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A General Review of Congenital Talipes Equinovarus: Causes, Treatments, and Long-Term Outcomes

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A B S T R A C T

Congenital Talipes Equinovarus (CTEV), also known as clubfoot, is a common congenital orthopedic disorder characterized by a downward and inward rotation of the foot. Causes are divided into idiopathic which usually occurs alone without other disorders and non-idiopathic, which are associated with genetic syndromes, chromosomal abnormalities, or neuromuscular disorders. Idiopathic cases tend to respond better to therapy than non-idiopathic cases, which generally require more complex treatment and are more likely to recur. Modern management standards emphasize the importance of early, non-surgical intervention, with the globally recognized Ponseti method being the primary option, involving staged manipulation and cast placement, and, if necessary, Achilles tenotomy and bracing to maintain the correction. In cases with severe deformity or when non-operative measures are unsuccessful, surgical procedures such as tendon transfers or soft tissue releases may be considered. Long-term results of Ponseti therapy are generally excellent, both functionally and aesthetically, although ankle stiffness or radiological changes may persist. Although recurrence, especially in non-idiopathic cases, is not uncommon, most children can maintain adequate leg function without extensive surgery, especially with adherence to braces.

INTRODUCTION

Congenital talipes equinovarus (CTEV), more commonly known as clubfoot, is a congenital deformity characterized by an inward, downward-turning position of the foot. This condition results in a characteristic foot orientation, often described as resembling a handstand, with adduction (pointing toward the midline of the body), supination (outward rotation), and varus (inward-angled heel). This deformity is present at birth and typically involves an inversion of the entire foot, an elevated heel, and an adducted forefoot. This abnormal position is caused by structural abnormalities of the bones, tendons, and ligaments of the foot and ankle, including a shortened Achilles tendon and medial soft-tissue contractures that restrict normal movement. Affected feet typically appear smaller than normal and may be accompanied by a cavus deformity (high arch).

Clubfoot (CTEV) involves musculoskeletal abnormalities distal to the knee, affecting the foot, ankle, hindfoot, and midfoot. These abnormalities involve not only bony malposition but also significant soft-tissue contractures of the tendons and ligaments, resulting in an abnormally fixed foot position. The talus is abnormally shaped and positioned, while the calcaneus, navicular, and cuboid bones are rotated medially relative to the talus. This combination of bony deformity and soft-tissue tension results in an inward and downward twisting of the foot. Clubfoot can be idiopathic (isolated) or syndromic if accompanied by other congenital abnormalities. This condition occurs in approximately 1 to 2 per 1,000 live births and affects both feet in nearly half of cases. Early orthopedic treatment, such as the Ponseti method, which involves gradual cast placement and the use of braces, is crucial to correct the deformity and prevent long-term disability.

Evaluation of mid- and long-term functional outcomes in congenital talipes equinovarus (CTEV) is crucial given the complex impact this condition has on foot structure and gait mechanics. CTEV, more commonly known as clubfoot, affects biomechanical components of the gait pattern, including the heel strike, mid-stance, swing, and toe-off phases, often leading to gait abnormalities, particularly in unilateral cases where imbalance is present. The severity of CTEV is associated with potential gait impairment and functional limitations, with more severe deformities typically requiring additional surgical intervention beyond initial treatment such as the Ponseti method. Recurrence rates and the need for further surgical correction are of major concern, particularly in bilateral and severe cases. Beyond physical aspects, psychosocial effects are also noteworthy, including reports of learning and attention deficits in some children with bilateral CTEV. Therefore, comprehensive long-term monitoring is essential to address both orthopedic outcomes and child development.

Despite this, patient and parent satisfaction with treatment outcomes is generally high, with studies showing satisfaction rates exceeding 85%, particularly when intervention is early and appropriate. Parental education about the condition plays a crucial role in treatment adherence, particularly regarding post-correction brace use. However, counseling regarding prognosis and potential complications remains crucial to provide realistic expectations and

prepare families for potential medium- and long-term effects, including gait abnormalities and relapse. Effective counseling also supports informed decision-making and psychosocial adjustment, contributing to overall treatment success. Developing standardized outcome measures, both through patient reports and clinical assessments with a minimum of five years of follow-up, aims to improve the consistency and quality of CTEV management and research, ultimately improving long-term functional outcomes and quality of life for affected children.

LITERATURE REVIEW

Congenital talipes equinovarus (CTEV), also known as clubfoot, is a relatively common congenital musculoskeletal disorder characterized by foot deformities including cavus, adductus, varus, and equinus positions. Epidemiologically, CTEV occurs in approximately 1 to 2 per 1,000 live births worldwide, with variations depending on geographic and ethnic populations. For example, the incidence ranges from approximately 0.3 per 1,000 in China to 6–7 per 1,000 in Polynesian populations, with an estimated global prevalence of approximately 1.18 per 1,000 births. This disorder is more common in males, with a male-to-female ratio of approximately 2:1 to 2.5:1. CTEV can occur unilaterally or bilaterally, with both feet involved in approximately half of cases. Most cases (approximately 80–95%) are idiopathic, while the remainder are associated with other syndromes or disorders. Risk factors include a genetic predisposition, supported by family history and twin studies, as well as environmental factors such as maternal smoking and low birth weight. This deformity can often be detected antenatally through ultrasound, even as early as the second trimester, although a definitive diagnosis is usually made after birth, within the first few weeks to months of life.

