"FUNCTIONAL OUTCOME ANALYSIS OF COLUMN SPECIFIC FIXATION IN THE MANAGEMENT OF PROXIMAL TIBIAL FRACTURES"

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ABBREVIATIONS

ACL	:	Anterior Cruciate Ligament
PCL	:	Posterior Cruciate Ligament
MCL	:	Medial Collateral Ligament
LCL	:	Lateral Collateral Ligament
AP	:	Anteroposterior
CXR	:	Chest X-ray
DVT	:	Deep Vein Thrombosis
PE	:	Pulmonary Embolism
SD	:	Standard Deviation
TKA	:	Total Knee Arthroplasty
VAS	:	Visual Analogue Scale

ABSTRACT

Introduction:

Tibial plateau fractures commonly refer to intraarticular fractures of proximal tibia are mostly caused by high-energy injuries or even slight strike in the elderly, and the majority of patients suffering from such fractures present with soft tissue and nerve injuries, which have still not been treated properly and completely until now and can lead to poor prognosis in patients. Therefore, this condition requires a prompt interventional surgery for the sake of protecting patients' knee joint function, which should be conducted with stringent specification as the differences in various approaches have a decisive effect on treatment efficacy [1]. Also, the traditional treatment guided by the Schatzker classification has some drawbacks in terms of precision, especially in describing posterior tibial plateau fractures in patients [2].

Studies conducted in recent years have shown that the traditional theory of fracture classification has been unable to meet clinical needs. For example, the theoretical basis of Schatzker classification is two-dimensional images, characterized by superposition, thus hardly fully demonstrating the spatial relationship of the tibial plateau and then leading to some errors. However, the theory of three-column classification, in which the tibial columns are classified into 3 parts, proposed by the scholar Congfeng Luo [1], enables orthopaedist to enrich their perceptions of disparate fracture types and then enhance the scientificity in the selection of surgical approaches, comprehensively optimizing the therapeutic effects of the surgical treatment for tibial plateau fractures [2].

As there is lack of enough evidence and research regarding this in Indian population, we propose to explore the effects of surgical treatment guided by the three-column classification method on knee joint function and postoperative complications in patients with proximal tibial fractures.

Objective:

To assess and analyze the functional outcome of proximal tibial fractures fixed according to 3 column classification after a follow up period of 6 months.

Methods:

Our prospective study was conducted in Dr. Prabhakar Kore Hospital and Medical Research Centre. After institutional ethical committee approval, 26 patients presenting with tibial plateau fractures underwent systematic clinical and radiological evaluation, and those meeting the selection criteria (23 patients) were enrolled in the study. 3 patients were excluded. The study was aimed to analyze the functional outcomes of surgically managed tibial plateau fractures over a six-month follow-up period using Modified Rasmussen Functional Scoring System and VAS score.

Results:

In our study, 82.6% of the patients were males and road traffic accidents [82.6%] were the major cause of injury. 34.8% of the patients had 1 column fracture while 43.5 % of them had two column and 21.7% had three column fracture respectively. By the end of 6 months 47.8% of the subjects had 'Excellent' outcome, 47.8% of the patients had 'Good' while only 4.34% of the patients had 'Fair' outcomes as per Modified Rasmussen Scoring System. 78.2% of the patients experienced 'Mild' and 21.7% had 'Moderate' pain levels as per VAS score and had resumed their pre-injury activities. Complications, such as knee stiffness 8.7%, post-operative infection being 4.3%, no instances of implant prominence or failures and 82.6% had nil complications.

Conclusion:

Our study's outcomes indicate that column-specific fixation, guided by the three-column classification, enhances functional recovery in complex fracture scenarios. By strategically stabilizing individual columns, this method minimizes soft tissue damage and promotes better postoperative rehabilitation. Conversely, the Schatzker's classification, while effective for simpler fracture patterns, may not adequately address the intricacies of multi-fragmentary and comminuted fractures, potentially leading to suboptimal alignment and functional results.

In conclusion, adopting precise classification system and implementing column-specific fixation are crucial for optimizing functional outcomes in proximal tibial fractures. The three-column classification offers a comprehensive framework for managing complex fracture patterns, thereby improving stability, alignment, and overall recovery.

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INTRODUCTION

Proximal tibial fractures, commonly referred to as "tibial plateau fractures," are a significant challenge to orthopedic surgeons because they have a high tendency to affect the articular surface of the knee, which can compromise the stability and mobility of this weight-bearing joint [1,2]. These fractures most often occur from high-energy mechanisms, including traffic accidents and falls from considerable heights, but can also be seen in low-energy mechanisms in the elderly with osteoporotic bone stock [3]. In addition to the bony injury, secondary compromise of surrounding soft tissues or nerves can cloud outcomes, often necessitating aggressive, multi-modal therapy. Re-establishment of articular congruity and stable internal fixation is an absolute priority; failure to accomplish this contributes significantly to chronic pain, stiffness, instability, post-traumatic osteoarthritis, and long-term functional impairment [4,5].

Historically, the most common system that has been used for the categorization of tibial plateau fractures is Schatzker classification [6,7]. Developed in the 1970s, based on plain radiographs, Schatzker's classification divided tibial plateau fractures into six types, focusing on the fracture pattern and severity [2]. Due to its lucidity, prevalence and commonality of use, critics say that plain radiographs are not exactly sufficient in presenting the three-dimensional anatomy of these fractures [8]. Moreover, when computing and imaging technologies evolved, the use of two-dimensional images for diagnosis and treatment planning tends to leave loopholes in terms of the subtle spatial relationship between the medial, lateral, and posterior columns of the proximal tibia [9]. Misidentification of fracture lines or critical fragments may result in poor surgical planning, thus elevating the risk of complications like malunion or varus/valgus collapse [10,11]. This is particularly important in posterior tibial plateau fractures, which tend to be underestimated or underestimated on plain radiographs [12].

As awareness of the shortcomings of two-dimensional classification grows, more recent systems have appeared to better delineate fracture anatomy [13]. Among these, the three-column classification put forward by Luo and co-workers has drawn much attention due to the increased utility in surgical planning in those fractures [1]. Luo divided his model into medial, lateral, and posterior columns of the proximal tibia by specific anatomical landmarks. Axial, coronal, and sagittal views from CT can better understand the fracture morphology and patterns of displacement [1,14]. This fine understanding further enables surgeons to choose a more specific surgical approach, be it anterolateral, posteromedial, posterolateral, or in combination, which then results in improved reduction of fracture and stable fixation [15]. Such precision is deemed critical because mal-reduction of posterior fragments may substantially alter knee biomechanics and accelerate degenerative changes [16].

RATIONALE FOR COLUMN-SPECIFIC FIXATION

Column-specific fracture management strategies follow naturally from the classification into three columns [17]. Instead of solely relying on lateral locked plating or using classic dual plating constructs, a surgeon will often individualize treatment to appropriately address each violated column [18,19]. Biomechanical and clinical studies suggest that a fixation technique tailored to specific fracture zones may yield superior outcomes in terms of articular reduction, stability, and soft tissue preservation [20]. For instance, in bicondylar fractures with a large posteromedial fragment, a targeted posteromedial approach and fixation can significantly reduce the risk of mal-reduction compared to using only an anterolateral approach [21]. The rationale is straightforward: each column, if disrupted, requires independent mechanical support to maintain anatomic alignment, so an all-encompassing fixation plan is usually the most stable solution [14,22]. However, while the theoretical advantages of column-specific fixation are compelling, further evidence-based corroboration, especially within different population subsets is necessary to substantiate its clinical benefits [23].

EPIDEMIOLOGY AND CLINICAL IMPORTANCE

Tibial plateau fractures account for approximately 1% of all fractures and represent up to 8% of fractures in the elderly, underscoring their prevalence [3,24]. The incidence continues to rise partly due to demographic shifts toward an older population, accompanied by reduced bone density and increased fall risk. In younger individuals, high-energy mechanisms dominate, often producing complex fracture patterns and significant soft-tissue compromise [3]. Regardless of the demographic, the primary treatment goal remains anatomically precise reduction and stable fixation to allow early mobilization, decrease the risk of joint stiffness, and prevent post-traumatic osteoarthritis [25]. The complexity of these fractures is further magnified by associated injuries to the menisci and ligaments, necessitating a comprehensive assessment of knee stability [5,21]. Even after a successful initial fixation, the potential for complications—such as infection, implant failure, malunion, and arthrofibrosis—highlights the need for continuous refinement in fixation techniques [4,14].

SHORTCOMINGS OF TRADITIONAL CLASSIFICATIONS AND SURGICAL APPROACHES

Limited Accuracy of Radiograph-Based Classifications: Fractures of the tibial plateau comprise multi-planar components that cannot be fully appreciated on plain radiographs [6]. Consequently, subtle yet clinically impactful patterns—particularly in the posterior column—may be under-recognized or misinterpreted [7,12]. The Schatzker system, while historically influential, may lack the granularity required for complex fracture scenarios, wherein the posterior fragments exert considerable influence on knee function [1,9,23].

Insufficient Addressing of Posterior Columns: Traditional fixation approaches often focus on the lateral aspect, especially for bicondylar fractures, assuming that indirect reduction of the medial or posterior fragment is sufficient [2,16]. However, inadequate attention to the posterior region can lead to depressed or displaced articular surfaces that remain mal-reduced [8]. This overlooked pathology predisposes patients to joint incongruity and subsequent osteoarthritic changes [12,24].

Risk of Soft-Tissue Complications: High-energy fractures often present with compromised soft tissue envelopes—e.g., swelling, blistering, or open wounds that complicate traditional dual plating which might necessitate extensive exposures [4,5]. Increasingly, surgeons are favoring less invasive approaches that utilize smaller incisions targeted to the specific columns. These surgical modifications aim to reduce wound complications, while ensuring stable biomechanical support [14,20]. Dual plating performed through a single incision or with insufficient respect for soft-tissue planes may be associated with higher rates of infection and implant failure [22].

Variable Functional Outcomes: A critical issue in the literature is the inconsistent reporting of postoperative function and patient satisfaction [10,22]. Factors that contribute to unpredictable outcomes include initial fracture complexity, surgeon experience, quality of reduction, fixation construct, and postoperative rehabilitation protocols [3]. Evaluating the functional outcome, therefore, becomes a necessary metric for assessing the real-world impact of refined classification systems and column-specific surgeries.

THE EVOLUTION OF THREE-COLUMN CLASSIFICATION

Luo et al. introduced a three-column classification to mitigate some of the drawbacks linked with traditional radiographic approaches [1]. By examining axial CT scans, their method partitions the proximal tibia into medial, lateral, and posterior columns, drawing lines through four key anatomical landmarks.

