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Review

The Influence of Pelvic Tilt and Femoral Torsion on Hip Biomechanics: Implications for Clinical Assessment and Treatment

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Abstract: Background: Hip biomechanics are crucial in understanding movement disorders and joint pathologies. Pelvic tilt and femoral torsion are key factors influencing hip function and stability. This review aims to elucidate their effects on acetabular orientation, hip range of motion (ROM), and associated compensatory mechanisms. Methods: A comprehensive search of databases, including PubMed, Scopus, and Pedro, was conducted. Studies were selected based on Population, Concept, and Context (PCC) criteria, focusing on those examining the relationship between pelvic tilt, femoral torsion, and hip biomechanics. Eight studies were included, utilizing methodologies such as CT imaging, musculoskeletal modeling, and gait analysis, covering populations ranging from asymptomatic adults to elderly women with pelvic retroversion. Results: The review identified significant effects of pelvic retroversion on acetabular anteversion and hip extension. Some studies found no correlation between pelvic index (PI) and acetabular orientation, while others reported a linear increase in acetabular anteversion with pelvic retroversion. Subjects with pelvic retroversion showed greater hip extension. Additionally, femoral anteversion was linked to increased internal rotation and altered hip joint contact forces during gait, with changes in hip ROM and force distribution. No relationship was found between femoral and acetabular anteversion in patients with hip osteoarthritis. Conclusions: Pelvic tilt and femoral torsion significantly affect hip biomechanics, influencing acetabular orientation, ROM, and compensatory mechanisms. Future studies should include symptomatic populations to explore these relationships further. These findings emphasize the critical need for individualized clinical assessments and further research on symptomatic populations to enhance our understanding of pelvic tilt and femoral torsion's impact on hip biomechanics.

Keywords: pelvic tilt; hip biomechanics; gait analysis; compensatory mechanisms; regional interdependence

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1. Introduction

The concept of 'regional interdependence' (RI), introduced in 1955, posits that biomechanical changes in one region of the body affect others. Although the direct literature on this topic is limited, the theoretical foundations of the concept date back to 1955 when Steindler described the human body as a series of interconnected joints, where the movement of one directly influences adjacent joints [1–3]. This biomechanical model suggests that alterations in one region, such as the pelvis, can have repercussions on distally connected areas like the hip and knee [1,4–9]. Clinical practice has embraced this model to support decision-making processes [1,2], with Vaughn highlighting the importance of regional examination to identify disorders in seemingly unrelated structures that contribute to the primary symptom of the patient [10–13]. For instance, a study by Vaughn demonstrated that nonspecific knee pain can be caused by sacroiliac dysfunction [11,14–18]. In clinical evaluation, understanding the biomechanical interactions between the anatomical components of the pelvis and the hip joint is crucial. The pelvis, composed of the sacrum, coccyx, and two os coxae, acts as a key structural unit in transferring body weight from the axial skeleton to the lower limbs [19]. The joints within the pelvis, such as the sacroiliac joint and the pubic symphysis, contribute to the overall stability of the pelvic structure and its ability to facilitate complex movements in the sagittal, frontal, and transverse planes [20,21]. The hip joint, formed by the acetabulum and the femoral head, is critical for maintaining mobility and stability during movement [22]. Variations in the orientation of the acetabulum, such as anteversion and retroversion, significantly influence hip biomechanics and can contribute to pain and pathology [23–26]. Furthermore, femoral neck anteversion (FNA) alters muscle lever arms and contact forces, impacting overall hip biomechanics [27–31]. Despite this knowledge, the relationship between pelvic tilt and the biomechanical characteristics of the hip, such as femoral neck anteversion, acetabular anteversion, and joint mobility, remains inadequately understood [32]. Understanding these interactions is particularly important in pathological conditions like hip osteoarthritis, where alterations in joint biomechanics can exacerbate tissue degradation [33–37]. Inadequate comprehension of the dynamics between pelvic tilt, femoral torsion, and their effects on hip biomechanics such as acetabular orientation, hip range of motion, and compensatory mechanisms can lead to suboptimal clinical assessments and therapeutic interventions [38–42]. To address this gap in the literature, this systematic review aims to systematically analyze the relationship between pelvic tilt and the biomechanical characteristics of the hip. Specifically, it seeks to examine how variations in pelvic tilt influence femoral neck anteversion, acetabular anteversion, and hip mobility in the horizontal, frontal, and sagittal planes. Analyzing these relationships can provide a clearer understanding of the biomechanical interactions affecting the hip and pelvis, thus improving clinical practices and therapeutic treatments. Understanding the biomechanical interplay between the pelvic region, femur, and other adjacent structures is critical for diagnosing and treating various pathologies. For example, pelvic retroversion not only alters acetabular anteversion but also influences hip extension and lumbar spine compensatory mechanisms, which can lead to musculoskeletal dysfunctions. These interactions are particularly significant in patients with hip dysplasia, osteoarthritis, and other degenerative joint diseases. Future research should focus on investigating these correlations in symptomatic populations to refine treatment strategies and enhance clinical outcomes. Utilizing advanced imaging techniques, such as dynamic MRI and 3D gait analysis, will further elucidate how alterations in one region impact the biomechanics of surrounding structures.

