied, 12 (80%) demonstrated previously undiagnosed in-toeing gait attributable to torsional deformity or metatarsus adductus in all but one child.

Conclusions: Many children with confirmed type I osteogenesis imperfecta have in-toeing gait caused by torsional deformity or metatarsus adductus. Detection and control of in-toeing gait in children with osteogenesis imperfecta is important to prevent fractures resulting from trauma directly related to these conditions. (J Am Podiatr Med Assoc 99(4): 326-329, 2009)
variable phenotype; type V, moderately deforming, mineralized interosseous membrane, hyperplastic cal-
lus; type VI, moderately deforming, osteoid accumu-
lation, abnormal lamellation; and type VII, moderately
deforming, short humeri/femora.

Osteogenesis imperfecta is a rare disease, with a
reported annual incidence of up to 1 in 30,000. This
estimate is regarded as a lower limit, however, be-
cause the milder forms of the disease are frequently
undiagnosed. The condition is seen in both sexes
and in all races. The overall worldwide prevalence of
osteogenesis imperfecta is 0.008%, or approximately
0.5 million people. Clinically and biochemically, it is
characterized by various combinations of blue scler-
ae, triangular facies, macrocephaly, hearing loss, de-
fective dentition, barrel chest, vertebral compression
and scoliosis, progressive limb deformity and bowing,
joint laxity, and varying degrees of growth retarda-
tion. Thus, an infant with severe osteogenesis imper-
fecta requires specialized help from many disciplines.
Greater clinical severity of osteogenesis imperfecta is
associated with an increased frequency of fractures,
progressive deformity, chronic bone pain, and loss of
mobility. In type I osteogenesis imperfecta, the milde-
est form of the disease, fractures are not commonly
observed at birth but begin with ambulation and sub-
sequent falls during juvenile development, then com-
monly decrease after puberty. Currently, no defini-
tive cure is available for osteogenesis imperfecta.
Historically, treatment options have consisted of vita-
mine or hormone supplementation, analgesics to alle-
ivate chronic bone pain, prompt fracture detection
and casting, and orthopedic bracing or intramedul-
lar pins to prevent progressive deformity. Nonop-
erative management is the mainstay of orthopedic
treatment, with the goals of preventing and treating
fractures and enhancing locomotion. Operative inter-
vention is indicated in cases of recurrent fractures or
deformity that impairs function. Osteogenesis imper-
fecta generally results in multiple fractures through-
out the patient’s life, frequently affecting the foot.
Moreover, children with osteogenesis imperfecta pre-
sent with many pediatric medical problems requiring
biomechanical, orthopedic, and surgical treatment.
Therefore, management of foot abnormalities in in-
fants with osteogenesis imperfecta is important, par-
ticularly given the need to minimize the risk of falls and
subsequent fractures in patients with this disease.

In-toeing affects many children as a result of a va-
riety of pathologic entities. In the infant, the most
common cause is metatarsus adductus deformity. In
this condition, the entire forefoot is adducted at the
tarsometatarsal level, with the rearfoot remaining in
its normal position. In-toeing presenting during the
second year of life is commonly caused by internal
tibial torsion. After 3 years of age, the problem is usu-
ally attributable to excessive femoral anteversion.
When a child presents with severe in-toeing, a combi-
nation of causes should be suspected. These condi-
tions can result in frequent tripping and other func-
tional problems. Given the importance of preventing
falls and subsequent fractures in patients with osteo-
genesis imperfecta, the present study was conducted
to determine the prevalence of in-toeing gait in chil-
dren with type I osteogenesis imperfecta and whether
it results from tibial or femoral torsion or from meta-
tarsus adductus deformity.

Materials and Methods

This study was conducted in Madrid, Spain, as part of
the 12th Annual National Congress on Osteogenesis
Imperfecta, sponsored by the Asociación Huesos de
Cristal de España (Brittle-Bone Disease Association
of Spain). This association represents patients with
osteogenesis imperfecta and their families in Spain,
where nearly 2,000 people have been diagnosed as
having this condition.

The study involved orthopedic and biomechanical
examination of children with previously diagnosed
type I osteogenesis imperfecta. Patients who used as-
sistive ambulatory devices, such as canes, crutches,
and wheelchairs, were excluded from the study. Pa-
tients with this mild form of osteogenesis imperfecta
can generally walk unassisted, and fractures usually
result from falls, generally occurring before the onset
of puberty. The participants’ parents were interviewed
to ensure that there was no previous diagnosis of in-
toeing or treatment for this condition. Informed con-
sent was obtained from all of the parents and chil-
dren before enrollment in the study. The final study
sample consisted of 15 children (9 girls and 6 boys)
with type I osteogenesis imperfecta. They ranged in
age from 4 to 9 years, with a mean of 6 years, an arith-
etic mean of 3.75 years, and a standard deviation of
2.87 years.