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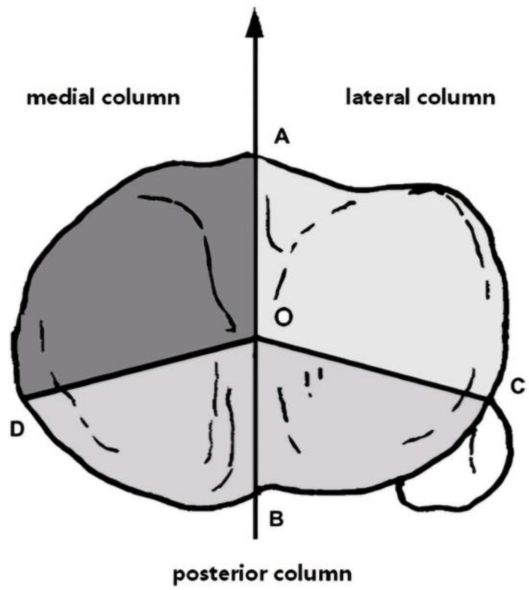


Figure 1: Schematic Representation of the Three Columns of the Proximal Tibia

Point A, located at the anterior tibial tuberosity; point C, at the anterior aspect of the fibular head; point D at the posteromedial tibial ridge; and point O, at the midpoint of the tibial spine [1]. The lines outlining these points outline the proximal tibial plateau in a manner more congruent with actual fracture lines. This description gives surgeons an opportunity to identify fragments and displacements frequently overlooked on conventional AP and lateral radiographs [17]. Thus, surgeons are now able to better tailor their operative strategy; taking either a medial approach to large posteromedial fragments or using a posterolateral approach to depressed articular segments on the lateral side [15,24].

FUNCTIONAL OUTCOME ANALYSIS

In orthopedics, the ultimate metric of success is not merely radiographic union but also the patient's return to daily activities, functional independence, and overall quality of life [11]. Evaluating functional outcomes in proximal tibial fractures typically involves standardized scoring tools such as the Knee Society Score (KSS), Lysholm Knee Score, or the Rasmussen scoring system [12,23]. Each system offers insights into knee pain, stability, range of motion, and capacity to perform daily activities. Studies indicate that anatomic restoration of the articular surface correlates strongly with improved functional scores and a lower incidence of late-stage osteoarthritis [3,6,25]. However, these analyses must account for confounding variables, such as patient age, comorbidities, and the presence of associated ligamentous or meniscal injuries. Given the biomechanical intricacies of the knee joint, a single small mal-reduced fragment can significantly alter weight-bearing distribution, leading to progressive cartilage wear [10,25].

SIGNIFICANCE AND NEED FOR THE PRESENT STUDY

While the theoretical and biomechanical advantages of column-specific fixation strategies have been extensively discussed, robust clinical data particularly regarding long-term functional outcomes in diverse patient populations remain limited [13,14]. In many regions, including large parts of the Indian subcontinent, the literature has historically focused on the Schatzker classification, with less emphasis placed on three-column based management [16]. Moreover, published studies tend to focus on immediate radiographic outcomes or short-term complications rather than systematically analyzing mid to long term functional results [6,19]. Thus, there is a need to elucidate how these refined approaches to fixation translate into tangible patient benefits, especially in settings where comorbidities and delayed presentations are common [22,25].

Further, demographic differences such as a higher prevalence of osteoporosis in older females or a higher incidence of high-energy trauma in young males underscore the necessity of region-specific research [3]. The interplay of cultural factors, health-care infrastructure, and the availability of advanced imaging further dictates the surgical approach's success [21]. By focusing on investigating a population where such factors are applicable, the current study aims at providing contextually grounded recommendations so that the standard of care of proximal tibial fractures can be made more refined.

POTENTIAL IMPACT

Insights from this study may streamline the decision-making process for managing complex proximal tibial fractures, potentially reducing rates of postoperative complications and poor functional outcomes. By highlighting the importance of three-dimensional understanding and column-specific fixation, the research aims to foster a paradigm shift in resource-limited settings that still rely heavily on plain radiography and conventional fixation methods [2,3,22]. The evidence generated could also serve as a catalyst for future multicenter, randomized controlled trials comparing Schatzker classification-based treatment with column-specific approaches for varied fracture patterns [13,18]. Ultimately, improving functional outcomes in patients with proximal tibial fractures resonates with the broader goals of orthopedic trauma care: restoring mobility, maintaining independence, and enhancing overall quality of life.

AIMS AND OBJECTIVES

AIM

To assess and analyze the functional outcomes of a three-column concept-based surgical approach in the management of tibial plateau fractures.

OBJECTIVES

To Assess Functional Outcomes: Evaluate stability and functional improvements using imaging and standardized knee scoring systems.

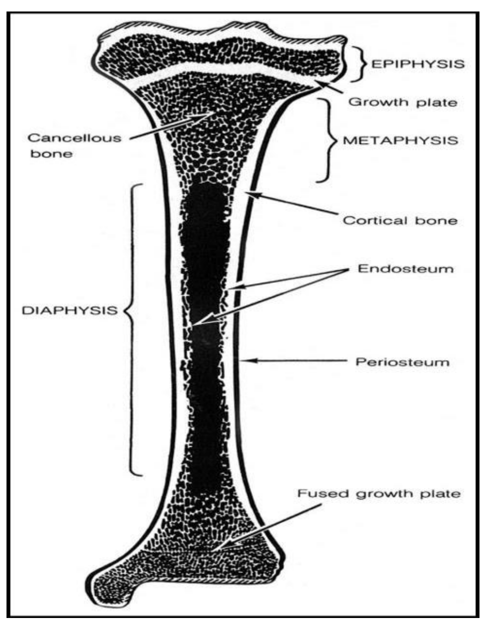
Determine Complication Rates: Analyze incidence of infection, nonunion, malunion, loss of reduction, and hardware failure.

ANATOMY

The proximal tibia is an important part of the knee joint that acts as a significant weight-bearing structure to support complex movements such as flexion, extension, and minimal rotational movements. Its complex anatomy consisting of discrete bony columns, ligamentous elements, and neurovascular elements is essential for knee stability and function. Proximal tibial fractures with articular surface involvement are amongst the greatest challenges of orthopedic treatment because restoration of both anatomical alignment and mechanical strength of the bone is required. Column-specific fixation has become a leading-edge surgical technique meant to resolve such complexities by focusing on the medial, lateral, and posterior columns of the proximal tibia. This method aims at the upgrading of fracture stabilization, optimization of the healing process, and improving functional recovery of patients.

This chapter provides a comprehensive discussion of the proximal tibia, covering its embryological development, gross anatomical features, joint articulations within the knee, key ligament and muscular attachments, neurovascular components, and biomechanical considerations. The focus is on how each of these anatomical landmarks influences the column-specific approach to fixation, enabling optimal operative intervention and beneficial patient prognostic outcomes.

Figure 2: Schematic Diagram of the Proximal Tibia



Embryological Overview

The embryological formation of the proximal tibia is the blue-print for its adult shape and guides its vulnerability to particular patterns of fractures and the patterns of healing. Between weeks four and eight of embryonic growth, the tibia and fibula form from the mesoderm, with chondrification marking the initial ossification process. Secondary ossification facilities emerge later in both the distal and proximal tibia, and via about the twelfth week of fetal life, the proximal tibial physis (increase plate) is clear. This growth plate persists until skeletal maturity and is the major contributor to the longitudinal tibial growth.

The physeal organization in the proximal tibia is complex, consisting of several zones each with distinct growth functions. The proximal physis is responsible for about 80–85% of the lengthening of the tibia. Abnormalities in physeal growth, either due to genetic defects or trauma, can lead to angular deformities and changes in mechanical loading, making the bone susceptible to certain types of fractures. The sequential process of ossification proceeds to the proximal tibial features typical of the tibial plateau, intercondylar eminence, and tibial spines. Genetic and perinatal influences on embryogenesis account for proximal tibia size, shape, and orientation variations, thereby influencing knee joint biomechanics and susceptibility to fractures.

Macroscopic Osteology of the Proximal Tibia

The proximal tibia has a complex shape tailored to handle weight bearing and facilitate joint motion. Its upper surface, known as the tibial plateau, consists of medial and lateral condyles that are vital for supporting body weight and forming articulations with the femoral condyles. The medial condyle is larger and more convex, enhancing stability, whereas the lateral condyle is smaller and less convex, aligning with the lateral femoral condyle.

Situated between these condyles is the intercondylar eminence, which features anterior and posterior tibial spines—attachment points for the anterior and posterior cruciate ligaments (ACL and PCL). These ligaments are pivotal in maintaining knee stability. On the front of the tibia, the tibial tuberosity projects outward to anchor the patellar ligament, playing a critical role in the mechanics of knee extension. The proximal tibial articular surface slopes about seven to ten degrees compared to the bone's longitudinal axis, which allows for ease of movement in the knee joint

These anatomical structures play a critical role in the understanding of fracture patterns and the use of column-specific fixation methods. The cortical bone and trabecular structure of the proximal tibia offer resistance to bending and torsional stresses, which are critical to sustaining structural integrity under conditions of dynamic loading.

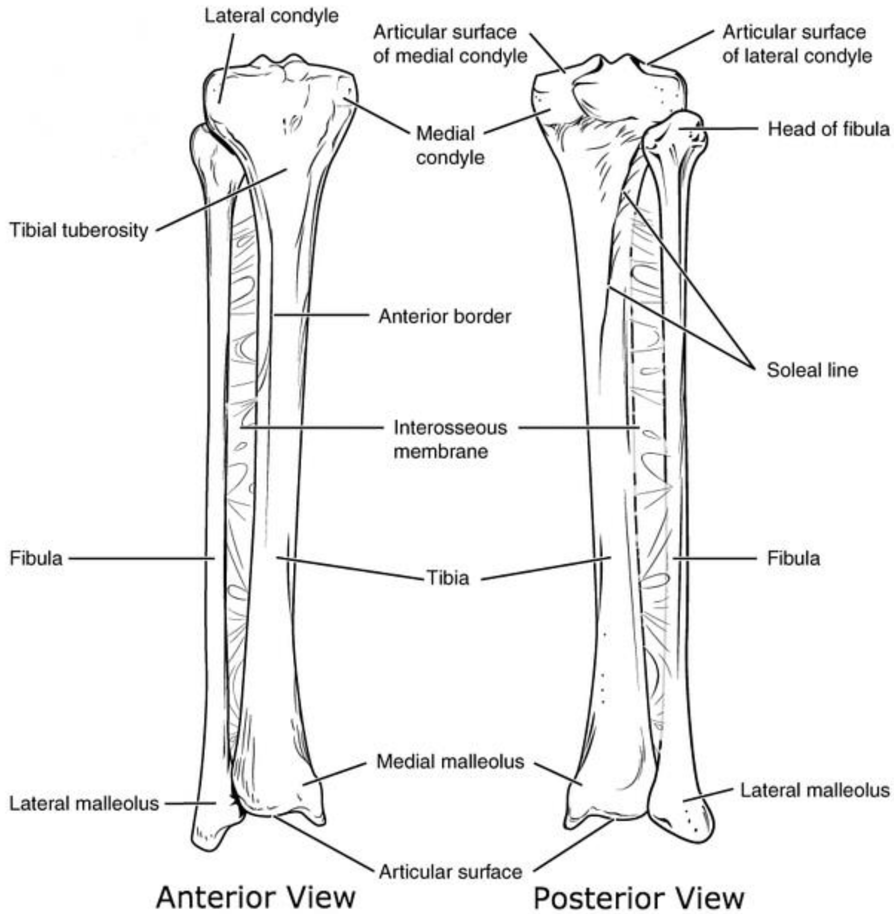


Figure 3: Proximal Tibial Osteology—Medial and Lateral Condyles

The knee joint, being the complex and biggest of all human body joints, is made up of the tibiofemoral joint formed by articulation between the tibia, femur, and patella. The tibiofemoral joint is formed when the proximal tibia articulates with the femoral condyles. The patella also articulates with the femoral trochlea to create the patellofemoral joint. The tibiofemoral joint is also subdivided into medial and lateral compartments, each containing a meniscus— the medial meniscus and the lateral meniscus. These fibrocartilaginous structures serve as shock absorbers, increasing joint stability and load distribution evenly across the tibial plateau.

