International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Effort, Lever, and Fulcrum Failures in the Development of Trendelenburg Sign and Gait: A Physiotherapist's Insight

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ABSTRACT:
This short review explores how failures related to the fulcrum, lever, and effort of the hip joint contribute to the development of a positive Trendelenburg sign and gait. It highlights the anatomy and biomechanics of the hip joint, emphasising its function as a first-class lever essential for lower limb activities such as walking. The review discusses how various pathologies affecting the hip joint's lever arm, fulcrum, and effort can lead to instability and compensatory gait patterns. By understanding the biomechanical principles and anatomical structures involved, healthcare professionals can devise effective interventions aimed at restoring normal hip function and improving patient outcomes.

Keywords: Trendelenburg sign, Gait, Hip joint, Lever system

1. INTRODUCTION

The hip joint functions as a ball-and-socket joint, serving as the pivot point in a lever system that connects the pelvis to the lower limbs. This complex structure comprises bones, ligaments, and muscles that transfer body weight from the axial skeleton to the lower limbs and convey forces from the ground back to the body [1]. The soft tissues contributing to joint stability can be classified into static and dynamic structures, with each movement plane stabilised by a combination of a muscle-tendon unit as the dynamic portion and a ligament as the static stabiliser. Muscles can adjust their length according to demand while ligaments cannot [2]. The hip joint plays crucial roles in maintaining balance, supporting the weight of the upper body, and facilitating functional activities such as walking [3]. During walking, the structures of the hip joint experience significant forces - approximately three times an individual's body weight. Pathologies affecting the hip joint can disrupt its biomechanics and also influence the functioning of the body regions both above and below it [4].

The Trendelenburg sign, named after German surgeon Friedrich Trendelenburg, was first identified in 1897 as a method to detect progressive muscular atrophy and weakness in the hip abductor muscles in individuals suffering from congenital hip dislocation. The Trendelenburg sign is a significant clinical indicator used in the assessment of weakness in the hip abductor muscles and evaluating various mechanical, neurological, and spinal conditions [5]. A thorough understanding of the anatomy of the hip and pelvic girdle is vital for grasping the fundamentals of the Trendelenburg sign and gait. Disruptions in the function or structure of these components can lead to a positive Trendelenburg sign or gait, indicating that further clinical evaluation and intervention may be necessary.

2. ANATOMICAL STRUCTURES INVOLVED

- **Muscular Anatomy**

Hip abduction is primarily supported by the gluteus medius (GMed) and gluteus minimus (GMin). The GMed has three proximal attachment points on the iliac bone: the gluteal fossa, gluteal aponeurosis, and the posterior inferior iliac spine. Meanwhile, the GMin originates from the gluteal fossa, the joint capsule, and the deep side of its tendon. Together, their tendon insertions on the greater trochanter create a gluteal fan shape. The gluteus medius has two points of insertion: one at the posterior (capsular) region, and the other at the anterior (bony) region. Additionally, the tensor fascia lata (TFL), the third abductor muscle, connects to bone through its fascia on the anterolateral ilium but does not have a direct muscle-to-bone attachment, as it is contained within the fascia lata extending to the proximal tibia, making it a bi-articular muscle. All three structures are innervated by the superior gluteal nerve [6].

Other important muscles include the iliopsoas, a key hip flexor, the gluteus maximus, a powerful hip extensor, the adductor muscles found on the medial aspect of the thigh, and the hamstrings located posterior to the thigh. These muscles collaborate to enable complex movements and generate the necessary force for activities like walking, running, and jumping.

- **Bony Anatomy**

The hip joint is formed by the articulation of the femur and the pelvic/hip bone. The superior portion of the femur comprises the head, neck, and trochanters. The neck, extends from the shaft, forming an angle with the shaft that varies between 125 and 135 degrees. The greater trochanter, which serves as a common site for the attachment of the hip abductor muscles, extends over the broadened area where the neck meets the shaft of the femur, and at the back, it connects to the lesser trochanter via the intertrochanteric crest, with the lesser trochanter protruding from the posteromedial side of the proximal shaft [7]. The long, cylindrical femoral shaft extends from the lower border of the lesser trochanter to just above the femoral condyles. It is divided into three main sections: the proximal third, the middle third, and the distal third shaft. The primary blood supply to the femoral shaft comes from the deep femoral artery, which branches into a nutrient artery and several muscular branches. These vessels create a complex network of anastomoses that ensures sufficient blood flow to the shaft [8]. The acetabulum is a cup-shaped structure formed by the innominate bone (pelvic/hip bone), incorporating contributions from the ilium, ischium, and pubis. Its articular surface appears lunate when viewed from within, and it contains a central area called the central inferior acetabular fossa. This region is filled with adipose tissue that houses a synovial-covered fat pad and the attachment of the ligamentum teres. The hip socket is further completed by the inferior transverse ligament, while the rim of the acetabulum is encircled by a fibrocartilaginous structure known as the acetabular labrum [9]. The hip joint not only facilitates movement but also supports weight-bearing, with its stability stemming from the acetabulum's shape and depth, which accommodates the femoral head. The acetabular labrum, enhances stability by aiding load transmission, maintaining negative pressure (a "vacuum seal"), and regulating synovial fluid properties [10].