The objective of this review is to evaluate the effect of pelvic tilt on femoral neck anteversion, acetabular anteversion, and hip mobility in the three planes of space in the general population, according to the concept of regional interdependence. This study aims to fill existing gaps in the literature and provide new perspectives for the assessment and treatment of hip and pelvic pathologies.

2. Methods

This scoping review was conducted following the methodology of the Joanna Briggs Institute (JBI), applying its Population, Concept, and Context (PCC) framework to define eligibility criteria. Studies were selected if they involved populations with varying pelvic tilt and femoral torsion, focused on the biomechanical impact of these variables (Concept), and were conducted in clinical or experimental settings (Context). The inclusion criteria emphasized studies with robust methodologies, such as randomized controlled trials and observational studies, while grey literature and expert opinions were also considered. Additionally, clear parameters for exclusion were applied, such as studies that lacked proper control groups or did not focus on pelvic and femoral biomechanics. The JBI methodology provides a comprehensive framework for conducting systematic reviews and scoping reviews, which includes detailed guidance on searching, selecting, appraising, and synthesizing evidence. The JBI Manual for Evidence Synthesis outlines specific steps to ensure rigor and transparency in the review process, such as defining clear inclusion and exclusion criteria, systematic searching of multiple databases, and using standardized data extraction tools.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist was used to draft this article. PRISMA-ScR is an extension of the PRISMA guidelines specifically designed for scoping reviews. It provides a structured approach to reporting scoping reviews, ensuring clarity and completeness in presenting the review process and findings. This checklist includes essential items such as the rationale for the review, detailed search strategies, inclusion criteria, and methods for data synthesis [43–45].

2.1. Research Question

The research question guiding this review is: “This review seeks to explore how variations in pelvic tilt influence the acetabular orientation, femoral neck anteversion, and overall hip mobility across three spatial planes”.

2.2. Eligibility Criteria

Studies were selected based on the Population, Concept, and Context (PCC) criteria:

Population (P): This criterion refers to the characteristics of the participants in the included studies. Eligible studies had to involve adolescents and adults (aged from 10 to 80 years) without previous surgical interventions affecting the pelvis or hip. These participants were meant to represent the general population, rather than individuals with specific hip or pelvic pathologies, with natural variations in pelvic tilt and femoral torsion.

Concept (C): This refers to the main research concept studied, which is the effect of pelvic tilt and related parameters (such as femoral neck anteversion and acetabular anteversion) on hip mobility across the three spatial planes (horizontal, frontal, and sagittal). The studies needed to focus on how these biomechanical variables influence hip joint function and compensatory mechanisms.

Context (C): The context concerns the setting and conditions in which the research was conducted. The studies had to be set in clinical or experimental settings that examined the biomechanical and functional correlations between the pelvic girdle and the hip joint. This included biomechanics labs, clinical studies, and research on posture and movement, without geographic or study type limitations.

Exclusion Criteria

Studies that did not meet specific PCC criteria were excluded.

2.3. Search Strategy

The search strategy used was as follows: An initial limited search on MEDLINE was conducted through the PubMed interface to identify relevant articles. This initial search helped to develop a comprehensive search strategy for MEDLINE. Following this, a thorough search was conducted across several databases, including MEDLINE, Cochrane Central, Scopus, and the Physiotherapy Evidence Database (PEDro). The selection process occurred in two stages. Initially, two independent reviewers screened the titles and abstracts of all identified studies based on the predefined eligibility criteria. In the second stage, the full texts of the selected studies were assessed. Discrepancies between the reviewers were resolved through discussion, and when consensus could not be reached, a third expert with extensive experience in systematic review methodology was consulted to adjudicate the final decision. This rigorous process ensured a thorough and unbiased selection of studies, enhancing the reliability and validity of the review. The searches were conducted on 23 April 2023, with no date limitations, using the terms: "pelvic tilt" AND "hip mobility" OR "acetabular anteversion" AND "femoral neck anteversion" OR "regional interdependence" AND "hip biomechanics" OR "pelvis" AND "hip joint" AND "biomechanics" OR "pelvic incidence" AND "hip function" OR "pelvic tilt" AND "femoral anteversion" OR "pelvic bones" AND "hip range of motion" OR "hip anatomy" AND "pelvic alignment" OR "acetabulum" AND "femoral neck" AND "torsion" OR "lumbo-pelvic motion" AND "hip kinematics", "pelvic tilt" AND "hip mobility" OR "acetabular anteversion" AND "femoral neck anteversion" OR "regional interdependence" AND "hip biomechanics" OR "pelvis" AND "hip joint" AND "biomechanics" OR "pelvic incidence" AND "hip function" OR "pelvic tilt" AND "femoral anteversion" OR "pelvic bones" AND "hip range of motion" OR "hip anatomy" AND "pelvic alignment" OR "acetabulum" AND "femoral neck" AND "torsion" OR "lumbo-pelvic motion" AND "hip kinematics". MESH Terms: "Bone Anteversion" OR "Hip Joint" OR "Pelvic Bones" OR "Pelvic Incidence" OR "Acetabulum" OR "Acetabulofemoral Joint".