The patellofemoral joint is of immense importance to knee extension biomechanics as a fulcrum provided by the patella helps amplify the power of the quadriceps muscles. The tibia-femur articulation accommodates the effortless flexion and extension and restrains unnecessary motion that might imperil joint stability. The congruence of the femoral condyles with the tibial plateau is of utmost importance to ensure joint stability and reduce wear and tear that may result in osteoarthritis.

Figure 4: Tibiofemoral and Patellofemoral Joint Anatomy

Ligamentous Structures

Ligaments play a pivotal characteristic in preserving the knee joint's stability and structural integrity.

Cruciate Ligaments: ACL originates from the lateral femoral condyle and inserts into the anterior intercondylar area of the tibia, preventing anterior tibial translation. PCL extends from the medial femoral condyle to the posterior intercondylar area of the tibia, restraining posterior tibial displacement. These ligaments are essential for controlling the forward and backward movements of the tibia relative to the femur, thereby maintaining knee stability during dynamic activities.

Collateral Ligaments: MCL connects the medial femoral epicondyle to the medial tibial condyle, resisting valgus forces. LCL attaches the lateral femoral epicondyle to the lateral tibial condyle and the fibular head, countering varus stresses and securing lateral stability.

Capsular Ligaments: The knee joint capsule is stabilized by several ligamentous bands that provide general knee stability. They are the anterolateral and posteromedial capsules, which contribute to further stability against rotational stress and support to keep the tibiofemoral and patellofemoral joints congruent.

Knowledge of the spatial relationship and attachment sites of these ligaments is important for successful surgical planning and fixation. Preservation of ligamentous structures in fracture management is important to ensure knee stability and avoid chronic instability or malalignment.

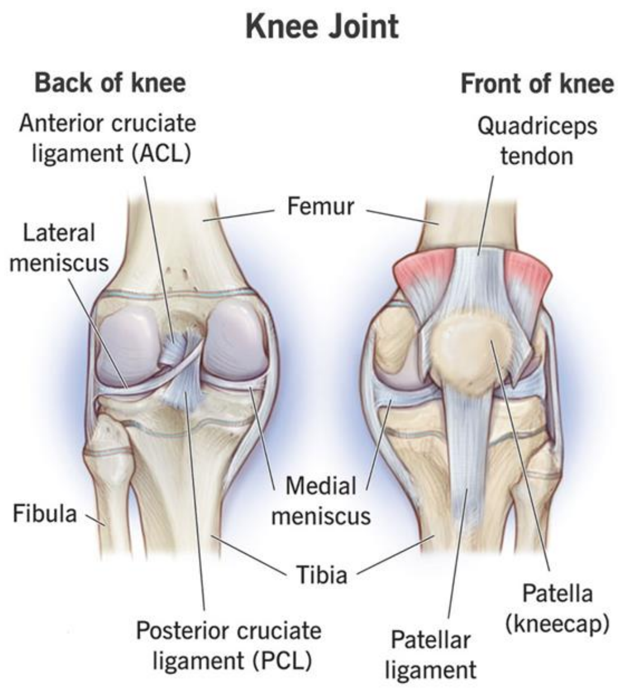


Figure 5: Ligamentous Anatomy of the Knee Joint

Muscular and Tendinous Attachments

The proximal tibia serves as a significant anchoring point and fulcrum for various muscles and tendons, influencing both knee mechanics and overall stability. These muscular attachments are essential for coordinated knee motion and the transmission of forces across the joint.

Quadriceps Mechanism: The quadriceps femoris muscle group—comprising the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius—connects to the tibial tuberosity through the patellar tendon. This configuration is necessary for knee extension, with the quadriceps providing the force required to extend the leg during walking, running, and jumping.

Hamstring Muscles: The hamstrings—biceps femoris, semitendinosus, and semimembranosus—begin near the ischial tuberosity and insert into the rear portion of the proximal tibia. These muscles facilitate knee flexion and safeguard joint stability by curbing undue forward movement of the tibia, particularly during dynamic tasks.

Calf Muscles: The gastrocnemius originates at the femoral condyles and traverses the knee joint, inserting into the Achilles tendon. It contributes to both knee flexion and ankle plantar flexion, playing a pivotal role in actions such as standing on tiptoe and propelling the body forward during walking.

Pes Anserinus: The tendons of the sartorius, gracilis, and semitendinosus merge on the anteromedial side of the proximal tibia to create the pes anserinus. This anatomical structure supports knee flexion while offering additional medial stabilization, which is particularly beneficial during weight-bearing activities

Effective control of these musculotendinous attachments in surgical procedures is important to ensure knee function and avoid postoperative complications like irritation or rupture of the tendons.

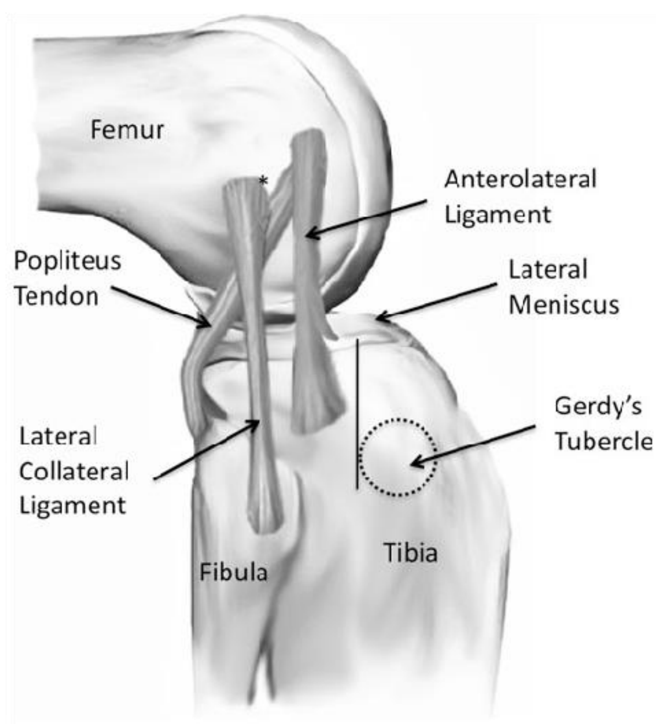


Figure 6: Ligamentous Anatomy of the Knee Joint in lateral view

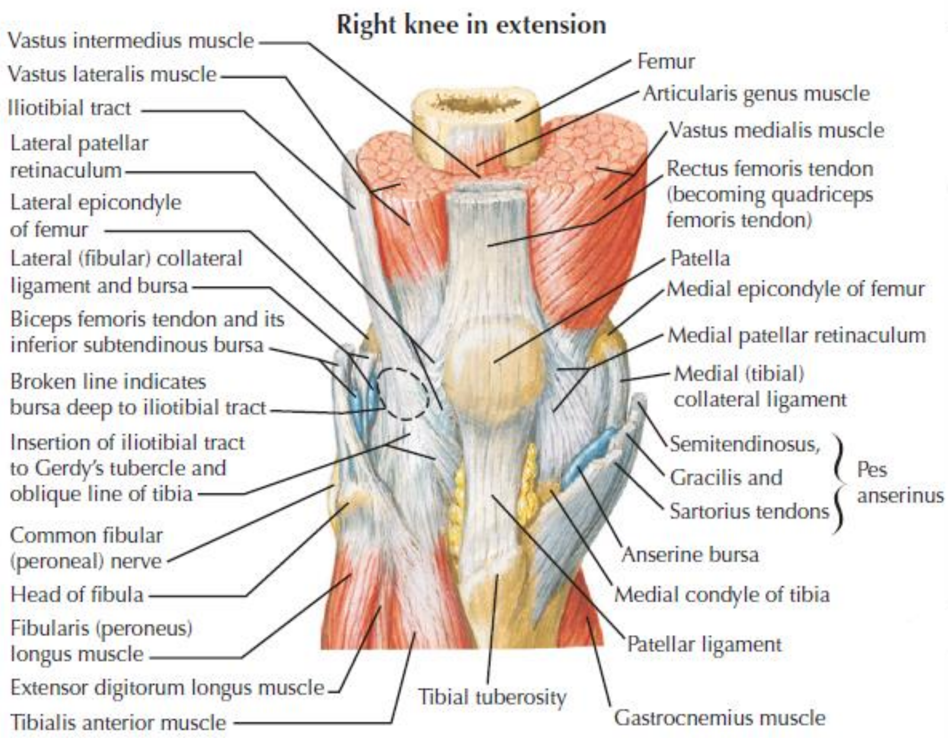


Figure 7: Muscular Attachments Around the Proximal Tibia

Blood Supply and Innervation of Nerves

The presence of sufficient vascular supply and innervation is essential for bone consolidation, joint mobility, and general limb health. The proximal tibia has an abundant blood supply and nerve supply that must be maintained intact throughout surgical fixation in order to avoid complications.

Arterial Supply: The proximal tibia primarily receives blood flow through several genicular arteries, including the superior medial, superior lateral, middle, inferior medial, and inferior lateral genicular arteries. This network forms an extensive vascular system around the knee, ensuring that the tibial plateau and intercondylar eminence are well supplied with nutrients. Perforating branches pass through the cortical bone, providing intraosseous circulation necessary for fracture healing

Venous Drainage: Venous drainage occurs via corresponding genicular veins, which mirror the arterial supply and drain into popliteal veins. Further, deep veins are present in association with arteries to enable effective venous return from the proximal tibia.

Nerve Supply: Sensory innervation to the medial side of the knee and the proximal tibia is via the saphenous nerve, a continuation of the femoral nerve. The common peroneal nerve, running laterally close to the head of the fibula, gives both motor and sensory innervation to the lower leg and foot. The tibial nerve passes posteriorly to supply the muscles of the posterior compartment and send sensory fibers to the medial side of the foot.

Their preservation during surgical fixation is crucial in order to avoid complications like ischemia, neuropathy, or chronic pain. Anatomical accuracy and minimally invasive surgery are the tools of choice in order to spare these vital structures.

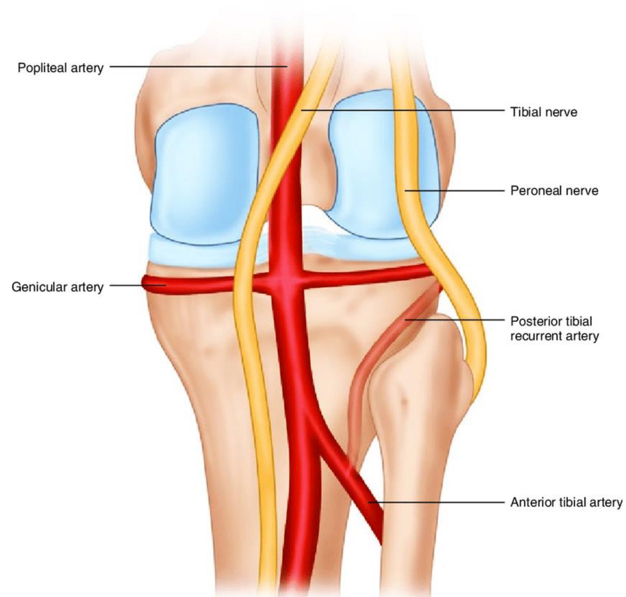


Figure 8: Vascular and Nerve Supply to the Proximal Tibia

Biomechanical Considerations

The proximal tibia is subjected to a multitude of biomechanical forces that influence fracture patterns, fixation strategies, and healing outcomes. Understanding these forces is essential for effective column-specific fixation.