To determine the angle of gait, data were simulta-
nously collected for a minimum of three walking tri-
als at a freely selected walking speed, a slow walking
speed, and a fast walking speed. We measured the
foot progression angle as the angular difference be-
tween the long axis of the foot and the line of pro-
gression. Negative values indicate in-toeing, and posi-
tive values indicate out-toeing. In a healthy child, the
foot progression angle is 10° (range, –3° to 20°). We
measured the amount of internal femoral rotation
with the hip in complete extension and flexion of 90°.
using a manual goniometer in the prone position, following the procedure described by Hoppenfeld.\textsuperscript{17} To determine the amount of hip rotation, both hips were allowed to fall into their maximum internal and external rotation. Normally, the amounts of internal and external rotation of the hip are similar, with the total being approximately 80° to 90° (internal rotation of up to 35° and external rotation of up to 45°). Medial rotation of more than 50° suggests a diagnosis of pathologic femoral anteversion.\textsuperscript{17}

To determine the degree of tibial rotation, the thigh-foot angle was measured. The thigh-foot angle is the angular difference between the axis of the foot and the axis of the thigh when the patient is in the prone position with the knees flexed 90° and the foot and ankle in the neutral position. We used a manual goniometer to determine whether the children in the study sample had pathologic internal tibial torsion, with the norm being an average of 15° of external rotation with the child seated and the legs dropped at 90°.\textsuperscript{18} We diagnosed metatarsus adductus deformity if the lateral aspect of the child’s foot was a C-shaped curve rather than a straight border (ie, the forefoot was adducted and the lateral border of the foot was convex).\textsuperscript{19} Clinical examination and data collection were performed by the same physician to avoid interoperator differences.

Statistical analysis of the data was performed with SPSS version 14.0 (SPSS Inc, Chicago, Illinois). Frequency and contingency tables for each variable were obtained. Variables related to pathologic adduction in gait and the presence of internal tibial torsion, internal femoral torsion, and metatarsus adductus were analyzed.

**Results**

Of the 15 children who participated in the study, 12 (80%)—four of the six boys and eight of the nine girls—demonstrated previously undiagnosed pathologic adduction in gait attributable to torsional deformity or metatarsus adductus in all but one child. Of the 15 children, five (33%) had internal tibial torsion and ten (67%) did not. Children with internal tibial torsion had not been diagnosed or treated previously. All of the children with internal tibial torsion also demonstrated pathologic adduction in gait. Of the 15 children, seven (47%) had internal femoral torsion and eight (53%) did not. Again, this pathologic condition had not been diagnosed or treated previously. All of the children with internal femoral torsion also presented with pathologic adduction in gait. Regarding metatarsus adductus, five of the 15 children (33%) demonstrated this foot deformity and ten (67%) did not. All of the children with metatarsus adductus deformity also demonstrated in-toeing gait.

We found that the various pathologic entities were associated with one another: of children with torsional abnormalities or metatarsus adductus, only three did not have associated in-toeing. In the study sample, two children had simultaneous internal tibial and femoral torsion, one had internal tibial torsion and metatarsus adductus, one had internal femoral torsion and metatarsus adductus, and one had internal femoral and tibial torsion associated with metatarsus adductus.

**Discussion**

Osteogenesis imperfecta, similar to other diseases that are considered “rare,” has been given relatively little attention in the literature, especially regarding the mechanics and pathologic features of the foot and lower extremity. Because of the risk of falls, it is extremely important to detect problems related to the feet and lower extremities of children with osteogenesis imperfecta.\textsuperscript{20} The combination of osteogenesis imperfecta and pathologic adduction in gait can increase these children’s risk of sustaining fall-induced fractures.

Although the sample involved in this study may seem small, it reflects the fact that most children with osteogenesis imperfecta use assistive ambulatory devices, such as canes, crutches, and wheelchairs. As previously stated, there are approximately 2,000 patients with osteogenesis imperfecta in Spain; this figure includes both adults and children distributed among the seven different osteogenesis imperfecta types. Therefore, the number of children with a specific type of osteogenesis imperfecta is very small. Owing to the low overall prevalence of this disease, the sample used in this study can be considered representative. The small sample sizes of studies of variables involved in rare diseases are always subject to criticism, but this, of course, should not preclude the study of these patients and their health problems.

The results of this study show that many children with confirmed type I osteogenesis imperfecta demonstrate in-toeing gait associated with torsional abnormalities of the lower extremity or foot. Comparison of these results with study findings for the healthy population shows a higher prevalence of in-toeing in patients with osteogenesis imperfecta.\textsuperscript{21} Comparison of the present results with those of Fabry et al\textsuperscript{22} shows similar average degrees of anteversion and internal tibial torsion. Our review of the literature revealed an epidemiologic study\textsuperscript{23} that focused on the functional analysis of upper-limb deformities in osteogenesis im-
perfecta. Similar studies that focus on the lower extremity to identify the most prevalent deformities in the leg and foot are needed.

In conclusion, torsional abnormalities and metatarsus adductus deformity constitute additional risk factors for fracture in children with osteogenesis imperfecta. These pathologic entities cause tripping and falling in children even by themselves. Thus, their detection and management in children with osteogenesis imperfecta is essential to avoid fracture caused by trauma directly related to these conditions.

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References