Demographically, CTEV is found worldwide, with a higher incidence in low- and middle-income countries, particularly in Southeast Asia and Africa, where rates can reach or exceed 1.5 per 1,000 live births. Studies indicate that males are affected approximately twice as often as females; this difference is sometimes explained by the Carter effect theory, which states that females require a higher genetic load to manifest the disorder, but can pass predisposing genes to their offspring. The deformity can affect one foot (unilateral) or both feet (bilateral), with the right foot being more frequently affected in unilateral cases. Diagnosis is often made antenatally through routine ultrasound screening, which can identify the characteristic foot position, but definitive assessment and diagnosis generally occur after birth, usually within the first year of life. Early diagnosis is crucial for timely intervention to prevent long-term disability. These epidemiological data also confirm that the etiology of CTEV is multifactorial, involving complex patterns of genetic inheritance and environmental influences, and emphasize the importance of demographic studies in health service planning and resource allocation for effective treatment strategies.

METHODOLOGY

A literature review methodology was utilized in this study. The review explored the following aspects of CTEV: definition, epidemiology, etiology and predisposing factors, pathological anatomy, pathogenesis, clinical manifestations, diagnostic approaches, and management strategies. Electronic searches were conducted in bibliographic databases, including PubMed, ProQuest, ScienceDirect, and Google Scholar, employing the following search terms: "Congenital Talipes Equinovarus", "Incidence and prevalence of Congenital Talipes Equinovarus", "Etiology of Congenital Talipes Equinovarus", "Clinical Manifestation of Congenital Talipes Equinovarus", "Diagnose of Congenital Talipes Equinovarus", "Management and Treatment of Congenital Talipes Equinovarus", and "Pathophysiology of Congenital Talipes Equinovarus." Abstracts of potentially relevant articles were subsequently screened, and conclusions were synthesized based on the themes presented in the selected articles. Both Indonesian and English language publications were considered.

RESEARCH RESULT AND DISCUSSION

Etiology

Chen et al. presented a comprehensive summary of the risk factors associated with the etiology of Congenital Talipes Equinovarus (CTE), more commonly known as clubfoot. Through a meta-analysis and systematic review of 42 studies, this research successfully identified several significant risk factors that increase the likelihood of clubfoot in children. Family history showed the strongest association, with an Odds Ratio (OR) of 7.80, indicating a significant genetic predisposition. In addition, smoking habits in both mothers (OR = 1.65) and fathers (OR = 1.72) were both associated with an increased risk of clubfoot. Maternal obesity, as measured by a body mass index (BMI) greater than 30, was also noted to increase the chance of this disorder (OR = 1.46). Amniocentesis procedures undergone by the mother during pregnancy were associated with an increased risk (OR = 2.08) when compared with other procedures. The risk also increased in mothers exposed to Selective Serotonin Reuptake Inhibitors (SSRIs), particularly paroxetine (OR = 4.26) and sertraline (OR = 1.9), as well as SSRI use in general (OR = 1.78).

Other factors that are no less important are male gender in infants who have a higher risk (OR = 1.68), and Australian Aboriginal race which is also classified as a higher risk (OR = 2.35) compared to Caucasian individuals. Several other factors such as single maternal status (OR = 1.17), gestational diabetes (OR = 1.40), nulliparity (OR = 1.32), breech position of the baby during pregnancy (OR = 1.65), twin or more pregnancies (OR = 1.59), and the occurrence of oligohydramnios (OR = 1.51) also increase the chance of clubfoot. However, the results of this study also showed that high parity (para 3, gravidas 2, 3, or more than 4) and Asian or African descent were actually associated with a statistically significant decrease in the risk of clubfoot. Overall, the etiology of clubfoot is seen as the result of a multifactorial interaction, involving a complex role between genetic and environmental factors. Based on the findings of this study, the most

clinically relevant risk factors include family history, parental smoking, maternal obesity, amniocentesis procedures, and exposure to certain SSRIs.

Herceg et al. addressed the etiology of idiopathic congenital talipes equinovarus (clubfoot) by examining possible underlying neuromuscular causes of the condition. The study involved the analysis of muscle biopsies from 95 feet from 68 patients, with particular attention to the gastrocnemius, abductor hallucis, flexor digitorum longus, flexor hallucis, and tibialis posterior muscles. A total of 431 muscle specimens were analyzed, with 95 undergoing histochemical and electron microscopic examination. The results showed that the majority of muscle specimens (86.3%) showed no neuromuscular pathology, characterized by a normal muscle fiber type ratio and the absence of type I fiber clustering, a common indicator of neuromuscular disorders. Only a small proportion of specimens (0.9%) showed a predominance of type I fibers, and 12.8% showed muscle fiber atrophy. Based on these findings, the researchers concluded that primary neuromuscular abnormalities are not a significant factor in the etiology of idiopathic talipes equinovarus. Therefore, although clubfoot is a common condition and its causes are not fully understood, its origins do not appear to be related to neuromuscular pathology in the muscles involved.

Pathogenesis

The pathogenesis of Congenital Talipes Equinovarus (CTEV), better known as clubfoot, is a complex congenital disorder characterized by a downward-turned foot position. This abnormality is present at birth and occurs in approximately 1 in every 700 to 1,000 live births worldwide. The pathogenesis of CTEV is not fully understood, but it is generally believed to involve multifactorial factors, namely a combination of genetic and environmental factors that disrupt the normal development of the fetal foot.

From a genetic perspective, there is strong evidence to suggest a hereditary component to CTEV. Research, including twin studies, has shown a significantly higher degree of concordance in monozygotic twins compared to dizygotic twins, indicating a genetic predisposition. Family history is a significant risk factor, with up to 54% of cases in some populations having a family member with CTEV. The inheritance pattern of this disorder does not follow the classic Mendelian pattern, and is thought to involve a complex interaction of several genes. Genes suspected of playing a role include those related to limb formation, such as PITX1, HOXA, HOXD, TBX4, and RBM10, as well as genes related to muscle contraction. This disorder is believed to arise from disruptions in the developmental processes that regulate the formation of bones, joints, connective tissue, muscles, and the nervous system in the lower limbs.[1,10,11]

Environmental factors also play a significant role in the pathogenesis of CTEV. Several factors have been linked to an increased risk, including maternal smoking during pregnancy. Other possible contributing factors include limited intrauterine space, infections, exposure to certain medications, and placental abnormalities. The mechanical or positional hypothesis, which suggests that restricted fetal movement due to intrauterine pressure causes this abnormality, remains controversial and has not been conclusively supported, particularly

since CTEV can be detected as early as the second trimester, before uterine pressure becomes significant.