2.4. Study Selection

The study selection process was systematic and involved refining search results using the document management program ZOTERO for duplicate removal. The selection process occurred in two stages: an initial review of titles and abstracts, followed by a full-text assessment. These stages were conducted independently by two experts in the field of podiatry and footwear research, with a third expert, specialized in systematic review methodology, stepping in to resolve discrepancies such as differences in the selection of full-text articles for review. It is important to note that studies selected for the review were not critically appraised, as per the standard protocol for scoping reviews.

2.5. Data Extraction and Synthesis

In the data extraction and synthesis phase, relevant data were extracted from the included articles based on predefined criteria, including information on participants, interventions, comparisons, outcomes, and study conclusions. Specific data related to shoe fit, choice, and conditions were categorized into these broader criteria. For example, data on well-being and disorders were included under outcomes, while specific shoe fit interventions were classified under interventions. A qualitative synthesis was performed to integrate this information, focusing on how it addressed the primary research question. The analysis approach involved thematic synthesis, where key themes and patterns were identified across the studies to provide a comprehensive understanding of the impact of shoe fit on foot health and overall well-being.

3. Results

The flowchart of article selection is presented in Figure 1. A total of 607 records were initially identified through bibliographic searches across different databases: MEDLINE (373 records), Scopus (89 records), PEDro (64 records), Cochrane central (81 records), and grey literature. After removing 187 duplicates using an automated reference management tool, a manual check was performed to ensure no additional duplicates remained. Duplicates were identified based on matching titles, authors, publication years, and DOIs. Articles that appeared multiple times due to being indexed in different databases were consolidated, retaining only the most complete version. The exclusion criteria also included studies that were not peer-reviewed, lacked full-text availability, or did not focus on the relationship between pelvic tilt, femoral torsion, and hip biomechanics. This comprehensive approach to managing duplicates ensured a streamlined dataset for further screening. Of these, 20 were screened based on titles and abstracts, and 12 were excluded for not meeting the inclusion criteria or because they did not align with the objective of this review. The full texts of eight reports were assessed for eligibility. Eight studies were finally included in the review (Table 1). The quality of the studies was assessed with the MINORS scale (Table 2).

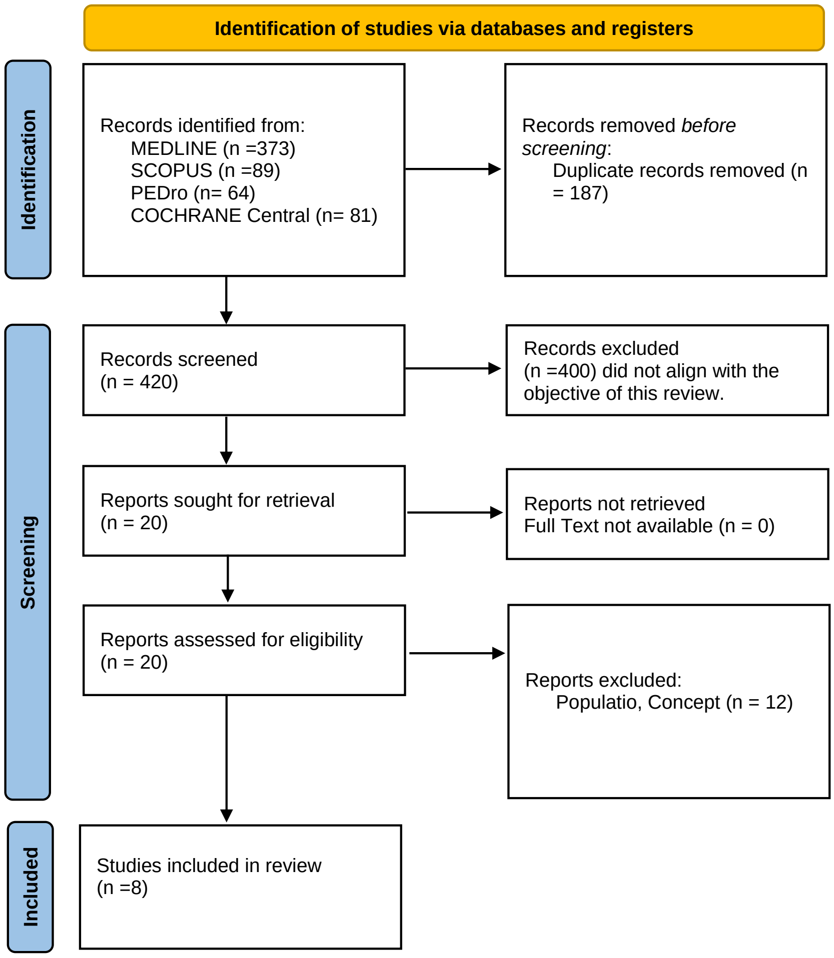

Figure 1. Preferred reporting items for systematic reviews and meta-analyses 2020 (PRISMA) flow-diagram.