- **Capsule and Ligaments**

The capsule of the hip joint enhances its stability and is strengthened by intrinsic capsular ligaments, while intra-articular components such as the labrum and ligamentum teres also influence its functional performance [11]. The ligamentum teres, also referred to as the ligament of the head of the femur, is a ligament that extends from the acetabulum to the fovea capitis of the femoral head; it is thought to contribute to the mechanical stability of the hip joint while also supplying blood vessels to the femoral head [12]. The hip joint capsule is thickest at the upper portion to support maximum load when standing. It features longitudinally arranged external fibres reinforced by ligaments that enhance stability and restrict movement. The iliofemoral ligament (Y ligament of Bigelow) is the strongest ligament in the body and it supports the superior and anterior aspects, limiting extension; the pubofemoral ligament reinforces the inferior aspect and restricts external rotation; and the ischiofemoral ligament strengthens the posterior aspect while limiting internal rotation and adduction. Additionally, the inner capsule encircles the femoral neck, reinforcing the joint at the orbicular zone or annular ligament [13].

- **Synovium and Bursae**

The synovium, which lines the joint capsule, acetabular labrum, fat pad in the acetabular fossa, and the ligament of the head of the femur, also lines the intra-articular portion of the femoral neck. The ilio-pectineal bursa, located beneath the iliopsoas muscle, which often communicates with the hip joint cavity, is the largest bursa on the anterior side of the hip. The trochanteric bursae are situated laterally beneath the gluteal muscles over the greater trochanter and the ischial bursa is located posteriorly beneath the hamstrings [14].

- **Neurovascular Supply**

The hip joint receives its blood supply mainly from the superior gluteal arteries, as well as the medial and lateral circumflex femoral arteries with the first perforating artery [15]. It is supplied by the femoral, obturator and superior gluteal nerves [10].

3. BIOMECHANICS AND FUNCTIONAL ANATOMY

The importance of the Trendelenburg sign goes beyond mere diagnosis; it assists clinicians in developing tailored treatment strategies aimed at addressing the underlying causes of hip instability. By understanding the mechanics involved, healthcare professionals can better evaluate the severity of the condition and monitor patient progress throughout rehabilitation.

- **Movements and Degrees of Freedom**

Hip movements are enabled by three intersecting axes that are oriented at right angles to each other, all converging at the centre of the femoral head. This configuration enables three degrees of freedom, allowing for the primary movements of flexion and extension, lateral and medial rotation, and abduction and adduction [3]. Pelvic movements are generally described as rotations around three cardinal axes, each corresponding to a specific plane of motion. Rotations about a mediolateral axis result in anterior or posterior pelvic tilt - in anterior tilt, the anterior superior iliac spines (ASIS) move forward and downward while the posterior superior iliac spines (PSIS) move upward, whereas in posterior tilt, the ASIS move backward and upward, and the PSIS move downward. Rotation around an anteroposterior axis creates pelvic drop or hike, where one side of the pelvis descends while the other ascends, typically during weight-bearing on one leg. Lastly, rotation about a vertical axis leads to forward and backward rotation, with the movement named based on the opposite side of the hip; for example, when standing on the right lower limb, forward rotation occurs when the left side moves forward, while backward rotation happens when it moves backward [16].

- **Normal Gait Cycle**

Normal gait is characterised by several fundamental principles, such as safety, energy efficiency, and adaptability to different situations. Realising these principles involves a combination of factors associated with balance, kinematics, and kinetics. Ensuring a safe gait is contingent upon maintaining good balance and postural stability, which requires sustaining equilibrium throughout the gait cycle to reduce the likelihood of falls and injuries [17]. Normal gait is defined by particular events within the gait cycle and the length of its phases [18]. Each gait cycle is divided into two main periods: stance and swing phases. The stance phase includes the entire duration that the foot remains in contact with the ground, beginning with the moment of initial contact. In contrast, the swing phase refers to the period when the foot is off the ground, allowing for limb advancement, beginning as the foot is lifted from the ground [19].

Perry (2008) outlines the following points:

Stance phase (accounting for 60% of the gait cycle) comprises:

- **Phase 1 - Initial Contact:** The foot makes contact with the ground and is the first factor influencing how the limb is loaded.
- **Phase 2 - Loading Response:** Accepts the body weight and maintains forward progression.
- **Phase 3 - Midstance:** The ankle acts as a rocker, enabling the limb to move forward over the stationary foot.
- **Phase 4 - Terminal Stance:** The forefoot functions as a rocker, allowing both the foot and limb to roll forward.