Load Transmission: The proximal tibia transmits the majority of the body's weight from the femur to the tibia and fibula, distributing forces through the tibial plateau.

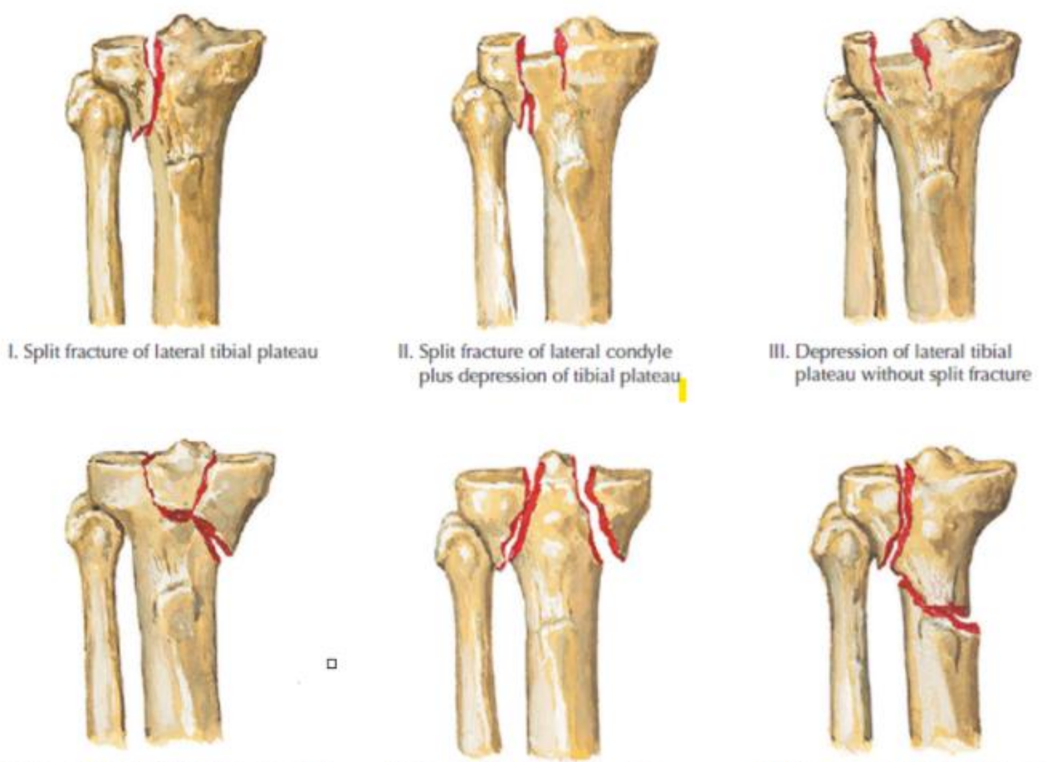
Shear and Rotational Forces: The knee joint experiences shear forces during activities such as walking, running, and jumping, which can lead to fracture displacement if not adequately stabilized. Rotational stresses influence the intercondylar eminence and cruciate ligament attachments, affecting knee stability and kinematics. Proper fixation must restore the natural load transmission pathways to prevent malalignment and joint degeneration.

Articular Congruence: Maintaining the congruity of the tibiofemoral and patellofemoral joints is crucial for minimizing wear and tear on the articular surfaces. The medial and lateral menisci play a significant role in distributing load and absorbing shock, contributing to joint stability and congruence. It is essential to restore accurate alignment of the articular surfaces during fracture fixation to maintain joint function and avert enduring complications, such as post-traumatic osteoarthritis.

Flexural Stiffness and Stability: The proximal tibia's cortical thickness and trabecular architecture provide resistance to bending and torsional forces. Rigid fixation methods must restore the bone's inherent flexural stiffness to maintain structural integrity and promote proper healing. Fixation devices must counteract the biomechanical stresses to prevent hardware failure, malunion, or nonunion of fractures.

TIBIAL PLATEAU FRACTURE CLASSIFICATIONS

I. SCHATZKERS CLASSIFICATION: It is based on plain radiograph of the proximal tibia.



Tibial Plateau Fracture

I. Split fracture of lateral tibial plateau

II. Split fracture of lateral condyle plus depression of tibial plateau

III. Depression of lateral tibial plateau without split fracture

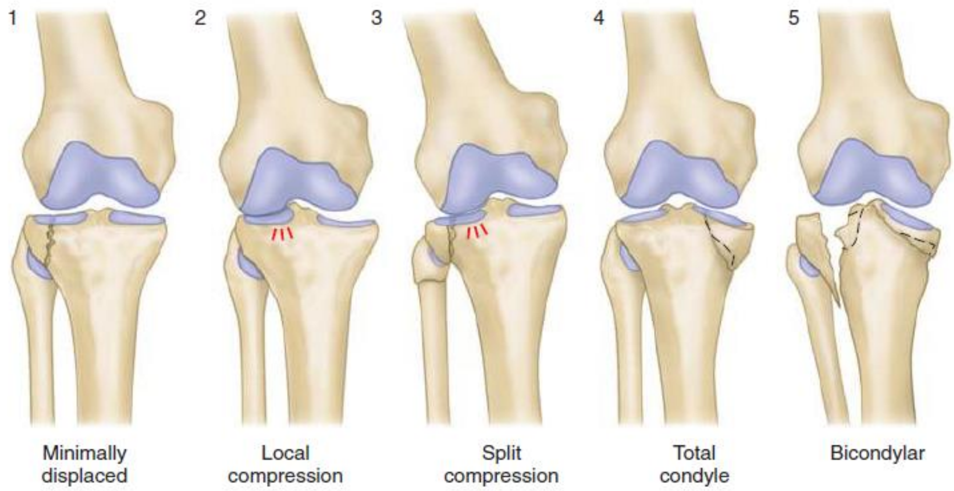
IV. Comminuted split fracture of medial tibial plateau and tibial spine

V. Biocondylar fracture involving both tibial plateaus with widening

VI. Fracture of lateral tibial plateau with separation of metaphyseal-diaphyseal junction

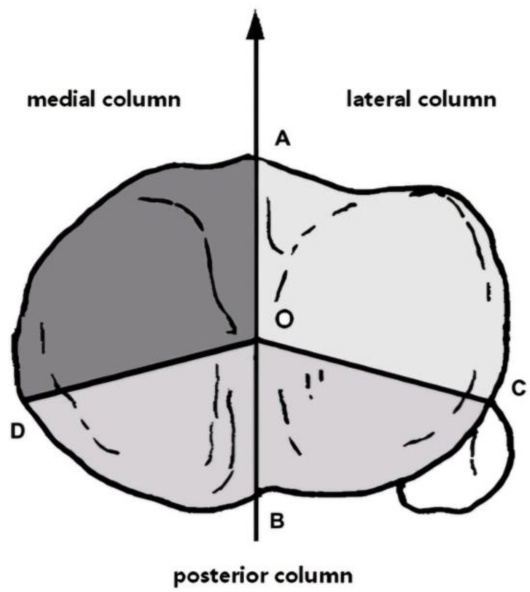
Schatzker's classification divides tibial plateau fractures into six main categories. Type 1 presents as a simple split fracture of the lateral tibial plateau, whereas Type 2 shows a lateral tibial condyle fracture with both a split and depression component. Type 3 comprises purely depressed fractures. Type 4 involves a comminuted split fracture of the medial tibial plateau, while Type 5 encompasses bicondylar fractures. Finally, Type 6 includes a plateau fracture coupled with metaphyseal-diaphyseal separation.

II HOHL AND MOORE'S CLASSIFICATION.



Hohl and Moore categorized tibial plateau fractures based on plain radiographic findings into several principal groups. Type I encompasses non-displaced fractures, whereas Type II features displaced fractures involving the articular surface. Type III is characterized by rim avulsion fractures and often includes neurovascular compromise. Type IV denotes a total compression fracture of the medial condyle accompanied by ligamentous injury. Finally, Type V describes a comminuted four-part fracture in which the tibial eminence is separated from both the condyles and the shaft.

III. LUO'S THREE COLUMN CLASSIFICATION



Point A, located at the anterior tibial tuberosity; point C, at the anterior aspect of the fibular head; point D at the posteromedial tibial ridge; and point O, at the midpoint of the tibial spine

The Three Column Concept

The three-column approach divides the proximal tibia into medial, lateral, and posterior columns, helping clinicians identify fracture patterns more accurately and guide surgical interventions based on the distinct biomechanical functions of each column

Zero column - Pure depression affecting only the articular surface

One column - Tibial plateau fracture that features a lateral split and/or split-depression

Two column - Fracture involving the anterolateral column combined with depression in the posterolateral articular surface, or a fracture of the anteromedial column coupled with posteromedial articular depression.

Three column – A fracture involving minimum of one independent articular fragment in each column.

SURGICAL ANATOMY AND APPROACHES

Effective column-specific fixation of proximal tibial fractures necessitates a thorough understanding of the surgical anatomy and the various approaches available for optimal access and stabilization. The selection of the surgical approach is influenced by the fracture pattern, column involvement, and the need to preserve neurovascular structures and soft tissues.

Anterolateral Approach – This is the most commonly used approach to operate lateral condyle fractures. In this approach, split depression or pure depression fractures of lateral tibial condyle are managed. beginning 1 to two cm distal to joint line, L incision is taken and is curved anteriorly over Gerdy's tubercle and is distally extended with no internervous plane coming in between

Posteromedial Approach to the Proximal Tibia - Longitudinal incision taken over the posteromedial aspect of tibia and length of the incision will depend on the nature fracture and the implant to be used. In this appraoch, the plane between gastrocnemius and the bone is utilised with no internervous plane in between.

Anterior border of sartorius and pes are retracted posteriorly to expose the bursa below the tendon. Gracilis and semitendinosis tendons are identified and are retracted posteriorly to expose the posteromedial border of tibia.

Posterolateral Approach to the Tibial Plateau-Patient is made to lie in prone position and knee is made to flex 20 degrees by keeping a pillow under the ankle. Incision is taken from a point of 2 cm above the knee crease and extended distally along the medial border of fibula, common peroneal nerve is identified and isolated. Plane is made between common peroneal nerve and biceps tendon laterally with lateral head of gastrocnemius muscle medially to expose popliteus. Popliteus is then elevated and origin of soleus muscle is detached to expose the posterolateral corner of knee joint.

Fragment-Specific Approaches: Consistent with the column-specific fixation idea, fragment-specific techniques or mini-incisions can be used to treat a single fracture fragment. For example, a fracture of the medial column might demand a medial incision for maximum reduction and fixation, whereas a fracture of the lateral column could demand a lateral incision. Fractures of the posterior column can be treated with specialized posterior incisions to stabilize the intercondylar eminence without jeopardizing neurovascular tissues. This custom-designed approach allows for greater precision during surgery and fosters better functional results.

VARIATIONS AND ANOMALIES

Recognizing anatomical variations and anomalies is critical when using column-specific fixation methods for proximal tibial fractures, as these differences can affect fracture types, fixation strategies, and healing results. Among these variations, the proximal tibia often differs in the slope of the tibial plateau and the breadth of the intercondylar notch. Alterations in the posterior tibial slope can influence knee stability and the likelihood of ligament injuries: a steeper slope may increase vulnerability to ACL tears, whereas a reduced slope might elevate the risk for PCL injuries. Furthermore, an unusually narrow or wide intercondylar notch can affect cruciate ligament attachments, potentially complicating fracture fixation.