Pathophysiologically, CTEV involves abnormal shortening and stiffness of the muscles, tendons, and ligaments in the medial and posterior portions of the foot. This results in characteristic deformities: hindfoot varus (inward-turning of the heel), forefoot adductus (inward-turning of the front of the foot), cavus (high medial arch), and equinus (plantar flexion of the ankle). These changes result from abnormal musculoskeletal development and possible disruption of the processes of apoptosis and remodeling during fetal development. As a result, the foot becomes stiff and fixed in an abnormal position, which, if left untreated, can lead to serious limitations in mobility and function.

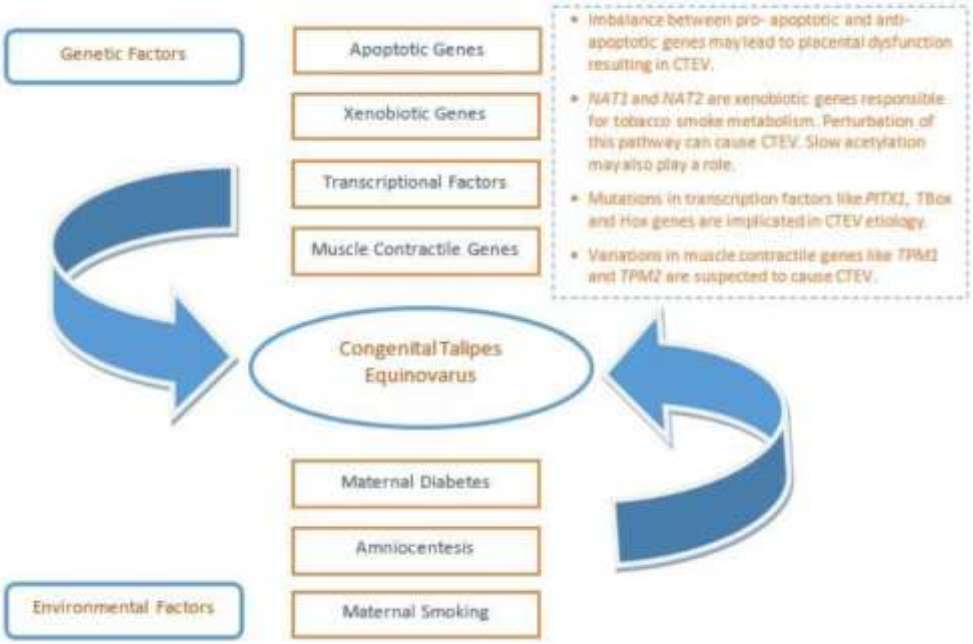

Figure 1. Etiological factors in Congenital Talipes Equinovarus (CTEV)

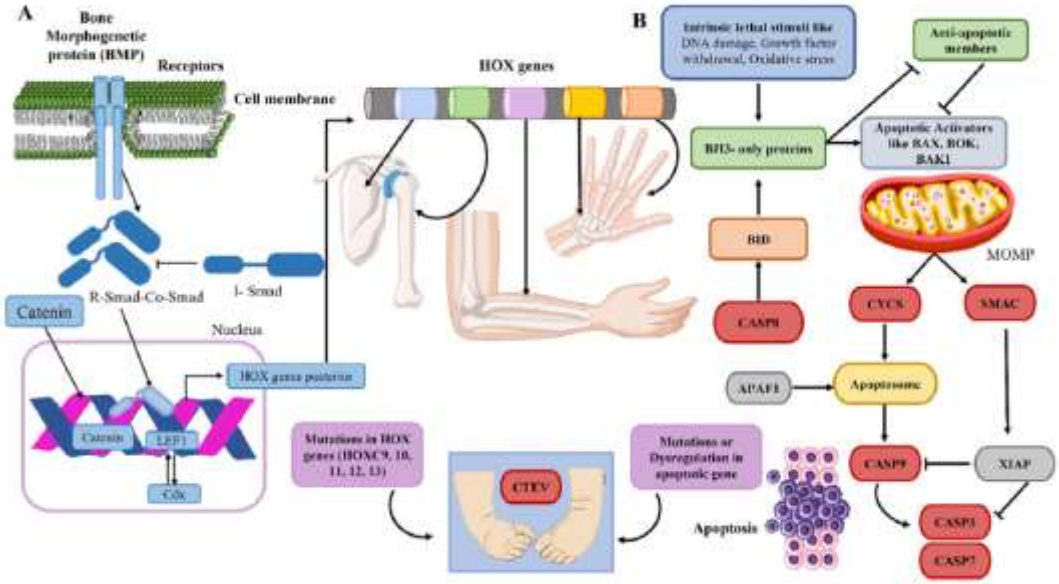

Figure 2. Model of the integration of Wnt and BMP signaling pathways by Axin1

(A) In the absence of Wnt stimulation, β-catenin is degraded by the destruction complex. Smad5 is also degraded by the Axin1-mediated destruction complex. (B) In the presence of Wnt ligands or the absence of Axin1, degradation of β-catenin and pSmad5 is inhibited, resulting in activation of β-catenin and BMP/pSmad5 signaling. Captions: BMP (bone morphogenetic protein), APC (adenomatous polyposis coli), GSK-3 (glycogen synthase kinase-3), DVL (disheveled), β-TrCP (beta-transducin repeats-containing protein), TCF (transcription factor)

