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Windswept Deformity of the Knee: A Comprehensive Literature Review on Etiology, Pathophysiology, Diagnosis, and Management

Bambang Tutuko[1], I Wayan Suryanto Dusak[1]

[1]Department of Orthopedic Surgery and Traumatology, Prof IGNG Ngoerah Hospital, Faculty of Medicine, Udayana University, Denpasar, Indonesia.

Corresponding Author: Bambang Tutuko

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ABSTRACT

Background: Windswept deformity is a rare musculoskeletal condition characterized by simultaneous genu valgum in one knee and genu varum in the contralateral knee. Its multifactorial etiology includes metabolic bone diseases, skeletal dysplasias, mechanical stress, arthritis, trauma, and iatrogenic causes. Comprehensive reviews on this condition remain limited.
Objective: This narrative review aims to summarize the current evidence on the definition, epidemiology, etiology, pathophysiology, biomechanics, diagnosis, and management of windswept deformity.
Method: A narrative literature review was conducted using PubMed, Google Scholar, and Scopus with keywords including "windswept deformity," "genu valgum," "genu varum," "rickets," and "guided growth." Relevant English-language articles were selected and critically appraised.
Results: Rickets due to vitamin D and calcium deficiency is the most common etiology. The deformity typically manifests in the second or third year of life, with valgus developing first followed by contralateral varus. Diagnosis requires thorough history, physical examination, radiographic and laboratory assessment. Management ranges from conservative measures to surgical interventions including corrective osteotomy, total knee arthroplasty, and guided growth, with the latter offering advantages in skeletally immature patients.
Conclusion: Windswept deformity requires individualized management based on the underlying etiology, patient age, and deformity severity. Early identification of the cause is essential for optimal outcomes.

Keywords: *windswept deformity, genu valgum, genu varum, rickets, corrective osteotomy, total knee arthroplasty, guided growth*

INTRODUCTION

"Windswept deformity" describes the appearance of abnormal valgus alignment in one knee accompanied by varus alignment in the contralateral knee. This asymmetrical condition gives the impression that the lower limbs have been swept in one direction by a strong wind. The term encompasses a spectrum of underlying conditions that result in this characteristic bilateral knee malalignment.

The etiology of windswept deformity can be broadly categorized into metabolic bone diseases, mechanical stress, reactive compensation to unilateral disease, genetic or racial predisposition, and traumatic causes. Among these, rickets remains the most common underlying etiology, particularly in

regions where vitamin D deficiency is prevalent.

Management of windswept deformity includes both surgical and conservative approaches. Surgical options encompass corrective osteotomy, total knee arthroplasty (TKA), and hemiepiphysiodesis or guided growth, while conservative management includes plaster casting. The choice of treatment depends on the underlying cause, patient age, severity of deformity, and associated comorbidities.

This literature review aims to provide a comprehensive overview of windswept deformity, covering its definition, epidemiology, etiology, pathophysiology, biomechanics, diagnostic approach, and current management strategies based on available evidence in the literature.

LITERATURE REVIEW
WINDSWEPT DEFORMITY

Definition

Windswept deformity describes a condition in which a patient presents with abnormal valgus alignment (genu valgum) in one knee and abnormal varus alignment (genu varum) in the contralateral knee. The knees are positioned at opposite ends of the deformity spectrum in the coronal plane, creating a characteristic asymmetrical lower limb appearance. Both osseous and soft tissue components contribute to this complex deformity, with the bony malalignment being the primary structural abnormality and ligamentous attenuation serving as a secondary contributor.[1]

Epidemiology

Windswept deformity is a relatively uncommon condition with geographic variation in prevalence. Higher incidence rates have been reported in sub-Saharan Africa and other regions where nutritional rickets remains endemic. In pediatric populations, the condition is predominantly associated with metabolic bone diseases, particularly rickets. In adult populations, windswept deformity may develop secondary to osteoarthritis or inflammatory arthritis. Shetty et al. examined the prevalence and predictive factors of windswept deformity in patients undergoing total knee arthroplasty, suggesting that the condition may be more prevalent than previously recognized in this patient population and emphasizing the importance of individualizing valgus correction angles during surgery.[2]

Etiology

The etiology of windswept deformity is multifactorial. Based on the available literature, the following etiological categories have been identified: (1) idiopathic; (2) metabolic bone diseases, including rickets, renal osteodystrophy, primary hyperparathyroidism, chronic fluoride toxicity, and distal renal tubular acidosis; (3) genetic and skeletal dysplasias, including pseudoachondroplasia, dysspondyloenchondromatosis, multiple epiphyseal dysplasia, metaphyseal dysplasia, parastremmatic dysplasia, and Schwartz-Jampel Syndrome; (4) mechanical stress; (5) compensatory response to unilateral deformity; (6) inflammatory arthritis, such as rheumatoid arthritis; (7) osteoarthritis; (8) trauma; and (9) iatrogenic overcorrection of genu varum on one side.