Congenital Anomalies: Congenital anomalies like tibial hemimelia, which involves a partial or complete absence of the tibia, and tibia Vara, leading to varus deformity, change the shape and alignment of the proximal tibia. Such anomalies require specialized fixation methods to fit the distorted anatomy and reestablish normal limb alignment. Knowledge of these congenital variations is crucial for surgeons to construct satisfactory fixation methods and obtain the best functional results.

Fracture-Specific Patterns: Proximal tibial fractures are presented in diverse patterns such as unicondylar, bicondylar, and comminuted fractures. Unicondylar fractures may occur on either the medial or lateral tibial plateau, and bicondylar fractures impact both condyles, usually extending to the intercondylar area. Comminuted fractures consist of more than two fragments, necessitating complex fixation plans to provide column integrity. Open fractures, with the bone penetrating through the skin, add complexities of soft tissue handling and infection control.

Soft Tissue Considerations: Soft tissue anatomy variations, such as subcutaneous tissue thickness and neurovascular bundle proximity, may affect the choice of surgical approach and fixation technique. Techniques must be adapted by surgeons to address these variations, avoiding impingement of fixation devices on soft tissues and protecting neurovascular structures.

SCORING SYSTEMS

MODIFIED RASMUSSEN SCORING SYSTEM

The Modified Rasmussen Score is a widely used system for evaluating the functional outcomes of patients treated for proximal tibial fractures. This grading method provides a thorough assessment of healing following treatment by evaluating a number of factors, such as pain, walking ability, range of motion, stability, and radiographic alignment. Clinical outcomes such as the presence or absence of pain, the patient's capacity for independent walking, and the degree of knee joint mobility and its stability are the emphasis of the functional component of the score. A score is given to each criterion, and the sum of these scores classifies the results where a score less than 10 is considered to be poor and 10-19 is fair. A score ranging between 20-26 is said to be good and a score of 27 to 30 is considered excellent.

Following is the summary of The Modified Rasmussen Score:

A. SUBJECTIVE ANALYSIS

PARAMETER	SCORE
Pain	0 - 6
Walking capacity	0 - 6

B. CLINICAL ANALYSIS

PARAMETER	SCORE
Knee extension	2 - 6
Total range of motion	0 - 6
Stability in flexion and extension	2 - 6

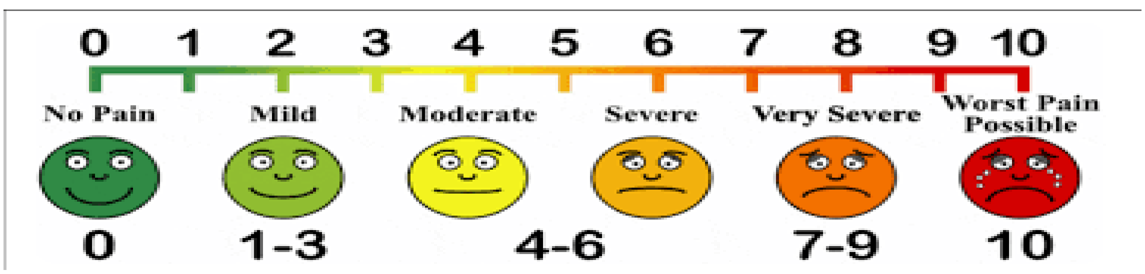
INTERPRETATION

Poor	<10
Fair	10-19
Good	20-26
Excellent	27-30

VISUAL ANALOGUE SCORING (VAS)

VAS is a popular, easy-to-use and useful instrument for evaluating subjective feelings such as pain level. With endpoints defining the extremes of the feeling being measured, such as "No pain" at one end and "Worst pain imaginable" at the opposite, this is generally depicted with the aid of a horizontal line that commonly measures 10 cm lengthy.

Patients suggest their level of pain by means of marking a spot on the line. the gap among the mark and the 'No pain' is measured to yield a score starting from 0 to 10. more intense pain is indicated by way of a higher score.



REVIEW OF LITERATURE

Schatzker et al. (1979): In their pivotal study on the Toronto experience from 1968 to 1975, Schatzker et al. meticulously analyzed 70 tibial plateau fractures. This research established the foundational six-type classification system that is extensively utilized today. The patient demographic predominantly consisted of males, who constituted approximately 60% of the subjects, with an average age of 48 years. The fractures were categorized based on their morphological characteristics, focusing on lateral plateaus splits (Type I), mixed split-depression (Type II), central depression (Type III), medial plateaus (Type IV), bicondylar (Type V), and metaphyseal-diaphyseal dissociation (Type VI). Through both radiological and clinical assessments, it was determined that the quality of anatomical reduction was paramount in achieving favorable outcomes. Fractures exhibiting more than 5 mm of articular incongruity were deemed significant candidates for surgery. Predominantly, open reduction and internal fixation were employed for 80–90% of all displaced fractures, yielding good functional results in up to 75% of cases, as long as there was rigid fixation and early mobilization. Conversely, inadequate reduction and prolonged immobilization contributed to increased joint stiffness—approximately 15%—and the development of secondary osteoarthritis in about 20% of the patients during the five-year follow-up. Notably, the complication rates, including wound infections and deep venous thrombosis, were below 5%. The study's conclusions emphasized the critical importance of restoring articular congruity and securing stable fixation to maximize long-term functionality. This seminal work not only introduced a systematic classification framework but also underscored the essential roles of surgical precision and postoperative care in managing tibial plateau fractures effectively [26].

Rasmussen (1973): The review involved 102 patients who had the tibial condylar fracture and ranged between the ages of 19 years and 76 years. Each was followed for a minimum period of one year following the treatment. A comprehensive scoring system to provide detailed measurement, which covered the dimensions such as pain, range of movement, stability, and radiographic alignment was later popularly known as the Rasmussen grading. Laterally condylar accounted for approximately 70%, and medically about 20%. Bicondylar accounts for around 10%. Operative treatment—principally open reduction with internal fixation—was chosen for fractures with more than 5 mm of articular step-off or gross instability, which accounted for nearly half (48%) of the cohort. The mean knee flexion obtained postoperatively was approximately 120 degrees, and 65% of patients achieved a functional and stable knee joint according to the Rasmussen criteria. Conversely, conservative management with traction or casting was used for less displaced fractures, and acceptable results were achieved in about 75% of these non-operatively treated patients. Rasmussen noted that about 10% of the surgically treated group had mild to moderate degenerative changes at final follow-up, indicating a correlation between the severity of the initial fracture and subsequent joint degeneration. Complications like infection were rare, about 3%, while malunion and residual deformities were noted more frequently in the non-operative cases, near 7%. Rasmussen's scoring system and his emphasis on anatomical reduction provided essential benchmarks for evaluating treatment efficacy and informed subsequent classification and management strategies for tibial condylar and plateau fractures [27].

Wicky et al. (2000): Wicky and coworkers compared 40 tibial plateau fractures on standard radiographs with spiral CT with 3D reconstruction. The study had a sample population of patients who were between the ages of 18 and 75 years; bicondylar accounted for 25% of them. The authors quantified the sensitivity of standard radiographs to detect articular depression and fracture lines by comparing each modality's results to intraoperative findings. They found that conventional X-rays underestimated the size of the depressed articular fragment by approximately 20% in nearly one-third of fractures. Conversely, spiral CT with 3D reconstruction demonstrated significantly higher accuracy, detecting almost 95% of occult fracture lines and more accurately measuring the degree of articular step-off. In addition, 3D CT reformatting helped to better delineate posterior and posteromedial components, which were missed or underestimated in approximately 15% of cases where only plain radiographs were employed. This increased definition of fracture morphology directly influenced the surgical plan in 25% of the patients, by changing approach, implant selection, and reduction technique. Post-operatively, in these patients, the incidence of residual articular incongruity was significantly reduced to around 5%, confirmed by follow-up imaging. The authors concluded that spiral CT with 3D reconstruction should be considered a critical tool in the evaluation of complex tibial plateau fractures, allowing for precise fracture classification, guiding tailored surgical strategies, and potentially improving overall functional outcomes through more accurate anatomical restoration [28].

Mueller et al. (2003): In a rigorous biomechanical study, Mueller et al. examined bicondylar tibial plateau fractures fixed by various constructs in cadaveric specimens. A total of 24 fresh-frozen cadaveric tibiae were osteotomized to create standardized bicondylar fracture patterns. The authors compared four fixation methods: single lateral plate, dual plating (medial and lateral), external fixation, and hybrid constructs. Axial loading, varus-valgus stress, and cyclic loading were applied to mimic physiologic conditions. Notably, dual plate constructs exhibited the highest load to failure, averaging around 2300 N before significant deformation, whereas lateral-only plating failed at approximately 1700 N. The study also showed that dual plating reduced micromotion at the fracture site by nearly 35% compared to single plating. Despite its mechanical advantages, dual plating was associated with a slightly higher risk of soft tissue irritation, as documented by a 10% to 15% incidence of hardware prominence in clinical correlates. External fixation demonstrated intermediate stability but was inferior to internal fixation under torsional loads. The authors emphasized that restoration of medial support is critical, as varus collapse was observed in up to 70% of specimens treated with lateral-only plating after repetitive loading. These biomechanical insights underscored the necessity for robust stabilization of both tibial columns when addressing bicondylar fractures, especially in high-demand or high-instability scenarios. Mueller et al. concluded that, while each fixation strategy has merits, dual plating offers superior biomechanical stability, potentially translating into improved clinical outcomes when balanced against the higher soft tissue risks [29].

Ali et al. (2003): Ali and colleagues conducted a retrospective analysis of 41 patients who suffered from complex tibial plateau fractures, all of whom were treated using a beam-loading ring fixation system. The median age of the patients was 44 years, with over 60% presenting bicondylar fracture patterns. The treatment protocol included debridement and fracture reduction followed by the application of a circular external fixator, equipped with hinged rods to facilitate early knee mobilization. Radiographic evidence indicated bone healing by an average of 16 weeks, with the majority of patients—approximately 70%—achieving full weight-bearing capacity by 12 weeks post-operation. Clinical evaluations, gauged by the Rasmussen score, revealed that 78% of patients achieved excellent or good outcomes at the one-year mark. Remarkably, minimal articular step-off (<2 mm) was observed in 85% of patients, which was associated with superior functional outcomes. Pin-site infections were reported in about 10% of cases, though these were effectively managed with localized care and antibiotic treatment. There were no occurrences of deep infection or significant neurovascular complications. The utilization of the ring fixation system facilitated immediate mobilization, contributing to a minimal incidence of post-traumatic stiffness (about 5%). Intraoperative fluoroscopy confirmed that the mechanical axis was maintained within 3 degrees of normal in 75% of the cohort. Ali et al. concluded that beam-loading ring fixators offer sufficient stability for managing complex tibial plateau fractures, while reducing soft tissue disruption and preserving periosteal blood supply, thus providing a beneficial alternative for cases where internal fixation may jeopardize soft tissue integrity [30].