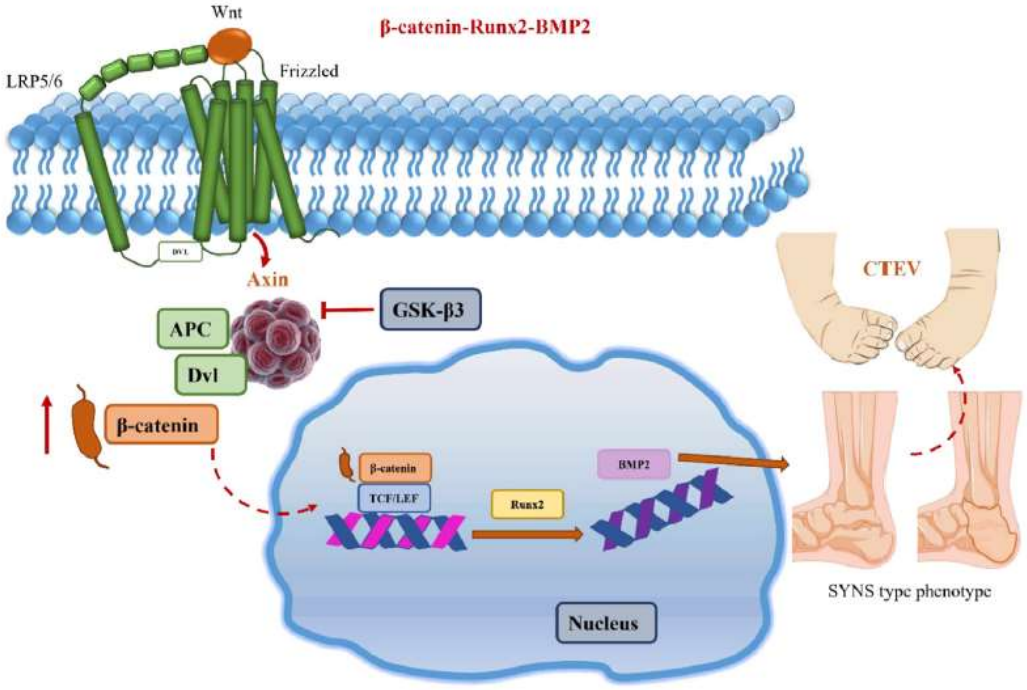

Figure 3. Morphogenic signaling pathways that activate Hox genes along with molecular interactions and cellular dynamics of CTEV in intrinsic apoptosis

(A) SMAD1/5/8 phosphorylated via the canonical BMP pathway forms a stable complex with β-catenin and LEF1 in the posterior HOX gene promoter region, and regulates their expression with the help of Cdx family members. Mutations in this pathway can cause congenital disorders such as Congenital Talipes Equinovarus (CTEV). (B) Induction of the pro-apoptotic BCL2 family leads to MOMP, which triggers cell death. MOMP releases pro-apoptotic proteins such as CYCS and SMAC into the cytosol, where CYCS forms the apoptosome with APAF1, dATP, and pro-CASP9, which then activates CASP9. CASP9 then activates the executioner caspases CASP3 and CASP7, with the support of SMAC inhibiting apoptosis inhibitory proteins of the IAP family. Description: BMP (bone morphogenetic protein), HOX (homeobox), CTEV (congenital talipes equinovarus), MOMP (mitochondrial outer membrane permeabilization), LEF1 (lymphoid enhancer binding factor 1), BCL2 (B cell lymphoma 2), CYCS (cytochrome c, somatic), SMAC (second mitochondria-derived activator of caspase), APAF1 (apoptotic protease-activating factor 1), dATP (deoxyadenosine triphosphate), CASP3/7/9 (caspase 3/7/9), pro-CASP9 (pro-caspase 9), XIAP (X-linked inhibitor of apoptosis).

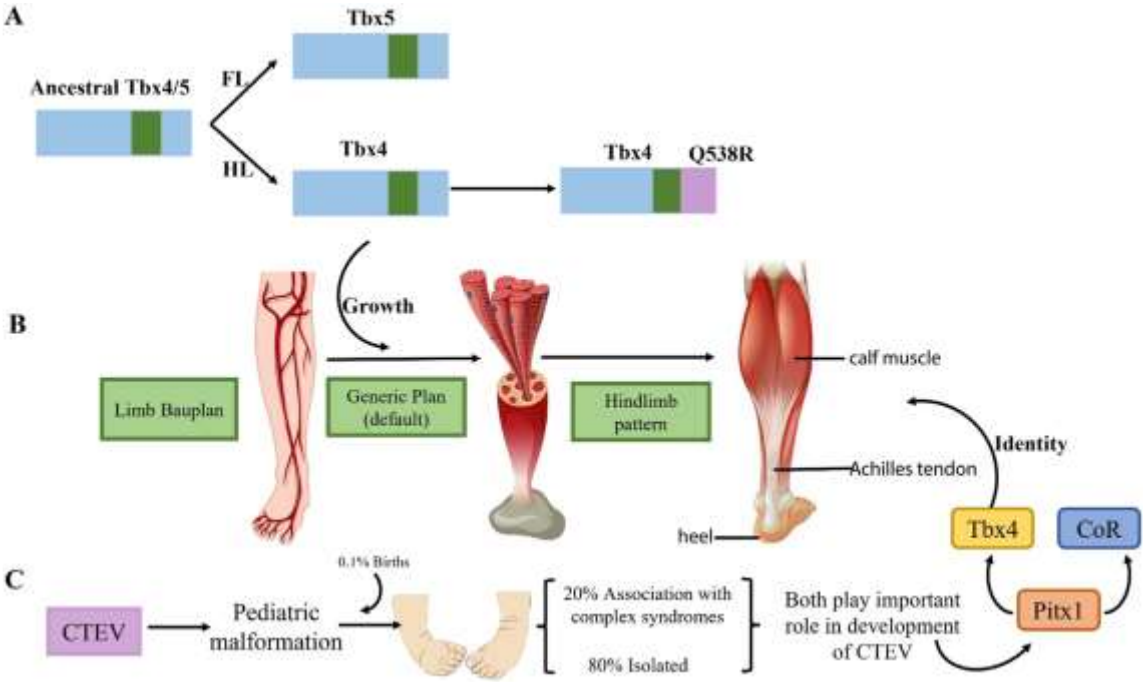

Figure 4. Schematic showing the structure of muscle at various levels of organization