Among these etiologies, rickets is the most commonly reported cause of windswept deformity, particularly in the pediatric population. The deficiency of phosphate and calcium, which is closely related to inadequate vitamin D intake, leads to progressive weakening and softening of the developing bones. When a child fails to meet the physiological requirements for vitamin D, the body compensates by producing hormones that stimulate the release of calcium and phosphate from the skeletal reservoir. This progressive mineral depletion renders the bones weak, soft, and susceptible to deformation under mechanical loading, ultimately resulting in the characteristic windswept pattern.[1]

Pathophysiology

The pathophysiology of windswept deformity varies according to the underlying etiology, though the most well-characterized mechanism involves rickets secondary to vitamin D and calcium deficiency. The deformity typically manifests during the second or third year of life, coinciding with the onset of independent ambulation when the softened bones are subjected to the mechanical forces of weight bearing. The valgus deformity generally develops first on one side, followed rapidly by the emergence of compensatory varus deformity on the contralateral limb.

Geographic and demographic factors play a significant role in the epidemiology of rickets-related windswept deformity. The condition is notably prevalent in Africa, attributable to dietary patterns characterized by low dairy consumption and the increased requirement for sunlight exposure in individuals with darker skin pigmentation to achieve adequate cutaneous vitamin D synthesis. X-linked hypophosphatemic rickets also contributes to the burden of disease in certain populations.

Several additional pathophysiological mechanisms have been described. Severe skin hyperkeratosis may lead to decreased vitamin D synthesis in the epidermis, subsequently stimulating parathyroid hormone secretion and resulting in rachitic changes. Skeletal dysplasias causing windswept deformity are attributed to specific genetic mutations that affect bone development and remodeling. Furthermore, congenital insensitivity to pain syndromes may result in fractures that go unrecognized and untreated, progressively culminating in windswept deformity.[1,3]

Biomechanics

The biomechanical consequences of windswept deformity are substantial and multifaceted. The presence of abnormal force moments—specifically, an adductor moment on the varus side and an abductor moment on the valgus side—produces a cascading effect on multiple aspects of lower extremity function. These altered force vectors affect gait patterns, joint loading distribution, muscle conditioning, and overall energy consumption during ambulation. The primary structural component of the deformity is osseous malalignment, with ligamentous attenuation serving as a contributing and potentially aggravating factor. Over time, these abnormal biomechanical forces accelerate degenerative changes within the knee joint, predisposing patients to progressive osteoarthritis.[4]

Diagnosis

The diagnosis of windswept deformity necessitates a systematic and comprehensive approach. The clinical evaluation begins with a thorough history, which should encompass detailed family history, developmental milestones, nutritional status, and any history of metabolic disorders or previous orthopedic interventions. Physical examination may reveal characteristic findings such as rachitic rosary (swelling of the costochondral junctions), which is pathognomonic for underlying rickets, in addition to the obvious bilateral knee deformity.

Radiographic assessment forms a cornerstone of the diagnostic workup. Standing anteroposterior long-leg radiographs are essential to evaluate the mechanical axis deviation and quantify the degree of deformity in both limbs. Laboratory investigations include serum calcium, phosphate, alkaline phosphatase, 25-hydroxyvitamin D levels, and parathyroid hormone to evaluate for metabolic bone disease. Urinalysis and renal ultrasonography may be indicated to assess for renal causes of rickets. In cases where skeletal dysplasia is suspected, genetic analysis should be performed. This multimodal diagnostic approach enables identification of the underlying cause and facilitates individualized treatment planning.[1]

Management

The management of windswept deformity is inherently complex and must be individualized based on the underlying etiology, patient age, skeletal maturity, severity of the deformity, and presence of associated comorbidities. Treatment options span a spectrum from conservative medical management to various surgical interventions, each with distinct indications, advantages, and limitations.