Table 1. Main characteristics of included studies.

Author and Year	Title	Methods	Number of Subjects	Sex	Mean Age (Years)	Results	Outcomes Achieved
Jung-Taek Kim et al., 2021 [23]	No linear correlation between pelvic incidence and acetabular orientation	CT scans of 100 pelvises (50 male, 50 female), aged 25–39 years, analyzed for pelvic incidence and acetabular orientation using 3D reconstruction.	100	50 male, 50 female	25–39	No significant correlation between pelvic incidence and acetabular orientation. Males had less anteversion (13.2° ± 4.9°) compared to females (17.5° ± 5.6°).	Clarified the lack of correlation between pelvic incidence and acetabular orientation; provided gender-specific insights.

Table 1. *Cont.*

Author and Year	Title	Methods	Number of Subjects	Sex	Mean Age (Years)	Results	Outcomes Achieved
S. Zilber et al., 2004 [46]	Variations of caudal, central, and cranial acetabular anteversion according to the tilt of the pelvis.	Analysis of 12 pelves (9 cadaveric, 3 live; 7 female, 5 male; average age 57.6 years) at four different pelvic inclinations using CT scans to measure acetabular anteversion.	12	7 female, 5 male	57.6	Increase in acetabular anteversion with increased pelvic retroversion. Anteversion decreased from caudal (52°) to cranial sections (2°) at 60° pelvic tilt.	Established the impact of pelvic inclination on acetabular anteversion, aiding in clinical assessments.
Sasaki et al., 2017 [27]	Evaluation of Sagittal Spine-Pelvis-Lower Limb Alignment in Elderly Women with Pelvic Retroversion while Standing and Walking Using a Three-Dimensional Musculoskeletal Model	Evaluation of 32 elderly women (20 with pelvic retroversion, 12 with normal alignment; mean age 78 years) using a 3D musculoskeletal model to assess spinal and pelvic parameters.	32	32 female	78	Pelvic retroversion correlated with increased sagittal parameters (PT, PI-LL, TPA) and decreased hip flexion. Group R had significantly higher PT (31.1° ± 7.4°) compared to Group N (15.5° ± 3.6°).	Identified significant effects of pelvic retroversion on spinal and hip alignment, aiding in preoperative planning.
Kathryn Kumagai et al., 2015 [47]	Regional interdependence of the hip and lumbo-pelvic region in division II collegiate level baseball pitchers: a preliminary study. International Journal of Sports Physical Therapy	Assessment of 29 collegiate baseball pitchers (23 right-handed, 6 left-handed; average age 20.0 ± 1.4 years) for passive hip rotation, muscle strength using a digital dynamometer, and motor control using the active rotation test.	29	23 right-handed, 6 left-handed	20.0 ± 1.4	Differences in hip rotation and muscle strength observed. Right hip IR was 35.2° ± 9.5°, ER was 45.1° ± 11.3°; left hip IR was 34.7° ± 9.2°, ER was 43.9° ± 11.1°.	Provided preliminary evidence for the impact of hip mechanics on athletic performance and injury prevention.

Table 1. *Cont.*

Author and Year	Title	Methods	Number of Subjects	Sex	Mean Age (Years)	Results	Outcomes Achieved
Enrico De Pieri et al., 2021 [48]	Subject-Specific Modeling of Femoral Torsion Influences the Prediction of Hip Loading During Gait in Asymptomatic Adults	Analysis of 37 asymptomatic adults (15 female, 22 male) using personalized musculoskeletal models based on motion-capture data and low-dose radiographic images.	37	15 female, 22 male	Not specified	Increased femoral anteversion led to alterations in muscle lever arms and compensatory mechanisms, impacting intrinsic muscle forces and hip joint contact forces.	Highlighted the relationship between femoral torsion and hip joint mechanics, emphasizing the need for comprehensive assessments.
Keisuke Uemura et al., 2018 [49]	Hip rotation during standing and dynamic activities and the compensatory effect of femoral anteversion: An in-vivo analysis of asymptomatic young adults using three-dimensional computed tomography models and dual fluoroscopy	Examination of 18 asymptomatic subjects (11 included, 7 excluded due to radiographic deformities) using 3D CT and dual fluoroscopy to measure femoral anteversion and hip rotation in static and dynamic conditions.	18	11 male	Not specified	Strong positive correlations between static and dynamic hip rotation, with greater femoral anteversion linked to increased internal rotation during dynamic activities.	Demonstrated the importance of femoral anteversion in influencing hip rotation dynamics.
Elyse Passmore et al., 2018 [33]	Hip- and patellofemoral-joint loading during gait are increased in children with idiopathic torsional deformities	Creation of specific musculoskeletal models for 15 patients (12 included, 3 excluded) with torsional deformities using biplanar radiography and 3D gait analysis.	15	4 male, 11 female	Not specified	Femoral neck anteversion and external tibial torsion increased internal hip rotation and decreased knee extensor efficacy during gait, leading to altered joint contact forces.	Highlighted the impact of torsional deformities on joint mechanics and the importance of individualized assessments.