(A) Thick and thin filaments are arranged in a symmetrical lattice. Each thick filament is surrounded by 6 thin filaments. (B) Muscle anatomy. (C) Thin filaments consist of actin, nebulin, tropomyosin, and the troponin complex (troponin I, T, and C). (D) Troponin complex.

Diagnosis

Diagnosis of Congenital Talipes Equinovarus (CTEV), better known as clubfoot, is a congenital disorder characterized by the position of the foot that turns inward at the ankle, causing the foot to be bent in an abnormal position. This disorder can affect one or both feet, with the characteristic foot being fixed in a combination of deformities such as cavus (high arch), adductus (inward rotation), varus (inward tilt of the heel), and equinus (downward pointing of the foot). The incidence of CTEV varies globally, generally ranging from 0.5 to 3.5 cases per 1000 live births, with a higher prevalence in males.

Diagnosis of CTEV can be made both prenatally and postnatally. Prenatal diagnosis is increasingly performed through routine ultrasound examinations, usually performed around 20 weeks of gestation. Ultrasonography can detect characteristic foot deformities, allowing for early identification and counseling of parents. However, assessing the severity of this abnormality during fetal development is often difficult, and some cases detected antenatally are mild and do not require treatment after birth. Studies have shown that although there are no false-positive cases with ultrasound diagnosis, a significant number of diagnosed feet do not require treatment, reflecting the variation in clinical severity.

Postnatal diagnosis is primarily clinical and relatively straightforward. The affected foot appears turned inward and pointed downward, with limited range

of motion due to abnormalities in soft tissues such as tendons, ligaments, and muscles. The Achilles tendon is typically shorter and tighter, leading to an equinus deformity. A physical examination will reveal the foot fixed in a "hand" position with a combination of adduction, supination, and varus. A medical history should also be reviewed, including any family history of clubfoot or neuromuscular disorders, as well as maternal factors such as smoking, alcohol consumption, or diabetes, which may contribute to this condition.

The etiology of CTEV is multifactorial and not fully understood. Several hypotheses have been proposed, including mechanical factors such as fetal position in the uterus or uterine space restriction, vascular abnormalities affecting blood supply to the developing legs, neurological dysfunction, and genetic predisposition. Genetic factors are found in 24–50% of cases, depending on the population studied, suggesting a significant hereditary component. Environmental influences and developmental abnormalities in connective tissue, muscle, and bone also contribute to the pathogenesis. However, no single cause can explain all cases, and it is likely that this disorder arises from an interaction between genetic and environmental factors.

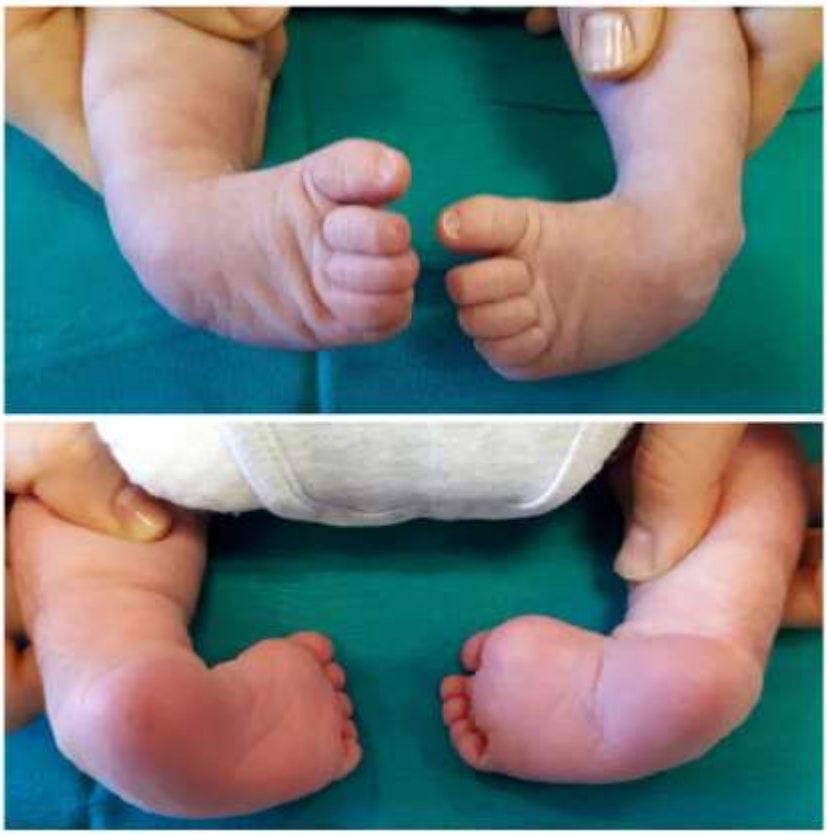

Figure 5. Front and rear views of idiopathic congenital Congenital Talipes Equinovarus (CTEV)