Swing phase (making up 40% of the gait cycle) includes:

- **Phase 5 - Pre-swing:** Ankle and hip actions of the unloaded limb initiate flexion at the knee in preparation for the swing.
- **Phase 6 - Initial Swing:** Muscle contractions at the hip, knee, and ankle raise the foot and propels the limb forward.
- **Phase 7 - Mid-swing:** The limb continues to advance through ongoing hip flexion and early knee extension. With the tibia in a vertical position, active foot support becomes essential.
- **Phase 8 - Terminal Swing:** This phase concludes limb advancement through knee extension, while further hip flexion is limited in readiness for the stance phase [20].

According to Büchler, et al. (2017), the process of walking in humans also involves a series of coordinated movements that can be broken down into distinct stages. These stages include:

- **Double Limb Stance:** During this phase, the body's weight is evenly distributed across both hips.
- **Anterior Pelvic Tilt:** In the sagittal plane, the pelvis tilts forward by approximately 5° while walking. This movement shifts the centre of gravity over the supporting leg.
- **Pelvic Rotation and Weight Transfer:** The pelvis rotates forward, allowing the swing leg to be released from weight-bearing.
- **Elevation of the Pelvis:** The pelvis rises by about 5-6° in the frontal plane, accompanied by a hip flexion of 40-50°, which facilitates the elevation of the swing leg.
- The most energy-efficient speed for walking is typically between 1.2 and 1.5 m/s (approximately 4 to 5 km/h), with a step length ranging from 0.65 to 0.75 m and a cadence of 105 to 130 steps per minute [21].
- **Muscle Activity**

The hip abductor muscle group is essential for pelvic stability during walking, helping to keep the opposite side of the pelvis level during single leg stance. The GMed and GMin also aid in rotational movements at the hip joint [22].

Earlier research indicates that, from a mechanical standpoint, the GMed and GMin muscles encounter considerable disadvantages in functioning as the primary hip abductors. In contrast, the TFL is favourably positioned to generate the necessary force to counterbalance the weight-bearing forces experienced throughout the entire stance phase of the gait cycle. The Trendelenburg test indicates weakness in the gluteal muscles, resulting in a sagging of the pelvis on the unaffected side, as the femoral head cannot be maintained in a stable position within the acetabulum [23]. Despite its relatively small size, the TFL functions in conjunction with several muscle groups to facilitate movement and stabilisation of both the hip and knee. It works alongside the gluteus medius and gluteus minimus to achieve internal rotation and abduction of the hip, engages with the gluteus maximus via the iliotibial band (ITB) to further assist in hip abduction, and contributes to hip flexion alongside the rectus femoris.

The study “Running Related Gluteus Medius Function in Health and Injury: A Systematic Review with Meta-analysis” by Semciw et al. (2016) reported that the GMed plays a vital role in running, primarily by helping to absorb ground reaction forces during the loading phase. It was noted that GMed generates the highest peak muscle force among the hip muscles during early stance, which is essential for maintaining vertical support alongside the gluteus maximus and adductor magnus. The research highlighted that individuals with injuries, such as patellofemoral pain syndrome, often exhibit reduced GMed activity while running, which can lead to compensatory movement patterns and increase the risk of further injury [24].

4. THE HIP JOINT AS A LEVER SYSTEM

To gain a comprehensive understanding of the role of the abductor muscles, it is crucial to recognise that the hip joint functions as a fulcrum in an unequal lever system. In this arrangement, the long arm supports the weight of the body, while the gluteal muscles control the shorter arm [25].

A lever is a rigid bar that rotates around a fixed point called the fulcrum (F). In human biomechanics, all three types of lever systems exist. The force exerted at one end is referred to as the effort (E), while the force at the opposite end is known as the weight (W). The perpendicular distance from the fulcrum to the effort is known as the effort arm (EA), while the distance from the fulcrum to the weight is called the weight arm (WA) [26].

Mechanical advantage refers to the efficiency of a lever system in moving a load with less effort. It occurs when the distance from the fulcrum to the point of effort (EA) is longer than the distance from the fulcrum to the weight (WA), resulting in a ratio greater than 1.0. This allows a smaller force to move a larger load. Conversely, mechanical disadvantage arises when the EA is shorter than the WA, leading to a ratio less than 1.0, which requires greater force to overcome the load. In situations of mechanical disadvantage, more effort is needed to lift the weight, making it less efficient for moving heavy objects [27].

The hip joint can function as both a class 3 lever and a class 1 lever due to the positioning of muscles, the fulcrum (the hip joint), and the load (the weight of the body or resistance). This review will focus on the hip joint’s function as a class 1 lever in the context of the Trendelenburg sign and gait, emphasising the role of the hip abductors as stabilisers of the pelvis rather than their typical role as hip abductors in a class 3 lever system.

- **Hip Joint as a Class 3 Lever:**

Third-class levers facilitate movements that prioritise speed and a greater range of motion. The hip joint can act as a class 3 lever when the iliopsoas contract to cause hip flexion while in standing position [28]. The same applies when the hip is abducted. In this scenario, the effort (muscle force) is applied by the hip abductors (GMed, GMin and TFL) between the fulcrum (the hip joint) and the load (the weight of the body or resistance).