Table 1. *Cont.*

Author and Year	Title	Methods	Number of Subjects	Sex	Mean Age (Years)	Results	Outcomes Achieved
O Reikerås et al., 1983 [50]	Influence of spino-pelvic and postural alignment parameters on gait kinematics	CT scans of 86 individuals (47 healthy, 39 with osteoarthritis) to measure acetabular and femoral neck anteversion and examine their relationship in different conditions.	86	26 female, 21 male (healthy), 27 female, 12 male (osteoarthritic)	Not specified	No significant relationship between femoral and acetabular anteversion in osteoarthritic hips, suggesting altered adaptation mechanisms in diseased conditions.	Questioned the direct relationship between femoral and acetabular anteversion in pathological states, indicating the need for further research.

Legend: CT: C-PT: cervical–pelvic tilt, C-SVA: cervical–sagittal vertical axis, C-TPA: cervical–T1 pelvic angle, CT: computed tomography, ER: external rotation, HCF: hip contact force, IR: internal rotation, PI: pelvic incidence, PI-LL: pelvic incidence–lumbar lordosis, PT: pelvic tilt, ROM: range of motion, TPA: T1 pelvic angle.

Table 2. MINORS scale.

Study	Total Score
Jung-Taek Kim et al., 2021 [23]	12
S. Zilber et al., 2004 [46]	11
Sasaki et al., 2017 [27]	15
Kathryn Kumagai et al., 2015 [47]	13
Enrico De Pieri et al., 2021 [48]	12
Keisuke Uemura et al., 2018 [49]	16
Elyse Passmore et al., 2018 [33]	12
O Reikerås et al., 1983 [50]	14

Methodological Index for Non-Randomized Studies (MINORS) table for evaluating the quality of the eight studies. The MINORS criteria include 12 items (the first 8 items for non-comparative studies and all 12 items for comparative studies), each scored from 0 to 2. The maximum possible score is 16 for non-comparative studies and 24 for comparative studies.

3.1. Pelvic Tilt and Acetabular Anteversion

Several studies explored the relationship between pelvic tilt and acetabular anteversion, yielding mixed results:

Jung-Taek Kim et al. (2021) [23] found no significant correlation between pelvic incidence and acetabular orientation in a sample of 100 pelvises, with males exhibiting less anteversion compared to females ($13.2° \pm 4.9°$ in males vs. $17.5° \pm 5.6°$ in females).

S. Zilber et al. (2004) [46], however, demonstrated that increasing pelvic retroversion led to a linear increase in acetabular anteversion. Specifically, as pelvic tilt increased to 60°, acetabular anteversion decreased from caudal (52°) to cranial sections (2°), indicating that pelvic retroversion significantly impacts acetabular orientation.

3.2. Pelvic Retroversion and Hip Extension

The study consistently noted that pelvic retroversion leads to increased hip extension:

Sasaki et al. (2017) [27] evaluated 32 elderly women and found that those with pelvic retroversion had significantly higher pelvic tilt ($31.1° \pm 7.4°$) compared to those with normal alignment ($15.5° \pm 3.6°$). This resulted in greater hip extension ($-6.9° \pm 5.9°$ for the retroversion group vs. $-4.5° \pm 8.5°$ in the control group).

3.3. Femoral Anteversion and Internal Rotation

Several studies highlighted the relationship between femoral anteversion and internal hip rotation:

Enrico De Pieri et al. (2021) [48] showed that increased femoral anteversion altered muscle lever arms and led to compensatory mechanisms, including increased internal rotation during gait. This internal rotation compensated for altered hip joint contact forces and stabilized joint movement.

Keisuke Uemura et al. (2018) [49] confirmed that subjects with increased femoral anteversion displayed greater internal rotation during both static and dynamic conditions. This was particularly noticeable during gait, where internal hip rotation ranged from 2.8° to 11.8° throughout different phases.

3.4. Torsional Deformities and Joint Mechanics

The effects of torsional deformities on joint mechanics were evaluated, particularly in pediatric populations:

Elyse Passmore et al. (2018) [33] studied children with idiopathic torsional deformities and found that increased femoral neck anteversion (mean: 38° ± 9°) and external tibial torsion (mean: 40° ± 10°) significantly affected hip and knee joint mechanics. These deformities increased internal hip rotation during gait, decreased knee extensor efficiency, and altered hip joint contact forces.

3.5. Lack of Correlation in Osteoarthritic Hips

One study examined the correlation between femoral and acetabular anteversion in individuals with osteoarthritis:

O. Reikerås et al. (1983) [50] found no significant relationship between femoral and acetabular anteversion in patients with hip osteoarthritis. This suggests that in pathological conditions such as osteoarthritis, the normal biomechanical relationship between femoral and acetabular orientation, may be disrupted due to disease-related changes in joint structure.