Figure 6. CTEV Weight

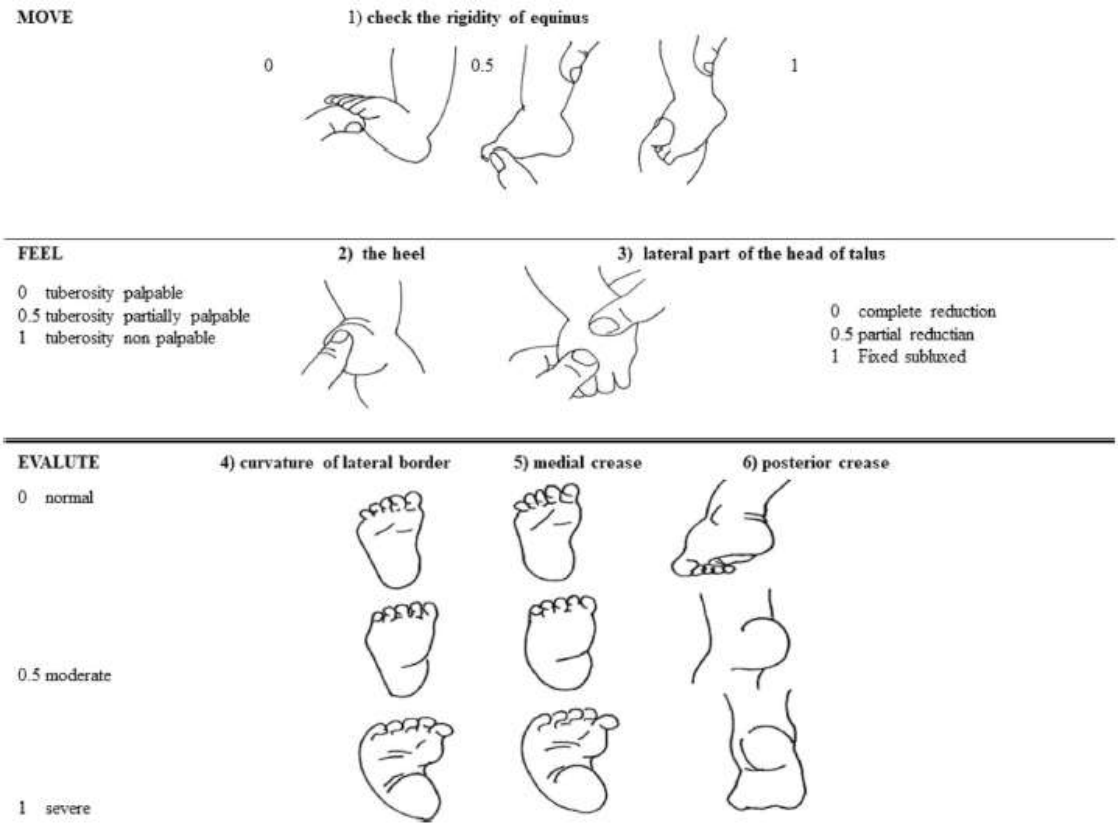

Figure 7. Pirani score for CTEV

Note: This scale consists of 6 items, where each item has a score of 0 to 1 (0 if normal, 0.5 if there is mild–moderate deformity, 1 if there is severe malformation); the higher the score, the more severe the deformity.

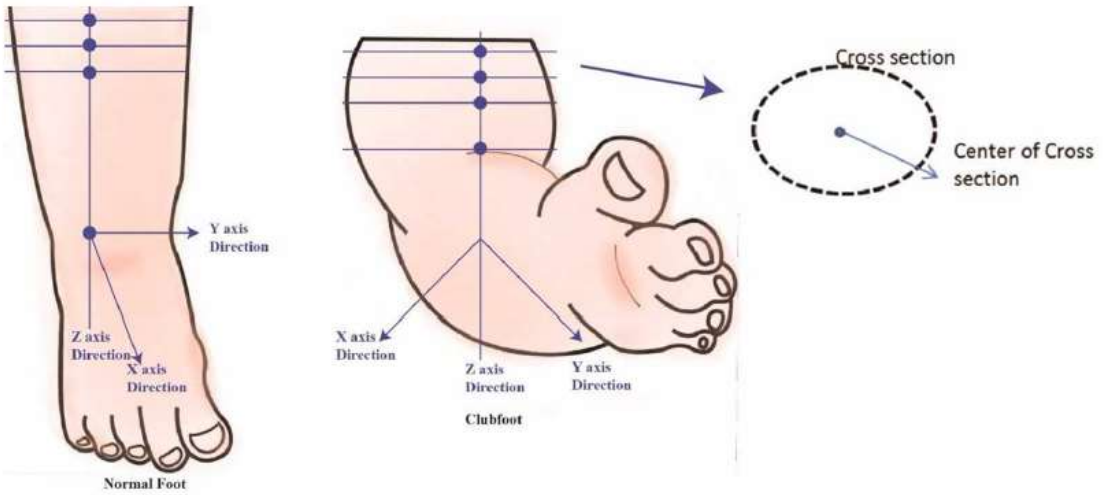

Figure 8. Parallelism of the Leg Lines

Management

Macnicop et al. reviewed the management of congenital talipes equinovarus (CTEV), or clubfoot, in Scotland from 1993 to 1997. This audit revealed significant variation in the conservative and surgical approaches employed across healthcare facilities. In this study, all children diagnosed with CTEV underwent conservative management as an initial step. The most commonly used method involved adhesive strapping, which was applied for an average duration of 17 weeks. The use of adhesive strapping as initial therapy appears suboptimal, given the high rate of subsequent surgical need, at 69% in boys and 76% in girls.