- **Hip Joint as a Class 1 Lever:**

First-class levers create balanced movements when the fulcrum is positioned midway between the effort and weight, similar to a seesaw. When the fulcrum is nearer to the effort, they generate speed and a greater range of motion. Conversely, when the fulcrum is closer to the weight, these levers produce forceful motion [28]. The hip joint and the abductor mechanism function similarly to a class 1 lever, where the effort and load are situated on opposite sides of the fulcrum. The centre of gravity of the supported body segments, typically located medial to the hip joint, generates a rotational force on the pelvis. To maintain pelvic stability, this force must be counterbalanced by the hip muscles. Consequently, the force transmitted through the hip joint comprises both the weight of the supported body and the tension from stabilising muscles. A long femoral neck is beneficial for hip function. If any pathology affects the fulcrum, lever arm, or effort - essentially any component of this lever system - it can result in a positive Trendelenburg sign and altered gait [29, 30].

- **Koch's Model**

In recent years, the hip biomechanics model originally proposed by John Koch in 1917 has been revisited and studied by numerous researchers. A study conducted by Fetto et al. (2002) critically evaluates Koch's original model of hip biomechanics, which suggested that the gluteus medius must exert a force equivalent to twice the body weight during single-leg stance to maintain pelvic stability. Koch's theories went largely unchallenged for nearly 70 years, primarily due to their foundational impact on the understanding of hip mechanics. In his research, Koch categorised forces along the medial and lateral surfaces of the femur by assigning positive values to compressive forces and negative values to tensile forces. He highlighted that tensile loads are present in the superior neck and the proximal three-quarters of the lateral femoral shaft, while the distal lateral femur and the entire medial surface are subjected to compressive loads but he did not clarify the reason for the transition from tensile to compressive loading observed in the distal lateral femur. The authors identify significant limitations in Koch's static approach, particularly its failure to account for dynamic factors such as the role of surrounding muscles and soft tissues in stabilising the hip joint. They present a more comprehensive model that includes the dynamic interactions of structures like the ITB, which contributes to hip stability during movement. For example, they point out that Pauwels showed that when the ITB is tensioned during a one-legged stance, it decreases the bending stresses on the proximal femur and increases its axial loading. This perspective highlights the importance of considering both static and dynamic elements in understanding hip biomechanics, especially in clinical contexts where conditions like below-knee amputations can affect hip stability despite intact gluteal function [31].

- **Pauwels' Model**

Notably, the work of Pauwels in 1976 significantly offered a more thorough insight into the mechanics of the hip joint. This model provides a more nuanced and functional understanding of hip biomechanics compared to Koch's original framework by integrating dynamic factors, emphasising the role of soft tissues, and accounting for varying lever arms, thus enhancing clinical applications and treatment strategies for hip stability.

- **Weight Distribution:** When an individual stands on both feet, the body weight is evenly distributed between the two hip joints, with each joint supporting approximately one-third of the total body weight.

- **Single Leg Support:** During activities such as walking, when weight is transferred to one leg, the pelvis tends to tilt downward on the non-weight-bearing side. The abductors on the weight-bearing side play a crucial role in maintaining pelvic stability and preventing this tilt.
- **Leverage System:** Pauwels conceptualised this biomechanical situation as a system of levers:
  - Lever k1: Represents the distance from the hip joint to the body's centre of gravity.
  - Lever k2: Represents the distance from the hip joint to the greater trochanter.
- **Force Balance:** As demonstrated in **Figure 1**, the forces acting on both sides of the hip can be expressed mathematically. In adults, lever k1 is approximately three times longer than lever k2, indicating that the force exerted by the abductor muscles must be three times greater than the body weight supported by each hip joint.
- **Increased Load:** When standing on one leg, each hip joint experiences a load that is roughly four times greater than body weight due to this leverage effect. Structural changes in the hip, such as dislocation or specific pathological conditions, can significantly influence the load each hip joint must support [32].