3.6. Compensatory Mechanisms in Athletic Populations

The role of compensatory mechanisms in athletes, particularly in sports with high demands on hip mobility, was highlighted:

Kathryn Kumagai et al. (2019) [47] assessed collegiate baseball pitchers and found significant asymmetry in hip internal and external rotation between the dominant and non-dominant limbs. This asymmetry may predispose athletes to injury by overloading the lumbopelvic region to compensate for limited hip rotation.

Jung-Taek Kim et al. [23] (2021)

Findings: No significant correlation between pelvic incidence and acetabular orientation; gender differences observed in acetabular anteversion.

Limitations: No inclusion of symptomatic subjects.

S. Zilber et al. [46] (2004)

Findings: Linear increase in acetabular anteversion with pelvic retroversion.

Limitations: Small sample size, mostly elderly cadavers.

Sasaki et al. [27] (2017)

Findings: Pelvic retroversion correlates with increased hip extension in elderly women.

Limitations: Study only included older women.

Kathryn Kumagai et al. [47] (2015)

Findings: Asymmetry in hip rotation among baseball players, suggesting compensatory mechanisms.

Limitations: Small sample size, focused only on male athletes.

Enrico De Pieri et al. [48] (2021)

Findings: Increased femoral anteversion impacts muscle lever arms and joint forces.

Limitations: Study focused on asymptomatic adults.

Keisuke Uemura et al. [49] (2018)

Findings: Greater femoral anteversion linked to increased internal hip rotation.

Limitations: Limited sample size and asymptomatic subjects.

Elyse Passmore et al. [33] (2018)

Findings: Torsional deformities in children affect hip and knee joint mechanics.

Limitations: Focused only on pediatric patients with deformities.

O. Reikerås et al. [50] (1983)

Findings: No correlation between femoral and acetabular anteversion in osteoarthritis patients.

Limitations: Small sample size and outdated methods.

4. Discussion

The objective of this study was to examine how pelvic tilt and femoral torsion affect hip biomechanics. The main findings showed that pelvic retroversion increases acetabular anteversion and hip extension, while femoral anteversion significantly influences internal hip rotation during gait. These results highlight the importance of biomechanical interactions for improving clinical assessments and treatments.

This review highlights the main factors for each group of studies presented. The first group of studies made it possible to observe the effect of pelvic tilt (or associated parameters) on acetabular anteversion and hip mobility. The results indicate that pelvic retroversion increases acetabular anteversion and hip extension. The differing interpretations arise from methodological and population differences between the studies. Jung-Taek Kim et al. [23] (2021) found no correlation likely due to analyzing static conditions, while S. Zilber et al. [46] (2004), under dynamic conditions, observed a linear relationship between pelvic retroversion and acetabular anteversion. This review integrates both results, suggesting that pelvic retroversion can influence acetabular anteversion and hip mobility, though the extent may depend on the conditions studied. This is relevant because acetabular orientation is considered a key morphological feature in determining acetabular function and symptoms. However, the effect of pelvic tilt on acetabular orientation remains under-investigated and contentious. The conflicting results between Jung-Taek Kim et al. [23] (2021) and S. Zilber et al. [46] (2004) regarding the effect of pelvic retroversion on acetabular anteversion can be attributed to differences in methodology and population. Kim's study used 3D reconstructions of CT scans focusing on ideal pelvic planes, which might not fully represent dynamic functional movement. In contrast, Zilber analyzed various pelvic inclinations under real-life conditions, providing more dynamic insights. Additionally, Kim's study involved a younger, asymptomatic population, while Zilber's included older individuals and cadaveric samples, highlighting how population differences might affect outcomes.

Notably, two studies presented differing results: Jung-Taek Kim et al. (2021) [23] found no significant correlation between pelvic tilt and acetabular anteversion, while S. Zilber et al. (2004) [46] confirmed that increasing pelvic retroversion linearly increased acetabular anteversion. The divergence in results may have been due to the first study analyzing pelvic morphological parameters (PI) on an ideal plane not reflecting the real plane, whereas the second study assessed acetabular anteversion variations at the caudal, central, and cranial levels in four different dorsoventral pelvic inclination positions, providing more clinically relevant insights. The mean anteversions at the 0°, 20°, 40°, and 60° sacral gradients were:

Caudal anteversions: 52°, 48°, 31°, and 15°.

Central anteversions: 45°, 36°, 26°, and 11°.

Cranial anteversions: 44°, 39°, 26°, and 2°.