Barei et al. (2006): Barei and colleagues evaluated the functional outcomes of 83 patients with severe bicondylar tibial plateau fractures treated using a dual incision approach and separate medial and lateral plates. The mean patient age was 46.5 years, with a slight male predominance (54%). Their protocol involved staged fixation for high-energy trauma: immediate external fixation to manage soft tissue swelling followed by definitive internal fixation within 7 to 14 days. Radiographic assessment showed that 90% of fractures had posteromedial fragments, emphasizing the complexity of bicondylar involvement. Postoperative alignment was restored to within 5 degrees of mechanical axis deviation in 88% of patients. At an average 28-month follow-up, the authors utilized validated outcome measures, including the Short Form-36 (SF-36) and the Musculoskeletal Function Assessment (MFA). They reported a mean knee flexion of 115 degrees, with 75% of patients returning to their pre-injury functional level or better. However, complications included deep infection in 5% of cases, hardware-related irritation in 10%, and secondary procedures for hardware removal in 12%. Notably, patients with high-energy mechanisms (e.g., motor vehicle accidents) exhibited an increased risk of postoperative stiffness (roughly 8%) and were more likely to require knee manipulation under anesthesia. Despite these challenges, Barei et al. concluded that anatomic reduction of both condyles combined with stable dual plate fixation yields favorable functional results, although a careful staged approach is crucial to mitigate infection and ensure optimal soft tissue management in severe, high-energy tibial plateau fractures [31].

Higgins et al. (2007): Higgins and coworkers performed a biomechanical comparison of lateral locking plate fixation against dual plate fixation for bicondylar tibial plateau fractures. Using 20 cadaveric tibiae, they artificially created standardized bicondylar fracture models before randomizing the specimens to either a single lateral locked plate or dual plating with lateral and medial plates. Under cyclic loading at physiological levels (up to 2500 N) and under torsional stress, the single lateral locking plate group demonstrated earlier mechanical failure—occurring at an average of 1950 N compared to 2300 N for the dual plating group. Furthermore, micromotion was significantly higher (by about 30%) in the lateral locking plate cohort, raising concerns over potential for varus collapse. However, the authors noted that the lateral locking plate system allowed for a minimally invasive surgical approach, which might reduce soft tissue complications in clinical settings. When investigating rotational stability, dual plating again offered superior resistance, with a 15% lower angular displacement under maximal torque. Complications observed in analogous clinical data suggested that single locked plating might have advantages in select cases with lower-energy fractures and simpler bicondylar patterns. Higgins et al. concluded that while lateral locking plates enhance stability over traditional non-locking constructs, they may not achieve the same biomechanical robustness as dual plating in high-demand or severely comminuted bicondylar fractures. These findings guided surgeons to balance the need for maximum stability with soft tissue considerations in complex tibial plateau fracture repair [32].

Barei et al. (2008): Barei and co-investigators analyzed 120 consecutive bicondylar tibial plateau fractures to determine the frequency and morphological characteristics of posteromedial fragments. In their sample, posteromedial involvement was identified in 59% of cases, indicating that such fragments are more common than previously recognized. Of these, over half measured more than 25% of the articular surface, underscoring the substantial structural impact. Radiographically, the authors noted that standard anteroposterior and lateral views often underestimated or entirely missed the posteromedial fragment in about 15% of the cohort, leading to potential under-treatment. Postoperative outcomes indicated that achieving anatomic restoration of the posteromedial articular surface correlated with better knee range of motion (mean 118 degrees) and improved functional scores on the Knee Society Score. Conversely, patients with residual step-off exceeding 2 mm in the posteromedial region exhibited a 20% higher incidence of post-traumatic arthritic changes within two years. The authors advocated routine preoperative advanced imaging—especially CT scans—to accurately delineate posterior shear components. This approach facilitated proper screw trajectory for interfragmentary fixation, thereby enhancing stability. They concluded that posteromedial fragments represent a frequent and clinically significant element of bicondylar tibial plateau fractures, necessitating meticulous assessment and targeted fixation to prevent articular incongruity and to optimize long-term functional outcomes [33].

Luo et al. (2010): Luo et al. introduced the concept of three-column fixation for the management of complex tibial plateau fractures, analyzing 58 cases with an emphasis on coronal plane injuries. Each tibial plateau was divided into medial, lateral, and posterior columns, with the treatment strategy tailored to restore stability in all three regions. Preoperative CT scans revealed combined medial and posterior column involvement in 45% of cases and tri-column involvement in 30%. The authors reported that the use of individualized fixation approaches—such as a separate posteromedial plate for posterior instability—led to significant improvements in articular congruity, with a residual step-off of less than 2 mm in 90% of patients. At an average follow-up of 18 months, knee range of motion exceeded 120 degrees in 75% of patients, and the Lysholm knee score was rated as excellent or good in 82%. Furthermore, the authors highlighted that only 5% of patients experienced major postoperative complications, such as deep infection or hardware failure. Notably, the three-column method facilitated targeted fixation of hidden posterior fragments, which were often overlooked in classical bicolumn fixations. Luo et al. concluded that addressing each column independently ensures robust overall construct stability, especially for comminuted fractures involving the posterior tibial plateau. By systematically evaluating each column via CT imaging, surgeons can optimize reduction techniques, implant choice, and surgical corridors, ultimately improving both radiological union and functional knee recovery [34].

Biggi et al. (2010): Biggi and colleagues conducted a retrospective review of 52 tibial plateau fractures treated with locking plates using the minimally invasive percutaneous osteosynthesis (MIPO) technique. Fractures were classified according to the Schatzker system: 22 were Type V and 30 were Type VI injuries. The mean patient age was 45 years, with a follow-up period of at least 12 months. Radiographic evaluation post-surgery revealed an articular step-off averaging under 2 mm in 80% of cases. By six months, 90% of fractures had achieved radiological union, with an additional 8% uniting by nine months. Clinically, the Knee Society Score was used to measure function, indicating that 70% of patients achieved excellent or good outcomes by one-year follow-up. Notably, the MIPO technique reduced soft tissue complications to less than 5%, compared to higher rates historically reported with extensive open approaches. Infection occurred in 3.8% of the cohort, and hardware irritation requiring eventual removal was reported in 6%. Additionally, the minimally invasive approach facilitated early knee mobilization, with most patients achieving 120 degrees of flexion at three months. A small subset of patients (around 4%) developed varus or valgus malalignment exceeding 5 degrees, underscoring the importance of precise intraoperative imaging. Biggi et al. concluded that locking plate fixation via MIPO offers a balance of stable fixation and minimal disruption of soft tissues, translating into accelerated rehabilitation schedules and overall favorable functional scores for high-grade tibial plateau fractures [35].

Yu et al. (2009): Yu and colleagues evaluated both the functional and radiological outcomes in 53 patients with high-energy tibial plateau fractures managed with double buttress plate fixation. These fractures were predominantly bicondylar (Schatzker Type V or VI) and frequently involved significant articular depression. All patients underwent open reduction and dual plating to stabilize both the medial and lateral columns. Radiographic assessment confirmed restoration of articular congruity to within 2 mm of step-off in 85% of cases. By the final follow-up at a mean of 16 months, 90% of the fractures showed radiological union, with only 6% requiring secondary bone grafting. Functionally, over 70% of patients reported good or excellent results according to the Lysholm score, and the mean range of knee flexion reached 115 degrees. Deep infection was documented in 2 cases (3.8%), while superficial infection or wound complications occurred in about 5%. Additionally, post-traumatic osteoarthritis changes were evident in approximately 8% of patients, generally correlated with initial fracture severity and articular cartilage damage. The authors noted that stable buttress plating enabled early active mobilization, which likely contributed to lower stiffness rates (under 10%). Yu et al. concluded that double buttress plate fixation yields promising results in achieving anatomical reduction, fostering union, and facilitating functional recovery for high-energy tibial plateau fractures, although meticulous surgical technique and vigilant postoperative care are critical to minimize complications [36].

Conserva et al. (2015): In this retrospective review, Conserva and colleagues compared two treatment methods for tibial plateau fractures without utilizing a formal staging protocol. A total of 68 patients (mean age 48 years) presenting with bicondylar fractures (Types V and VI) were allocated to either a single lateral locking plate (n=34) or dual plating (n=34), based on surgeon preference. Radiographic results indicated that dual plating provided superior articular reduction, with 88% achieving <2 mm step-off, compared to 76% in the single-plate cohort. Additionally, postoperative alignment remained within 5 degrees of neutral in 85% of the dual plating group, whereas the single-plate group reported a 70% rate of acceptable alignment. Functionally, measured by the Knee Society Score at one-year follow-up, the dual plating cohort attained a mean score of 82, versus 75 in the single-plate group. Complication rates, including infection and hardware failure, were similar in both arms (around 10–12%). Notably, the authors observed that immediate fixation without staged external fixation did not significantly increase soft tissue complications, which remained at 8–10% across groups. Conserva et al. concluded that while single lateral locked plating offers a less invasive option, dual plating yields better anatomical restoration and possibly superior functional scores in complex tibial plateau fractures, provided that surgical timing and soft tissue conditions are carefully optimized [37].

Chang et al. (2012): Chang and associates presented a unique surgical strategy for bicondylar tibial plateau fractures utilizing posterior coronal plating through a posteromedial incision coupled with an anterolateral approach. Their series included 34 patients with combined anterolateral and posteromedial fracture components. Patients were positioned supine, with the affected limb draped free, thereby eliminating the need for prone or lateral decubitus positioning.

Intraoperative findings revealed that the posterior column constituted a significant fragment averaging 28% of the articular surface. The authors employed a posterior T-plate or buttress plate, achieving anatomical reduction in 80% of cases, with less than 2 mm of residual depression. By six months postoperative, 90% of fractures had united. Clinically, the mean knee flexion was 120 degrees, and the Hospital for Special Surgery (HSS) knee score averaged 85 at 12 months, indicating good to excellent outcomes in 75% of patients. Although wound complications were reported in 8% of cases, no deep infections were documented. Notably, the posteromedial approach allowed direct visualization and lag screw fixation of posterior fragments without extensive soft tissue stripping. Early mobilization protocols—initiated within two weeks—further aided in preserving knee function. Chang et al. concluded that dual-column fixation addressing both anterior-lateral and posterior aspects via separate incisions can secure stable construct alignment while remaining technically feasible, yielding favorable union rates and functional results with a relatively low complication profile [38].

He et al. (2013): He and collaborators investigated the efficacy of a posterior inverted L-shaped approach for correcting posterior bicondylar tibial plateau fractures in 26 patients. This specialized surgical corridor was designed to enhance exposure of posterior fragments, particularly when the posteromedial segment comprised more than 20% of the articular surface. Intraoperative reduction was achieved in 85% of cases, as verified by <2 mm of step-off under direct visualization. The authors employed dual plating in 20 cases (77%), while 6 cases necessitated additional lateral fixation. Postoperative radiographs showed solid union at an average of 16 weeks, with no signs of hardware loosening or breakage. Functionally, the average knee flexion at final follow-up was 120 degrees, and the Lysholm score exceeded 80 in 70% of the patients, illustrating a generally positive outcome. Complications included one deep infection (3.8%) and two superficial wound dehiscence (7.7%), both successfully treated with antibiotics and local wound care. The authors highlighted the approach's advantage of preserving vital soft tissue around the popliteal fossa while providing direct access to the posterior tibial surface. Additionally, it facilitated accurate fixation of the posteromedial column, potentially reducing the risk of secondary collapse. He et al. concluded that the inverted L-shaped incision effectively addresses large posterior bicondylar fragments, enabling stable fixation and favorable functional recovery, although it necessitates careful surgical technique and thorough knowledge of posterior knee anatomy [39].