Figure 1: Hip Lever System

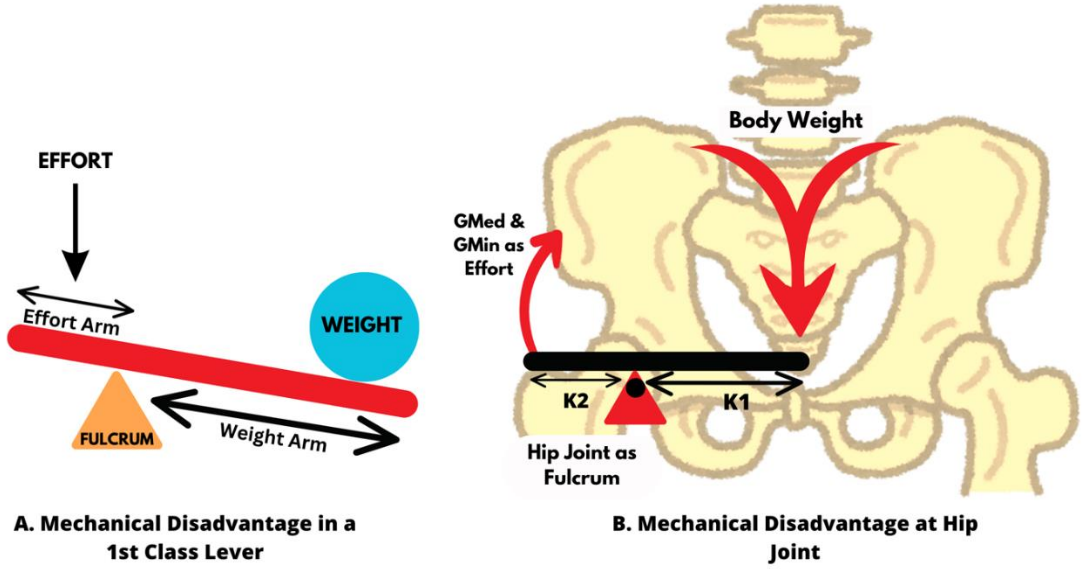

Figure 1 illustrates the relationship between the mechanical disadvantage faced by the hip joint as a first-class lever and the lengths of the lever arms is crucial for understanding hip biomechanics, particularly given that the body weight lever arm is 3 times longer than the abductor lever arm. As a result, the force exerted by the hip abductors must be 3 times greater than the body weight to maintain stability during activities such as walking or standing on one leg. **Image A** illustrates the concept of mechanical disadvantage in a lever system, while **Image B** demonstrates how this disadvantage specifically applies to the hip joint.

5. TRENDELENBURG SIGN AND GAIT

- **Trendelenburg Sign**

To assess the Trendelenburg sign, the Trendelenburg test can be used. This test is designed to assess the strength of the hip abductors and their ability to stabilise the pelvis. In this test, the patient stands on the affected leg while flexing the opposite leg forward. A normal or negative result is characterised by the pelvis on the non-affected side rising, whereas a positive result is indicated by the pelvis on the non-affected side dropping, suggesting that the abductors are insufficiently stabilising the pelvis [33]. These have been shown in **Figure 2**.

A study by McCarney et al. (2020) evaluated the effectiveness of the Trendelenburg test in assessing hip abductor strength and pelvic motion. The researchers identified significant discrepancies between subjective assessments made by practitioners and objective measurements obtained through 3D motion analysis, raising concerns about the test's validity, particularly in individuals without hip pathologies. The findings indicated that a hip drop may not always be visibly detectable by practitioners, which can result in false positives and negatives. The study emphasised the need for further research to clarify the clinical relevance of the Trendelenburg test and recommended incorporating objective measures alongside traditional assessments for more accurate evaluations of hip function. The study suggested that the Trendelenburg test necessitates a submaximal isometric contraction of the hip abductors, combined with an endurance component to maintain pelvic elevation, whereas the Biodex tests (which they used to record hip abductor torque) require maximal hip abduction effort over a brief duration. It also reported that during an isokinetic hip abduction test performed from a standing position, there is bilateral activation of the gluteus medius muscles, while the Trendelenburg test involves unilateral activation on the side of the stance limb. These differences in muscle activation and demand may help explain the observed lack of correlation between peak hip abductor torque and pelvic motion during the Trendelenburg test [34].

False positives in hip stability assessments can result from obesity, an impaired quadratus lumborum, pain, fixed adduction deformities, scoliosis, coxa vara, impaired balance, lack of cooperation or comprehension and costo-pelvic impingement. False negatives may arise from significant lateral trunk movement for balance, trick movements by using psoas, rectus femoris and supra-pelvic muscles and early osteonecrosis cases where abductor defects are not apparent [5].

Figure 2: Negative and Positive Trendelenburg Sign

A. Negative Trendelenburg Sign B. Positive Trendelenburg Sign

Figure 2 illustrates the distinctions between positive and negative Trendelenburg signs. As shown in **Image A**, a negative Trendelenburg sign occurs when the opposite abductors effectively stabilise the pelvis, preventing any significant pelvic drop. **Image B** demonstrates a positive Trendelenburg sign, characterised by a pelvic drop on the side opposite to the stance leg during single-leg support, indicating weakness in the hip abductor muscles, primarily the gluteus medius and minimus.

- **Trendelenburg Gait**

A lateral trunk lean that occurs during walking due to weakness in the hip abductor muscles is called a gluteus medius gait. If this lean is a response to hip joint pain, it is referred to as an antalgic gait. In cases of excessive abductor muscle weakness, the pelvis may drop on the unsupported side even while the trunk leans towards the supported side to compensate. When both the lateral lean and pelvic drop are present during walking, this pattern is typically identified as a Trendelenburg gait [35]. To assess the gait of a patient with hip pathology, a total of six to eight complete strides should be examined from both the frontal and sagittal planes, with particular focus on stride length, foot rotation (either internal or external), pelvic rotation, and the stance phase [36]. The difference between a positive and negative Trendelenburg gait has been demonstrated in **Figure 3**.