Furthermore, Plaster of Paris (POP) casts are often used after strapping, with an average duration of 24.1 weeks. This method is also not without its problems, with a significant percentage of children ultimately requiring surgery, at 42% in boys and 63% in girls. Meanwhile, the use of Denis Browne splints and custom shoes, especially after strapping therapy, showed the longest duration of conservative treatment, averaging 57.1 weeks. Interestingly, this method correlated with the lowest rate of need for surgery, at only 14% for boys and 33% for girls. These findings indicate that long-term conservative therapy with Denis Browne splints and custom shoes can effectively reduce the need for further surgical intervention.

Although all patients underwent conservative therapy initially, more than half (53.3%) ultimately required further surgical intervention. The most common surgical procedures were posterior or posteromedial releases. In some cases, reoperation was necessary to correct residual deformities, including the need for repeat releases. Other sporadic procedures included isolated Achilles tendon lengthening. Additionally, a small number of children received Ilizarov frames

as a primary intervention after one year of conservative treatment. It is noteworthy that no bony procedures were recorded during this audit.

One of the key challenges identified in this audit is the absence of a widely applied standardized approach to the management of CTEV. The audit also emphasized that the paucity of comparative studies means that neither the most effective treatment method nor the optimal duration of conservative therapy can be definitively established. Management variations often depend more on the geographic location of services and local clinical practices than on standardized considerations of deformity severity. Therefore, the authors of this document highlight the urgency of developing a universally accepted classification of CTEV and the importance of conducting long-term, multicenter, prospective studies to determine the most effective management strategies for CTEV.

Output

Viaris de le Segno et al. reviewed the results of prenatal diagnosis of clubfoot in depth. This retrospective study, conducted at a tertiary care center in France, aimed to evaluate the incidence of chromosomal abnormalities, associated findings, and pregnancy outcomes in clubfoot cases identified by prenatal ultrasound. The authors emphasized the importance of prenatal diagnosis in parental counseling and postnatal care planning. The study differentiated clubfoot into "complex" cases, defined as clubfoot accompanied by other structural abnormalities, and "isolated" cases, defined as clubfoot without additional structural abnormalities. This distinction suggests that the presence of additional defects likely influences the patient's clinical outcome. This study seeks to broaden the understanding of the prognosis of clubfoot following prenatal diagnosis, thus providing the basis for multidisciplinary management and appropriate education for patients and their families.

Mishima et al. reviewed the outcomes of idiopathic clubfoot management, focusing primarily on the recurrence of stiffness following treatment with the Ponseti method. This study sought to identify early radiographic risk factors that could be used to predict the likelihood of recurrence. Recurrence of stiffness in clubfoot patients is a significant negative outcome, as it often requires more extensive surgical intervention, such as soft tissue release, than is typically performed with initial Ponseti treatment. This study aims to improve the long-term outcomes of clubfoot therapy by enabling clinicians to identify feet at risk of stiffness recurrence earlier. This allows for more timely and appropriate intervention, potentially minimizing the need for extensive soft tissue release surgery.

Zhao et al. provide an in-depth review of the outcomes of clubfoot management, focusing on the risk of recurrence after treatment using the Ponseti method. In this study, the authors highlight that recurrence remains a significant challenge in some clubfoot cases that have undergone Ponseti correction. This study specifically examines various factors that can be used to predict the likelihood of recurrence. Several key aspects are highlighted in the discussion, including the initial Pirani score, which reflects the severity of the deformity at the time of diagnosis and is considered an important predictor of the risk of

recurrence. Furthermore, the number of dressings required during the correction process is considered an indicator of the course of treatment and its relationship to the likelihood of deformity recurrence is also evaluated. Post-correction bracing compliance is also a concern, as this factor has been shown to play a significant role in preventing clubfoot recurrence; this paper implicitly underscores the importance of continued brace use for long-term success. This study also introduced a new parameter, the Ratio of Correction Improvement (RCI), calculated by dividing the initial Pirani score by the number of dressings used, to assess its validity and predictive value in determining the risk of recurrence. Overall, the primary objective of Zhao et al.'s study was to identify and validate prognostic factors that can be used to predict the likelihood of recurrence, thereby influencing the optimization of long-term outcomes of clubfoot treatment using the Ponseti method.

Schelven et al. discussed the management of idiopathic clubfoot, focusing on the recurrence of the deformity after initial correction using the Ponseti method. This study explained that the recurrence rate after Ponseti treatment varies widely, ranging from 26% to 48%. This study systematically identified and assessed clinically relevant prognostic factors in predicting recurrence. The authors emphasized that a thorough understanding of these prognostic factors is crucial for predicting treatment outcomes and guiding appropriate management strategies. This study also provides a comprehensive overview of these prognostic factors, which is expected to assist clinicians in managing patients more effectively and reducing the likelihood of recurrence after Ponseti therapy. One important aspect analyzed was non-compliance with brace use, demonstrating the crucial role of compliance in the overall success of the Ponseti method.

CONCLUSIONS AND RECOMMENDATIONS

Congenital Talipes Equinovarus (CTEV), or clubfoot, is a congenital orthopedic disorder in which the baby's foot is turned inward, making it difficult to walk. Its etiology can be multifactorial—involving genetic factors, the environment during fetal development, and neuromuscular disorders—and is divided into idiopathic cases and those associated with specific disorders or syndromes. Current treatment strategies largely prioritize non-operative methods, with the Ponseti method being the global standard of care due to its effectiveness in correcting the deformity through serial repositioning and cast application, followed by a maintenance phase with a brace to prevent recurrence. This method has proven highly effective in idiopathic cases, with a satisfaction rate of 88-90%. However, post-correction lower limb stiffness may still be present, especially in non-idiopathic cases or those with genetic syndromes, which tend to have a higher recurrence rate and require long-term monitoring and often multidisciplinary management. Surgery itself is only indicated in certain cases that do not respond to conservative methods, but long-term outcomes are often associated with complications such as stiffness and pain. Thanks to early management and advances in non-operative techniques, the prognosis for CTEV

is now improving, with functional outcomes approaching normal with careful monitoring and treatment protocols.