The discrepancy between the findings of Jung-Taek Kim et al. [23] (2021) and S. Zilber et al. [46] (2004) regarding the relationship between pelvic tilt and acetabular anteversion can be explained by methodological differences. Kim's study used CT scans and 3D reconstructions to analyze pelvic incidence in static conditions, which may not fully capture the dynamic nature of pelvic movement. In contrast, Zilber's approach assessed acetabular anteversion across different sacral gradients (0°, 20°, 40°, 60°), providing more clinically relevant insights by accounting for varying dorsoventral pelvic inclinations. This difference in the measurement techniques and the focus on dynamic vs. static analysis likely explains the contradictory results. Pelvic retroversion, in addition to increasing acetabular anteversion, also resulted in increased hip extension. Ken Sasaki et al. (2017) [27] demonstrated that subjects with kyphosis attempted to maintain an upright position and walk using compensatory mechanisms, such as pelvic retroversion (>20°), leading to hip hyperextension. Subjects with retroversion had a hip extension of −6.9° ± 5.9°, while those without retroversion had −4.5° ± 8.5°. The finding that subjects with pelvic retroversion had a hip extension of −6.9° ± 5.9° has important clinical implications. Increased hip extension due to pelvic retroversion can lead to altered biomechanics, particularly during walking and weight-bearing activities. This compensatory mechanism might help maintain balance and posture, especially in individuals with spinal misalignment or kyphosis. However, this increased extension may also place added stress on the hip joint, potentially contributing to joint degeneration or discomfort over time.

From a rehabilitation perspective, understanding these biomechanical changes is crucial for developing effective treatment plans. For example, therapies should focus on improving pelvic alignment and hip mobility to reduce compensatory movements, which could otherwise exacerbate joint stress. Strengthening exercises for the hip extensors, along with postural correction strategies, may help alleviate symptoms and improve overall function in patients with pelvic retroversion. Manual therapy and gait retraining may also be employed to address the altered movement patterns caused by this hip extension.

Furthermore, the studies analyzed indicate that pelvic incidence (PI) is a crucial morphological parameter that regulates sagittal balance and influences spinal and hip positional parameters. Sagittal imbalance, due to increased spinal kyphosis or posterior pelvic tilt, is a critical factor affecting the quality of life. Kathryn Kumagai et al. (2015) [47] highlighted that retroverted hip orientation can cause conflicts between the femoral neck and the anterior acetabulum, limiting ROM, especially during rotational activities. The close proximity of the hip to the lumbopelvic region can predispose the lumbar area to excessive rotational forces when the proximal regions compensate for limited hip rotation. Regional interdependence between the lumbopelvic region and the hip is crucial for assessing excessive compensatory strategies. The second group of studies examined the effect of femoral neck torsion on hip adaptation in the three spatial planes. Three studies demonstrated that increased femoral anteversion leads to more pronounced internal hip rotation during gait, decreased abductor lever arms, and increased contact forces. Enrico De Pieri et al. (2021) [48] evaluated the effect of femoral torsion alone on hip loads, excluding parameters such as acetabular coverage, acetabular retroversion, and joint deformities. With increased femoral anteversion, a compensatory internal hip rotation (20°) occurred during the transition from stance to swing phases to restore abductor lever arms and stabilize the joint during dynamic movements. Keisuke Uemura et al. (2018) [49] confirmed that internal hip rotation during gait ranges from 2.8° to 11.8°, present throughout the stance phase and during mid-to-terminal swing phases. This study correlated femoral anteversion of 15.7° ± 6.3° with static internal hip rotation. Subjects with greater internal hip rotation in standing (≥11.3°) exhibited greater internal rotation during gait. Keisuke Uemura et al. [49] (2018) demonstrated that femoral anteversion leads to increased internal hip rotation during dynamic activities, which is particularly relevant in the context of symptomatic patients. In symptomatic individuals, such as those with hip pain or gait abnormalities, excessive femoral torsion can alter joint mechanics and increase the load on the hip joint, potentially leading to discomfort or further joint degeneration.

This altered internal rotation creates compensatory mechanisms that may not only affect the hip but also other regions, such as the knee and lumbar spine, as these areas attempt to maintain functional movement. In rehabilitation, addressing femoral torsion is critical for symptomatic patients, as it directly influences joint stability and muscle function during activities like walking. Therapeutic strategies might include exercises aimed at improving hip alignment, joint stabilization, and correcting abnormal gait patterns to prevent excessive internal rotation and reduce pain.

By focusing on these biomechanical abnormalities, clinicians can tailor rehabilitation to the specific needs of symptomatic patients, aiming to restore balanced hip mechanics and prevent further complications.