Figure 3: Negative and Positive Trendelenburg Gait

A. Negative Trendelenburg Gait B. Positive Trendelenburg Gait

Figure 3 illustrates the differences between positive and negative Trendelenburg gait patterns. Image A depicts a negative Trendelenburg gait which occurs when the opposite abductors effectively stabilise the pelvis, minimising the pelvic drop. In contrast, Image B shows a positive Trendelenburg gait, characterised by a pelvic drop on the unsupported side during walking, accompanied by a lateral lean of the trunk towards the supported side.

6. CONDITIONS AFFECTING FULCRUM INTEGRITY, EFFORT EXERTION, AND LEVER EFFICIENCY

Key factors contributing to a positive Trendelenburg sign and gait include fulcrum failures, effort failures, and lever failures.

- **Fulcrum failure**

A fulcrum failure can be described as a dysfunction or breakdown in the biomechanical system that disrupts the normal functioning of a joint or support structure, which acts as a fulcrum (pivot point) during movement. This can manifest in a variety of conditions, including developmental dysplasia of the hip, osteonecrosis of the hip and Legg-Calvé-Perthes disease. It may occur in cases of chronic hip dislocation resulting from trauma or infections, such as tuberculosis of the hip [30]. Additionally, the lack of a stable fulcrum results in a positive test, which typically indicates an unhealed fracture of the femoral neck [37]. The Trendelenburg gait is one of the significant abnormal walking patterns following total hip arthroplasty (THA). [38] Osteoarthritis (OA) impacts not only the cartilage but also the underlying bone, as well as the surrounding muscles and ligaments [39]. A recent study by Van Rossom et al. (2023) found that patients with hip OA modify their walking patterns to alleviate stress on their affected hip and knee. Specifically, these individuals tend to decrease the load on the affected limb while walking and ascending stairs, without compensating by shifting weight to the opposite limb. This adjustment often leads to increased flexion in the trunk and knee, alongside reduced hip extension. Consequently, there is a decrease in the moments of hip extension and adduction, as well as knee adduction, which helps lower the contact forces in both joints. These adaptations are likely compensatory strategies aimed at managing muscle weakness in the hip abductors and reducing strain on the damaged hip joint [40]. As a result, patients may experience a pronounced Trendelenburg gait, where the pelvis drops on the side opposite to the affected hip due to insufficient support from the weakened abductor muscles. Another study investigated changes in gait kinematics, kinetics, and hip contact forces in individuals with hip OA, revealing significant alterations in the frontal plane. Patients exhibited decreased hip adduction angles and hip abduction moments, indicating a tendency to avoid using weakened hip abductors. This strategy enhances medio-lateral stability while reducing the load on the affected hip. Additionally, factors such as fear of pain and slower walking speeds contribute to lower hip contact forces. The findings underscore the compensatory mechanisms employed by patients with hip OA to optimise stability and minimise joint loading during movement. The authors suggested further research to validate these results in a larger cohort [41].

- **Effort Failure**

An effort failure in this context refers to the insufficient activation or weakness of the hip abductor muscles, primarily the gluteus medius and minimus. Various medical conditions can lead to weakness in the hip abductor muscles, including Guillain-Barré syndrome, muscular dystrophy and poliomyelitis, while factors such as arthritis, hip instability, or surgical interventions can also contribute to this muscle weakness [42] as a result of muscle inhibition from pain and disuse. Furthermore, injury to the superior gluteal nerve can lead to paralysis of the hip abductor muscles [43]. An effort failure can arise as a complication following hip arthroplasty performed via a lateral approach, as this surgical technique may inadvertently harm the superior gluteal nerve or the GMed muscle [44].

Myofascial trigger points (MTrPs) are defined as sensitive or tender areas within taut muscle fibres of the skeletal muscles, which can elicit local or referred pain when compressed or stretched. These trigger points are often linked to myofascial pain syndrome [45]. The GMed muscle is highly susceptible to myofascial pain syndrome, which typically results from repetitive microtrauma from activities like running or overusing exercise equipment that involves hip abduction. MTrPs in this condition can arise from single injuries or chronic muscle strain and deconditioning. Contributing factors include poor posture during sedentary activities, previous injuries that disrupt muscle function, and exacerbating conditions such as poor nutrition and psychological issues like chronic stress and depression [46].

Individuals with posterior pelvic pain often experience a muscle imbalance between the posterior gluteus medius (PGM) and TFL, where the PGM is lengthened and weakened, while the TFL is shortened and stronger. This imbalance can lead to a preference for using the TFL during abduction of the hip. Although many may not have symptoms, overuse of the PGM can result in pain and strain, particularly influenced by factors like weight gain, which increases demand on the muscle. Persistent muscle guarding from injury can create a cycle of pain and increased tension, potentially leading to mTrPs and pain referral patterns [47]. Both latent and active mTrPs can lead to muscle dysfunction and weakness [48]. One study examined the relationship between latent mTrPs and strength of the GMed muscle in healthy adults. Latent mTrPs can contribute to restrictions in joint movement and overload by interfering with motor activation patterns and mechanisms of reciprocal inhibition. The results revealed that gluteus medius abduction strength below 9.7 kg may indicate the presence of latent mTrPs, demonstrating high sensitivity but low specificity. It is essential for clinicians to recognise the significance of latent mTrPs in the gluteus medius, given its important role in the lumbopelvic junction, and to implement appropriate treatment when such points are identified [49].