ADVANCED RESEARCH

Future advanced research on Congenital Talipes Equinovarus (CTEV) should focus on integrating genomics, biomechanics, and artificial intelligence to improve both diagnosis and treatment outcomes. Emerging genetic studies suggest the involvement of multiple candidate genes such as PITX1, HOX clusters, and TBX4, yet their exact functional mechanisms remain poorly defined, requiring large-scale genome-wide association studies and molecular pathway analyses. In parallel, the development of three-dimensional gait analysis and computational foot modeling can provide objective insights into long-term functional outcomes, surpassing the limitations of conventional clinical scoring systems like the Pirani scale. Furthermore, machine learning algorithms have the potential to predict recurrence risk by combining clinical data, radiological parameters, and treatment adherence patterns, enabling personalized interventions. Collaborative multicenter longitudinal studies, incorporating patient-reported outcomes and quality-of-life measures, are essential to establish standardized global benchmarks for CTEV management. Ultimately, translational research that bridges molecular biology, advanced imaging, and predictive analytics will pave the way for precision medicine in the management of clubfoot.

REFERENCES

Asuquo JE, Okokon EO, Lasebikan OA, et al. Assessment of Treatment Outcomes in the Management of Club foot using the Ponseti Technique: A cross-sectional study. Afr J Paediatr Surg. 2024;21(2):85-89.

Bacino CA, Hecht JT. Etiopathogenesis of equinovarus foot malformations. Eur J Med Genet. 2014;57(8):473-479.

Chen C, Kaushal N, Scher DM, Doyle SM, Blanco JS, Dodwell ER. Clubfoot Etiology : A Meta-Analysis and Systematic Review of Observational and Randomized Trials. 2018;38(8):462-469.

Dibello D, Di Carlo V, Colin G, Barbi E, Galimberti AMC. What a paediatrician should know about congenital clubfoot. Ital J Pediatr. 2020;46(1):1-6.

Ganesan B, Luximon A, Al-Jumaily AA, Yip J, Gibbons PJ, Chivers A. Developing a three-dimensional (3D) assessment method for clubfoot-A study protocol. Front Physiol. 2018;8(JAN):1-11.

Herceg MB, Weiner DS, Agamanolis DP, Hawk D. Histologic and Histochemical Analysis of Muscle Specimens in Idiopathic Talipes Equinovarus. 2006;26(1):2005-2007.

Ippolito E, Gorgolini G. Clubfoot pathology in fetus and pathogenesis. A new pathogenetic theory based on pathology, imaging findings and biomechanics—a narrative review. Ann Transl Med. 2021;9(13):1095-1095.

Macnicop MF. Management ofcongenital talipes equino vams in Scotland : a nationwide audit. 2004:1-5.

Miedzybrodzka Z. Congenital talipes equinovarus (clubfoot): A disorder of the foot but not the hand. J Anat. 2003;202(1):37-42.

Mishima K, Kitoh H, Matsushita M, et al. Foot and Ankle Surgery Early radiographic risk factors for rigid relapse in idiopathic clubfoot treated with the Ponseti method. Foot Ankle Surg. 2017.

Mustari MN, Faruk M, Bausat A, Fikry A. Congenital talipes equinovarus: A literature review. Ann Med Surg. 2022;81.

Ngariboyo P. Diagnosis dan Tatalaksana Congenital Talipes Equino Varus (CTEV). Cermin Dunia Kedokt. 2021;48(1):58-61.

Pavone V, Chisari E, Vescio A, Lucenti L, Sessa G, Testa G. The etiology of idiopathic congenital talipes equinovarus: A systematic review. J Orthop Surg Res. 2018;13(1).

Schelven HVAN, Moerman S, Steen MVANDER, Besselaar AT, Greve C. Prognostic factors for recurrent idiopathic clubfoot deformity : a systematic literature review and meta-analysis. 2022:11-28.

Smythe T, Rotenberg S, Lavy C. The global birth prevalence of clubfoot: a systematic review and meta-analysis. eClinicalMedicine. 2023;63.

Sharma R, Stone S, Alzeoubi A, Kumar S. PF.23 Medium Term Childhood Outcome of Isolated Congenital Talipes Equinovarus Diagnosed Antenatally. Arch Dis Child - Fetal Neonatal Ed. 2013;98(Suppl 1):A10.4-A10.

Sharma L, Agarwal A, Garg V, Ankitha KS, Sachdeva K. Parent reported outcomes for idiopathic clubfoot children treated with the Ponseti technique: An analysis of 140 feet followed minimum 5 years. J Clin Orthop Trauma. 2024;53.

Sinha N, A. Seeley M, S. Horwitz D, Maniar H, H. Seeley A. Pediatric Orthogenomics: The Latest Trends and Controversies. AIMS Med Sci. 2017;4(2):192-216.

Tillet RL, Fisk NM, Murphy K, Hunt DM. Clinical outcome of congenital talipes equinovarus diagnosed antenatally by ultrasound. J Bone Jt Surg - Ser B. 2000;82(6):876-880.

Umar M, Tong L, Jin H, Terebessy T, Chen D. Genetics, epidemiology and management of clubfoot and related disorders. Genes Dis. 2025;12(6):101690.

Viaris B, Segno D, Gruchy N, Bronfen C, Benoist G. Prenatal Diagnosis of Clubfoot : Chromosomal Abnormalities Associated with Fetal Defects and Outcome in a Tertiary Center. :1-6.

Zhao D, Li H, Zhao L, Kuo KN. Prognosticating Factors of Relapse in Clubfoot Management by Ponseti Method. 2016;00(00):1-7.