Zhu et al. (2013): Zhu and colleagues focused on the inter-observer reliability of three major classification systems—Schatzker, AO/OTA, and the three-column classification—in a cohort of 48 tibial plateau fractures. Twelve experienced orthopedic surgeons independently categorized each fracture using all three systems. Statistical analysis showed moderate agreement (κ=0.56) for the Schatzker classification and fair to moderate agreement (κ=0.40–0.58) for the AO/OTA system. In contrast, the three-column classification demonstrated significantly improved inter-observer reliability, with a κ value of 0.70. Discrepancies in the older classifications often arose in distinguishing complex bicondylar patterns and in assessing posterior involvement.

Additionally, surgeons reported that the three-column method facilitated a more systematic approach to treatment planning, allowing targeted fixation for each involved column. On average, the classification process took 30% less time using the column-based system, likely due to clearer guidelines for identifying posterior fragments. The authors emphasized that accurate fracture categorization is crucial for predicting outcomes, selecting fixation strategies, and communicating among surgical teams. They recommended routine use of CT imaging when employing any classification system, given that plain radiographs alone contributed to misclassification in nearly 15% of cases. Overall, Zhu et al. concluded that while all three systems are valuable, the three-column classification offers superior reliability and a practical framework to guide modern surgical management of tibial plateau fractures [40].

Yao et al. (2014): Yao and coauthors assessed the functional outcomes and identified risk factors in 61 patients with bicondylar tibial plateau fractures treated using dual buttress plates. The average patient age was 47 years, and almost 55% of fractures resulted from high-energy mechanisms such as traffic accidents. Postoperative radiographs showed an anatomical reduction (less than 2 mm of step-off) in 85% of the cases. At final evaluation, conducted at a mean of 14 months, the Hospital for Special Surgery (HSS) knee score was excellent or good in nearly 78% of patients. However, certain risk factors significantly affected results: age over 50 was associated with a 20% higher incidence of suboptimal outcomes, while fractures with significant comminution (more than three major fragments) correlated with a 15% increase in malreduction. Additionally, a delay in definitive surgery beyond two weeks resulted in 10% worse functional scores, underscoring the importance of timely intervention. The overall complication rate was around 12%, with infection being the most common (6.5%). Mechanical varus collapse was noted in 5%, primarily linked to insufficient medial buttress support. Notably, patients who engaged in early rehabilitation protocols regained knee flexion more rapidly and reported fewer complaints of stiffness (less than 5%). The authors concluded that dual buttress plating remains an effective strategy for bicondylar tibial plateau fractures but advocated careful preoperative planning, prompt surgical management, and structured postoperative rehabilitation, especially for older individuals or those with multi-fragmentary patterns [41].

Zhai et al. (2014): Zhai and coworkers investigated the outcomes of multi-plate reconstruction in 42 young adults with severe bicondylar tibial plateau fractures. Each fracture typically involved extensive comminution, including posteromedial fragments in 60% of cases and subchondral depression in 40%. The authors employed two or three locking plates strategically placed to stabilize each major fracture fragment. Postoperative radiographs indicated successful reduction (<2 mm depression) in 85% of cases, and all patients achieved radiographic union by 18 weeks, on average. Functionally, the mean Knee Society Score improved from 50 preoperatively to 86 at the 12-month follow-up. Over 75% of patients returned to their pre-injury level of sports or work activities. Complications were relatively low: infection occurred in 4.8% and implant failure in 2.4%. However, the study noted that the multi-plate technique resulted in longer operative times (a mean of 150 minutes) compared to traditional dual plating, potentially elevating the risk of soft tissue complications. Nonetheless, no significant correlation was found between operative duration and infection rates. Zhai et al. emphasized the importance of meticulous fragment-specific fixation, ensuring each condylar segment was independently stabilized to counteract shearing forces. They concluded that multi-plate reconstruction offers robust stability for younger patients with high functional demands, but warned that careful surgical planning and advanced imaging are prerequisites for achieving optimal outcomes in such complex fracture patterns [42].

Lin et al. (2016): Lin and associates examined the efficacy of a three-column internal fixation system using anatomical locking plates in 36 patients with comminuted tibial plateau fractures. Each plateau was stratified into medial, lateral, and posterior columns, and individual plates were applied as needed to fully secure each column. Nearly half (47%) of the fractures were secondary to road accidents, with a mean age of 43.8 years. Radiographic follow-up at 16 weeks demonstrated fracture union in 92% of patients, with an average time to full weight-bearing of 14 weeks. Additionally, postoperative CT scans confirmed that 80% of patients achieved articular step-offs of ≤1 mm. Functionally, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score averaged 24 at one year, indicating mild residual disability in daily activities. Only one deep infection (2.8%) and two superficial wound complications (5.6%) were recorded, suggesting that the multiple plating approach did not drastically elevate the risk of wound breakdown. Importantly, the authors attributed the high rate of anatomic reduction to the improved visualization and targeted fixation of difficult posterior and posteromedial fragments. Lin et al. concluded that the three-column system with anatomical locking plates enhances fracture stabilization in comminuted tibial plateau injuries, facilitating earlier mobilization and higher rates of successful union. However, they noted that the technique requires advanced surgical expertise and comprehensive imaging to accurately identify and address each fracture fragment [43].

Moradiya et al. (2016): Moradiya and colleagues presented a prospective study on 63 cases of tibial plateau fractures treated with locking tibial plates. The cohort included a mix of Schatzker Type I to VI fractures, with the most common being Type V (32%) and Type VI (28%). The mean time from injury to surgery was 7 days, largely dictated by soft tissue readiness. Radiological evaluation at 12 weeks showed signs of bone union in 88% of patients, and by 20 weeks, union was confirmed in 95%. Early mobilization protocols allowed partial weight-bearing by 10 weeks in 70% of patients. The Knee Society Score, assessed at six months, was excellent or good in 72% of cases, moderate in 18%, and poor in 10%. Notably, 8% of patients encountered wound complications, 3% developed deep infections, and 4% required secondary procedures for hardware removal or bone grafting. The study highlighted that locking plates provided stable constructs, especially in osteoporotic bone and multi-fragmented patterns, minimizing the need for prolonged external immobilization. Patients who presented with severe soft tissue compromise or significant comorbidities (e.g., diabetes) exhibited a heightened risk of infection (approximately 5%). Overall, Moradiya et al. endorsed locking plate fixation for its favorable balance between rigidity, reduced risk of secondary displacement, and facilitation of early physiotherapy, thereby promoting satisfactory functional outcomes in the majority of patients with tibial plateau fractures [44].

Khatri et al. (2017): Khatri and collaborators evaluated both the functional and radiological results of 52 tibial plateau fractures classified as Schatzker Type V and VI managed with dual plating. The patients, with a mean age of 42 years, were followed for a minimum of 12 months. Surgical intervention involved separate medial and lateral incisions, facilitating direct reduction of both condyles. Radiographic assessment demonstrated restoration of articular congruity with less than 2 mm step-off in 86% of cases. By six months, fracture union was documented in 90% of the cohort, with the remainder uniting by nine months. Clinically, the Rasmussen Functional Knee Score revealed that 75% of patients achieved excellent or good results, while 15% were fair, and 10% were poor—often correlated with severe initial injury or inadequate rehabilitation. Postoperative infections occurred in four cases (7.7%), predominantly superficial, and were successfully resolved with wound management and antibiotics. Deep venous thrombosis was diagnosed in two patients, emphasizing the need for vigilant thromboprophylaxis in high-energy fractures. The authors noted that dual plating conferred enhanced stability, particularly against varus and valgus stresses, allowing for earlier initiation of knee range-of-motion exercises. Khatri et al. concluded that while dual plating may entail more extensive soft tissue dissection and potential wound complications, it remains a reliable method for achieving anatomical reduction and strong fixation in complex bicondylar tibial plateau fractures. They advocated meticulous surgical planning, precise incision placement, and strict adherence to postoperative rehabilitation protocols to optimize outcome [45].

MATERIALS AND METHODS

Study Design and Setting:

This prospective study was conducted in Dr. Prabhakar Kore Hospital and Medical Research Centre. Patients presenting with tibial plateau fractures underwent systematic clinical and radiological evaluation, and those meeting the selection criteria were enrolled in the study. The study was aimed to analyze the functional and radiological outcomes of surgically managed tibial plateau fractures over a six-month follow-up period.

Study Population and Sampling Technique:

As per statistical calculations, 22 patients were needed to be included in our study. After getting institutional ethical approval, total of 26 patients with tibial plateau fractures were screened during this period. 3 patients were excluded [2 patients had open fractures and 1 patient was treated conservatively due to serious comorbidities], so, 23 patients were included in our study. Every adult patient suspected of having a tibial plateau fracture who arrived at Dr. Prabhakar Kore Hospital and Medical Research Centre were first assessed. A comprehensive history was obtained, followed by a thorough clinical examination. Once the patients' general conditions stabilized, relevant imaging studies were performed, including plain radiographs (anteroposterior and lateral views) and computed tomography (CT) scans. These investigations were used to classify the fracture type, assess displacement, and determine the degree of articular depression according to the three-column concept classification.

Subsequent management decisions regarding the need for surgical intervention, the timing of surgery, and the specific fixation method were based on the fracture classification, soft tissue status, patient comorbidities, and the extent of fracture displacement and depression. Patients were taken up for surgery as soon as possible once they were medically optimized and soft tissue conditions permitted.

Inclusion Criteria

Patients aged 18 to 70 years, of either sex.

Patients with closed tibial plateau fractures.

Patients willing to provide informed written consent to participate in the study.

Exclusion Criteria

Patients younger than 18 years of age.

Patients with open tibial plateau fractures.

Patients medically unfit for surgical intervention.

Pathological fractures.

Patients presenting with neurovascular injuries or compartment syndrome.

Surgical Protocol

Once a fracture of the tibial plateau was confirmed, patients were prepared for operative management following standard preoperative protocols. All surgeries were performed under sterile conditions in the operating room, with the aid of an image intensifier for real-time fluoroscopic guidance. A standard open reduction and internal fixation (ORIF) approach was employed, with the choice of implants (e.g., plates, screws) determined by the fracture pattern and the degree of articular surface involvement.

Anesthesia and Positioning:

Patients were placed under spinal or general anesthesia according to the anesthesiologist's evaluation of their medical fitness and comorbidities. They were positioned supine or prone on a radiolucent operating table to facilitate intraoperative fluoroscopic imaging.

Reduction and Fixation:

After appropriate exposure of the fracture site (using medial, lateral, or combined approaches as indicated by the fracture configuration), careful reduction of the articular surface was achieved. Depressed fragments were elevated if necessary, and bone graft or substitute was used at the surgeon's discretion to support the subchondral area if required. The reduction was provisionally stabilized using K-wires or clamps, and definitive fixation was then performed with anatomical locking plates and screws or other suitable fixation devices under fluoroscopic control.

Closure and Postoperative Care:

Wound closure was performed in layers after thorough irrigation. A sterile dressing was applied, and a compression bandage or knee immobilizer was used as indicated. Patients received prophylactic antibiotics and thromboprophylaxis as per hospital protocol.

Postoperative Assessment and Follow-up:

All patients were encouraged to begin knee range-of-motion exercises and partial weight-bearing as tolerated and guided by the stability of the fixation and the fracture pattern. Weight-bearing status was advanced progressively based on clinical and radiological evidence of fracture healing.