Medical Management

Medical management is primarily directed at treating the underlying cause of windswept deformity. In cases attributable to metabolic bone disease, particularly rickets, treatment centers on vitamin D and calcium supplementation, dietary modification to increase dairy and mineral intake, and correction of any underlying metabolic abnormality such as renal osteodystrophy. Conservative orthopedic measures, including plaster casting, may be employed in mild cases or as an adjunctive measure to medical treatment, particularly in young children where spontaneous correction may still occur with normalization of the metabolic milieu.[4]

Corrective Osteotomy

Corrective osteotomy is a well-established surgical approach for the management of windswept deformity, involving deliberate surgical division of the bone to realign the mechanical axis. The procedure follows a systematic approach: detailed preoperative planning is first undertaken to determine the required correction angles and sites of osteotomy. Multiple osteotomies are then performed on the tibia and femur as indicated, with concurrent limb length equalization to correct the overall mechanical axis deviation. A Taylor spatial frame is applied to facilitate gradual, controlled correction of the deformity. Following achievement of full correction and radiographic evidence of acceptable bone consolidation, definitive intramedullary fixation using interlocking nails is inserted to maintain alignment and permit weight bearing. Final assessment of alignment and orientation is confirmed with anteroposterior full-length radiographs of the lower extremities.[5]

Total Knee Arthroplasty (TKA)

Total knee arthroplasty represents the definitive surgical treatment for windswept deformity in adult patients with end-stage arthritis. Single-stage bilateral TKA is generally preferred due to its association with decreased overall morbidity, lower cumulative cost, improved mechanical stability, and a shorter total period of disability compared to staged procedures. However, in patients who cannot tolerate prolonged anesthesia, such as elderly individuals or those with significant metabolic comorbidities, a staged bilateral approach remains a viable alternative.

The surgical technique for TKA in windswept deformity requires meticulous attention to individual knee-specific factors. A subvastus approach is employed to preserve the medial blood supply. The skin incision follows a gentle curve of approximately 18 cm directed laterally. Distal femoral resection is performed at 6° of femoral valgus and 6° of external rotation, referenced to the surgical epicondylar axis as evaluated by preoperative computed tomography, taking care to avoid excessive resection of the medial condyle. Tibial resection is performed 8 mm distal to the medial tibial plateau surface and at the level of the most distal aspect of the lateral bone loss area.

The iliotibial tract is elevated subperiosteally from the Gerdy tubercle, and lateral release is performed anterior to the iliotibial band at the level of the superior patella to maintain patellar blood supply. If medial laxity persists after trial reduction, a semi-constrained prosthesis design is utilized. The tibial component is cemented in a relatively externally rotated position. Patellar tracking is carefully assessed, and if patellar dislocation persists despite resurfacing and medialization, augmentation of the medial patellofemoral ligament (MPFL) using an

artificial ligament such as the Leeds-Keio Ligament may be performed. Shetty et al. emphasized the importance of individualizing the valgus correction angle for each knee rather than using a standard angle, as windswept deformity patients have asymmetric mechanical axes that require tailored correction to achieve optimal outcomes.[2,6]

Guided Growth (Hemi epiphysiodesis)

Guided growth, also known as hemi epiphysiodesis, is a minimally invasive surgical technique that manipulates the growth plate on one side to achieve gradual, physiological correction of axial deviation. The procedure involves the application of a tension band device—such as a two-hole plate and screw construct or a staple—across one side of the physis. Available devices include the eight-plate system, Orthofix, and Pediplate. As the growth plate continues to grow on the unrestricted side while being tethered on the treated side, angular correction is gradually achieved. This procedure must be performed before skeletal maturity, typically before 14 years of age in females and 16 years of age in males.

Guided growth offers several compelling advantages over corrective osteotomy, particularly in patients with windswept deformity secondary to dysplasia syndromes or metabolic disorders. In these patient populations, immunocompromised states resulting from uremia, chronic steroid use, or immunosuppressive therapy significantly increase the risk of wound complications and bone infection associated with osteotomy procedures. Furthermore, the poor bone quality commonly encountered in patients with osteomalacia and osteoporosis secondary to rickets predisposes to complications such as nonunion, stress fractures, and internal fixation failure following osteotomy. An additional advantage of hemi epiphysiodesis is that it can be performed at multiple levels simultaneously and can be repeated without significant morbidity if the deformity recurs, providing a safe and reproducible treatment option for this challenging patient population.[7]

CONCLUSION

Windswept deformity is a complex musculoskeletal condition characterized by the simultaneous presence of abnormal valgus alignment in one knee and varus alignment in the contralateral knee. The etiology is multifactorial and can be categorized into metabolic, mechanical, compensatory, genetic, and traumatic causes, with rickets being the most commonly reported underlying disorder. A systematic diagnostic approach encompassing thorough clinical history, physical examination, radiographic assessment, laboratory investigations, and genetic analysis when appropriate is essential for identifying the underlying etiology and guiding treatment decisions. Management options range from conservative medical treatment and plaster casting to surgical interventions including corrective osteotomy, total knee arthroplasty, and guided growth (hemiepiphysiodesis). The selection of treatment should be individualized based on the underlying cause, patient age, skeletal maturity, and severity of the deformity to achieve optimal clinical outcomes.

Declaration by Authors

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