- **Lever Failure**

A lever failure pertains to dysfunctions within the mechanical system that affects how forces are transmitted through the lever arm formed by the hip joint and associated musculature. Congenital dislocation of the hip and coxa vara, a condition characterised by a reduced angle between the femoral neck and body, are also prevalent causes of hip dysfunction; in these cases, the abnormal upward displacement of the greater trochanter leads to a shortening of the GMed muscle fibres, altering their orientation from vertical to more horizontal and impairing their ability to function effectively as hip abductors [44]. Femoral anteversion significantly affects stability, as greater anteversion enables increased internal rotation but can result in earlier impingement of the posterior neck against the posterior acetabular rim during external rotation. Consequently, excessive femoral anteversion may lead to anterior dislocation [50]. A study revealed that an anterior pelvic tilt (short-arc pelvis-on-femur flexion), results in muscle imbalances, particularly weakening the gluteus maximus and hamstrings due to contractures in the iliopsoas and rectus femoris (as seen in a lower cross syndrome). Additionally, habitual short-arc flexion causes tautness in the iliofemoral and pubofemoral ligaments, which resist hip extension and contribute to Trendelenburg gait by inhibiting hip abduction during the stance phase [51]. Significant shortening, or telescoping, of the femoral neck and intertrochanteric (IT) region following IT fractures has been shown to reduce mobility. This alteration may disrupt the length-tension relationship of the hip abductors, leading to weakness in these muscles and ultimately resulting in a Trendelenburg gait. However, the exact quantitative impact of this shortening on gait remains unclear [52]. Another study highlighted the implications of a neglected fracture of the neck of the femur, defined as one that has not been surgically treated within three weeks of the initial injury. Authors stated that patients with such fractures face a heightened risk of complications, including, avascular necrosis of head of femur, leg length discrepancies, coxa vara, secondary OA, non-union, muscular contractures, pathological gait, and pain in the hip. This condition can also lead to premature closure of the growth plate in children. Clinically, these patients typically present with moderate to severe pain in the groin and anterior thigh and often exhibit a Trendelenburg gait [53].

7. CLINICAL PEARLS

The various conditions contributing to lever, effort, and fulcrum failures exhibit distinct clinical presentations, and the duration of immobilisation or inactivity significantly influences patient outcomes. Recovery rates and prognoses are different in each case. It is imperative to implement a carefully structured loading regimen for the extremities to mitigate the risk of further injury associated with premature or excessive activity. Clinicians must perform comprehensive assessments of each patient's clinical characteristics to determine the appropriate timing for the introduction of weight-bearing activities where necessary. Furthermore, rehabilitation prescriptions should be individualised to align with the specific needs and capacities of each patient. Interprofessional collaboration among healthcare providers is essential to optimise rehabilitation strategies and ensure a comprehensive approach to patient care.

- **Trigger Point Therapy**

One effective treatment approach to mTrPs is manual trigger point therapy, where the therapist uses their hands in a systematic manner to deactivate mTrPs and address related connective tissue changes and movement limitations. Other treatment modalities include dry needling, laser therapy, manual therapy, and acupuncture [45]. By systematically deactivating these trigger points, therapists can enhance blood flow, reduce muscle tension, and alleviate pain in the hip abductors and improve muscle function.

- **Strengthening Exercises**

Progressive resistance training for the GMed and GMin can be done weight-bearing (closed kinetic chain) or non-weight bearing (open kinetic chain) positions. In open kinetic chain (OKC) exercises, the distal segments of the body are not fixed and can move freely, whereas in closed kinetic chain (CKC) exercises, these distal segments remain stationary and in contact with the ground [54]. Both OKC and CKC exercises play a crucial role in rehabilitation, as OKC exercises are effective for isolating specific muscles, while CKC exercises enhance joint stability and functional strength by engaging multiple muscle groups simultaneously. Additionally, OKC exercises allow for strengthening the muscles around a joint without placing much load or weight on that joint, making them particularly useful when there is a need to avoid joint loading or weight-bearing activities during recovery.

- **Biofeedback**

Surface electromyography (SEMG) biofeedback is a valuable tool for therapeutic interventions and assessments, as it enables patients to recognise their subtle muscle contractions, thereby motivating them to perform additional contractions. The main goals of SEMG biofeedback are to enhance maximum voluntary neuromuscular activity that is centrally mediated, differentiate between desired and undesired neuromuscular activity, and improve the patient’s overall control over their neuromuscular function [55]. Using biofeedback techniques can be beneficial for strengthening weak hip abductors to help correct Trendelenburg’s sign or gait.