However, these studies were conducted on healthy subjects, suggesting the need for future studies to include symptomatic patients with excessive femoral anteversion, who might exhibit more pronounced compensatory mechanisms to prevent pain. Elyse Passmore (2018) [33] studied children and adolescents, highlighting that torsional deformities at both the femoral neck and diaphysis levels increase compressive and medio-lateral contact forces in the hip and patellofemoral joints. Patients in this study had torsional deformities in both femurs and tibias with a mean femoral neck anteversion of 38° ± 9°, a mean neck-shaft angle of 133° ± 5°, and a mean external tibial torsion of 40° ± 10°. These subjects showed an increased hip internal rotation ROM of 13° (95% CI: 7°–19°), decreased external rotation ROM of 19° (95% CI: 13°–25°), increased abduction ROM of 11° (95% CI: 6°–16°), and increased knee extension ROM of 4° (95% CI: 2°–6°) compared to controls. Increased external tibial torsion during the stance phase, if associated with ligamentous laxity, can lead to knee pain and patellar instability. Thus, femoral anteversion, through altered kinematic strategies and muscle activations, can lead to altered contact forces and an increased risk of joint damage, necessitating comprehensive and functional assessments. The third group of studies examines the effect of acetabular anteversion relative to femoral neck anteversion. O. Reikerås et al. (1983) [50] reported no relationship between femoral and acetabular anteversion in subjects with coxarthrosis. However, empirical reasoning and the results of other included studies suggest that pelvic retroversion is correlated with increased acetabular anteversion and hip extension but not with femoral torsion. The lack of correlation in O. Reikerås's study may have been due to the presence of coxarthrosis, suggesting that osteoarthritic deformities of the femoral neck could confound the results, presenting a different acetabulum-femoral neck relationship in the non-coxarthrotic population. This reasoning suggests a potential linear relationship between pelvic anteversion/retroversion and femoral torsion, particularly in relation to hip mobility and compensatory mechanisms. However, future research should focus on specific areas such as symptomatic populations (e.g., patients with osteoarthritis or hip dysplasia) to determine if the biomechanical alterations observed in asymptomatic subjects apply to these conditions. Additionally, the use of dynamic imaging techniques, such as dual fluoroscopy, could provide a more detailed understanding of how changes in pelvic tilt affect hip biomechanics during functional activities. Moreover, it would be valuable to investigate how these parameters influence the outcomes of different therapeutic interventions, including exercise-based rehabilitation and corrective surgery, to refine clinical guidelines and improve patient care. This more targeted approach could help fill existing gaps in understanding the interaction between pelvic and femoral mechanics in both clinical and functional contexts.

4.1. Limitations of the Review

A major limitation of this review is the methodological variability among the included studies, which likely affected the consistency and comparability of the results. Different studies used diverse imaging techniques (e.g., CT scans vs. dynamic fluoroscopy), population characteristics (asymptomatic vs. symptomatic), and biomechanical parameters, making it difficult to draw uniform conclusions. These inconsistencies could lead to varying interpretations of how pelvic tilt and femoral torsion affect hip biomechanics.

To address these limitations, future research should aim for standardized methodologies, including the use of dynamic imaging techniques to capture real-time biomechanics, and should focus on larger, more diverse populations, particularly those with clinical conditions. By adopting more consistent approaches, researchers can produce more comparable and clinically relevant results.

Many studies in this review focused on healthy populations, which limits the applicability of the findings to clinical settings. Future research should prioritize including patients with specific conditions, such as osteoarthritis, femoroacetabular impingement, or hip dysplasia, to better understand how pelvic tilt and femoral torsion affect biomechanics in symptomatic individuals. By studying these populations, researchers can derive more clinically relevant insights, helping to tailor therapeutic interventions and improve outcomes for patients experiencing pain or dysfunction due to altered hip mechanics. This approach would enhance the clinical applicability of the research and inform more targeted treatment strategies. Some studies used small sample sizes, reducing the statistical power of the results. Most studies utilized radiographic or CT measurements, which may not accurately reflect dynamic movement during daily activities.

4.2. Clinical Implications

The clinical implications of this review are pertinent for the evaluation and treatment of pelvic and hip dysfunctions. The findings suggest that pelvic retroversion can significantly influence acetabular anteversion and hip mobility, necessitating thorough assessment of pelvic inclinations in patients with hip-related symptoms. Moreover, femoral anteversion and its biomechanical consequences should be considered in treatment planning, especially in patients with torsional deformities. Understanding the biomechanical interactions between the pelvis and hip can enhance diagnostic accuracy and inform targeted therapeutic interventions, ultimately improving patient outcomes.

5. Conclusions

This review highlights the impact of pelvic tilt and femoral torsion on hip biomechanics. Pelvic retroversion increases acetabular anteversion and hip extension, while femoral anteversion impacts internal rotation during gait and joint contact forces. Clinicians can apply these findings in treating patients, especially runners, by focusing on hip alignment and mobility. For instance, patients with excessive pelvic retroversion may benefit from exercises aimed at improving hip extension control and postural alignment to prevent excessive joint stress. In cases of femoral anteversion, addressing internal rotation mechanics through targeted strengthening and mobility exercises can help improve gait patterns and reduce the risk of overloading the hip joint, thus enhancing performance and reducing injury risk. These findings emphasize the importance of considering regional interdependence in clinical assessments and treatments. Future research should focus on symptomatic patients to better understand these biomechanical relationships. Clinically, a detailed evaluation of pelvic and femoral parameters is crucial for effective diagnosis and treatment. Clinicians should use dynamic imaging tools, such as 3D gait analysis, dual fluoroscopy, or motion capture systems, to assess real-time pelvic tilt and femoral torsion during functional activities like walking or running. Additionally, ultrasound and MRI can be useful for evaluating soft tissue and joint alignment. Incorporating these tools into regular assessments allows for a more precise understanding of biomechanical deviations and helps guide tailored rehabilitation strategies, including postural correction and targeted strength training.

6. Patents

Patient's consent was not required as there were no patients in this study.

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