- **Neuromuscular Re-education**

Incorporating balance and proprioceptive training is essential to improving coordination and control during functional activities. Balance control is fundamentally reliant on sensory feedback from muscle spindles and Golgi tendon organs, which help regulate postural stability against the forces of gravity and inertia in both stationary and moving situations. Effective balance is achieved through the coordination of sensory information and motor responses. Static balance involves maintaining an upright position with minimal movement over a stable base, whereas dynamic balance refers to the ability to stay stable while engaging in activities that involve a shifting base of support [56]. Proprioceptive Neuromuscular Facilitation (PNF) is a rehabilitation technique that activates the proprioceptive system through specific diagonal movements, facilitating improved muscle responses. This method allows weak muscles to perform better with the support of opposing muscles rather than functioning in isolation. As a result, PNF is commonly used in rehabilitation for individuals with compromised muscle or joint function. Furthermore, adding elastic band exercises to PNF can enhance the effectiveness of the rehabilitation programme and lead to better performance improvements [57].

- **Manual Therapy**

Manual therapy is a technique that applies passive movements to joints, classified as either mobilisation or manipulation, and includes methods such as oscillatory techniques and sustained stretching. Its primary goals are to reduce pain, improve joint movement and quality, enhance nerve mobility, increase muscle length, and restore normal function. The effects of manual therapy can be understood through physiological, biomechanical, and psychological lenses: it alleviates pain through mechanisms like the pain gate theory, improves tissue flexibility and fluid dynamics for healing, and elicits positive responses from physical contact and the therapeutic relationship between patient and therapist [58]. Techniques such as myofascial release and joint mobilisation can alleviate pain and improve joint mechanics, facilitating better fulcrum function.

- **Walking Canes**

A cane is a mobility aid typically designed as a long, slender stick that provides support and stability to individuals while walking.

In certain contexts, a reduction of one pound in body weight can lead to a decrease of three pounds in pressure on the hip joint. Moreover, the use of mobility aids, such as walking sticks or crutches, can play a crucial role in alleviating joint pressure and lessening the strain on the hip muscles [29].

The pressure on the head of the femur arises not only from body weight but also from the force exerted by the gluteal muscles. A 1969 paper laid important groundwork by demonstrating that using a cane in the opposite hand can relieve joint pressure and significantly reduce the workload of the hip muscles. The body weight creates a clockwise torque on the hip, which is countered by both the cane and the hip abductors generating an anti-clockwise torque. Consequently, it has been proposed that one effective strategy for re-educating the hip abductors involves patients gradually using lighter canes, thereby increasing the demand on their gluteal muscles over time [25].

Using a cane in the same hand as the affected side can help alleviate some pressure on the hip joint by allowing approximately 15% of a person's body weight to be transferred to the cane rather than through the hip, resulting in a reduction of hip joint compression; however, this method is less effective than leaning laterally away from the affected side, which can reduce compression even further, and overall, switching the cane to the opposite hand yields significantly better outcomes in terms of support and weight distribution [35].

- **Patient Education**

Patient education is now a crucial aspect of physiotherapy, with numerous professional organisations recommending universal health literacy strategies to ensure that information is clear and accessible to all patients, regardless of their literacy or educational background. This involves using simple language instead of medical jargon, breaking down instructions into small, manageable steps, focusing each session on three main points, and confirming understanding through methods like the teach-back technique. Furthermore, written materials should be designed at a reading level no higher than sixth grade, and incorporating visual aids can significantly enhance patient comprehension [59]. Educate patients on activity modification and the importance of maintaining a healthy weight to reduce stress on the hip joint.

8. FUTURE RESEARCH RECOMMENDATIONS

Future research in physiotherapy should aim to explore the relationship between trigger points in the gluteus medius and minimus muscles and the development of the Trendelenburg sign, as well as their effects on overall hip stability and gait mechanics. Conducting comprehensive assessments that incorporate both the identification of trigger points and functional evaluations could yield valuable insights into how these factors interact and contribute to hip dysfunction. Such studies have the potential to deepen our understanding of the underlying mechanisms at play and inform targeted rehabilitation strategies for individuals displaying signs of hip abductor weakness. Additionally, examining specific changes in muscle recruitment patterns and altered biomechanics that lead to increased joint stress and reduced propulsion during walking - resulting from mechanisms such as effort, fulcrum, or lever failures - can provide important clinical implications. This knowledge will enable clinicians to identify the precise factors contributing to muscle dysfunction, paving the way for more tailored rehabilitation interventions that effectively address the unique challenges faced by patients with hip abductor weakness. Investigating how underlying conditions correlate with variations in Trendelenburg gait could further enhance clinical practice and improve patient outcomes. Ultimately, these knowledge translation efforts will empower practitioners to deliver effective, evidence-based care, thereby enhancing mobility and overall quality of life for individuals affected by hip abductor weakness.

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