Radiographic Evaluation:

Follow-up radiographs were obtained at 6 weeks, 3 months, and 6 months postoperatively. Fracture union was assessed by the presence of bridging callus across the fracture lines and the absence of fracture line visibility on two radiographic views.

Functional Outcome:

Functional results were evaluated using the Modified Rasmussen Functional Scoring System. This scoring system included assessments of pain, walking capacity, knee extension, knee flexion, and stability. Each parameter was scored, and the cumulative score reflected the overall functional recovery of the knee joint.

Clinical Examination: During each follow-up visit, patients were evaluated for pain, swelling, range of motion, and any complications such as infection, implant failure, or malalignment.

Ethical Approval

Prior to beginning of our study, clearance from ethical committee was taken and each patient received an explanation of the objectives, potential risks, and benefits of the procedure. Written informed consent was obtained from all participants. The study was conducted in accordance with institutional ethics committee guidelines and the principles outlined in the Declaration of Helsinki.

Data Collection and Analysis

Relevant demographic information (age, sex), fracture characteristics, operative details, complications, and clinical outcomes were recorded. Findings were documented at each follow-up interval to monitor fracture healing and hardware integrity. At the end of the follow-up period, the collected data were analyzed to determine the overall functional outcome, rate of fracture union, and incidence of complications. The results were then compared with established standards in the literature to assess the efficacy of the applied treatment protocol.

RESULTS

Using three-column classifications, our study sought to evaluate the functional results of column-specific fixation in the treatment of proximal tibial fractures.

After getting institutional ethical approval, total of 26 patients with tibial plateau fractures were screened during this period. 3 patients were excluded [2 patients had open fractures and 1 patient was treated conservatively due to serious comorbidities], so, 23 patients were included. In our study, 82.6% of the patients were males and road traffic accidents [82.6%] were the major cause of injury. 34.8% of the patients had 1 column fracture while 43.5 % of them had two column and 21.7% had three column fracture respectively. By the end of 6 months 47.8% of the subjects had 'Excellent' outcome, 47.8% of the patients had 'Good' while only 4.34% of the patients had 'Fair' outcomes as per Modified Rasmussen Scoring System. 78.2% of the patients experienced 'Mild' and 21.7% had 'Moderate' pain levels as per VAS score and had resumed their pre-injury activities.

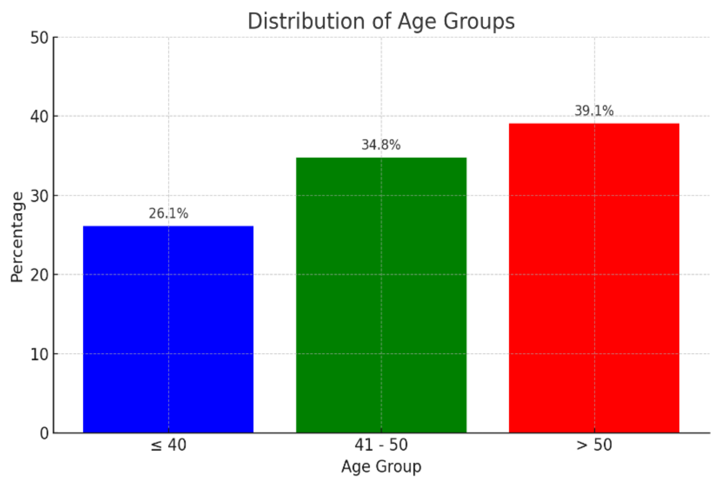
Complications, such as knee stiffness 8.7%, post-operative infection being 4.3%, and nil instances of implant prominence or failures and 82.6% had nil complications. CT-based planning has played a significant role in improving the precision of surgical approach and fracture assessment. A comprehensive three-dimensional picture of the fracture pattern provided by high-resolution CT imaging is essential to accurately identify the column involvement and direct the use of the proper fixing procedures. According to our study, preoperative CT scans were crucial for assessing the degree of displacement and comminution, which improved surgical planning and decreased intraoperative guesswork.

The results of our study support the use of the three-column categorisation for improved clinical outcomes and highlight the significance of customised surgical planning.

Total number of patients - 23

Age distribution

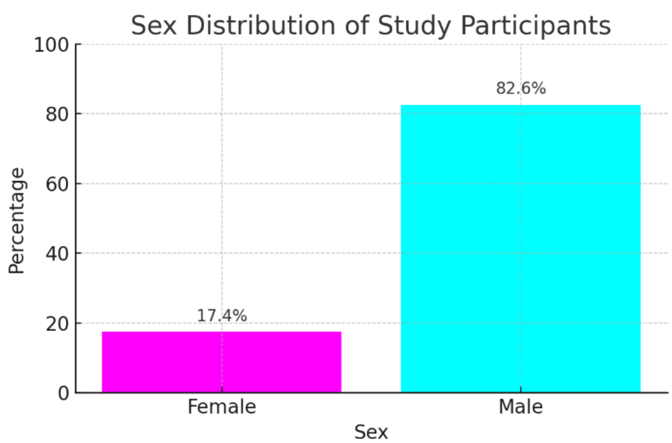
Age (yrs)	Frequency	Percent
≤ 40	6	26.1
41 - 50	8	34.8
> 50	9	39.1
Total	23	100.0



INTERPRETATION:
The age distribution of the study cohort is segmented into three distinct groups, representing varied stages. The data reveals a higher percentage of individuals aged over 50 years, accounting for 39.1% of the population, suggestive of a prominent presence of old aged subjects. This is followed closely by the 41-50 age group, comprising 34.8%, typically indicative of middle-aged individuals. The youngest cohort, aged 40 years or less, constitutes 26.1% of the study population.

Sex Distribution

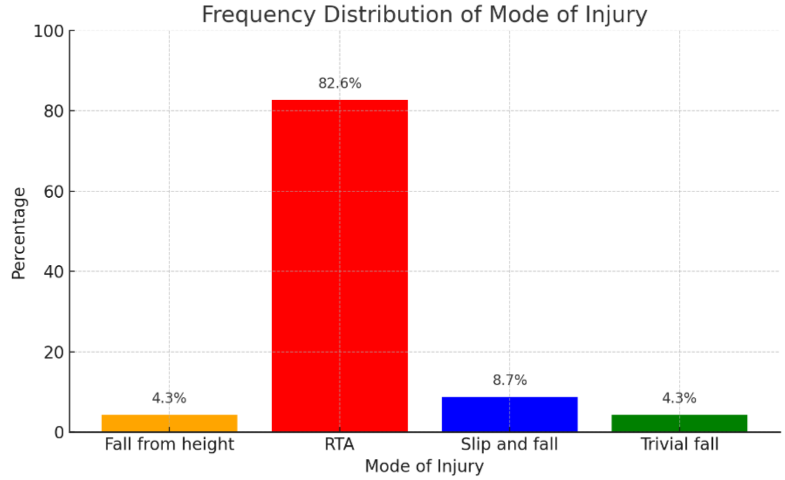
Sex	Frequency	Percent
Female	4	17.4
Male	19	82.6
Total	23	100.0



INTERPRETATION:
The sex distribution within the study cohort demonstrates a substantial predominance of male participants, who constitute 82.6% of the population. This significant majority could influence the generalizability of the study results, particularly in research focusing on conditions or responses that may manifest differently across sexes. Females are notably underrepresented, making up only 17.4% of the participants.

Frequency Distribution of Mode of injury

Mode of injury	Frequency	Percent
Fall from height	1	4.3
RTA	19	82.6
Slip and fall	2	8.7
Trivial fall	1	4.3
Total	23	100.0

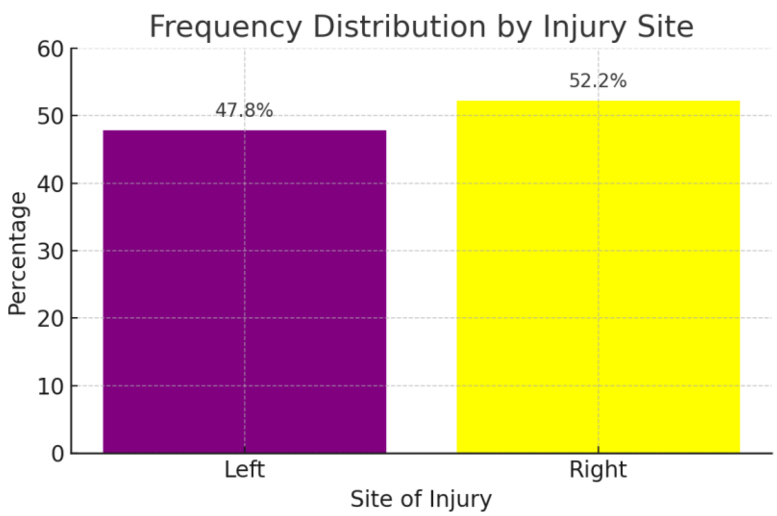


INTERPRETATION:

The frequency distribution of the mode of injury within the dataset distinctly highlights road traffic accidents (RTAs) as the predominant cause, accounting for a substantial 82.6% of the injuries. This high prevalence underscores the critical public health concern posed by RTAs and indicates a potential area for targeted preventive strategies. The other modes of injury, such as slips and falls, trivial falls, and falls from height, significantly lag behind, each constituting less than 10% of the cases. Specifically, slips and falls account for 8.7%, while falls from height and trivial falls each contribute only 4.3%.

Frequency Distribution of Site

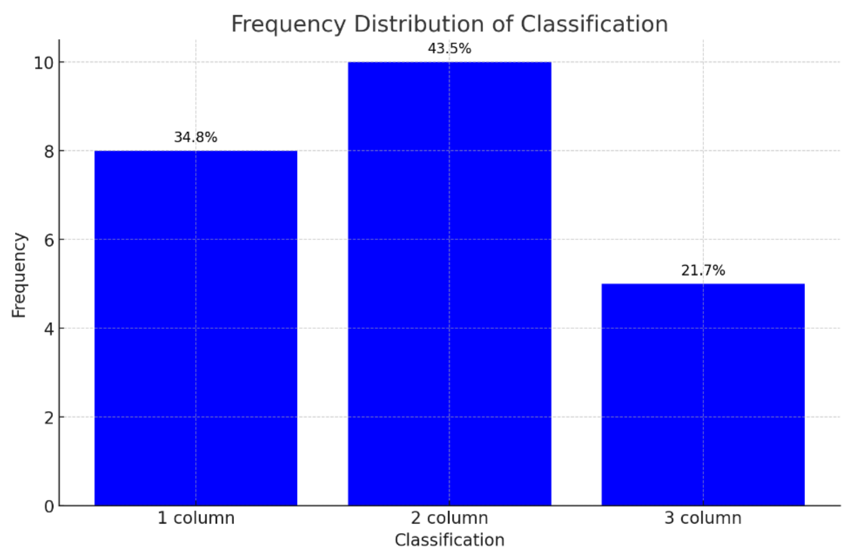
Site	Frequency	Percent
Left	11	47.8
Right	12	52.2
Total	23	100.0



Interpretation:
The frequency distribution by site of injury reveals a near-even division between injuries occurring on the left and right sides of the body, with a slight predominance on the right side, which accounts for 52.2% of cases. In contrast, the left side represents 47.8% of injuries. This balanced distribution suggests that both sides of the body are almost equally susceptible to injury in the contexts studied.

Frequency Distribution of Column Classification

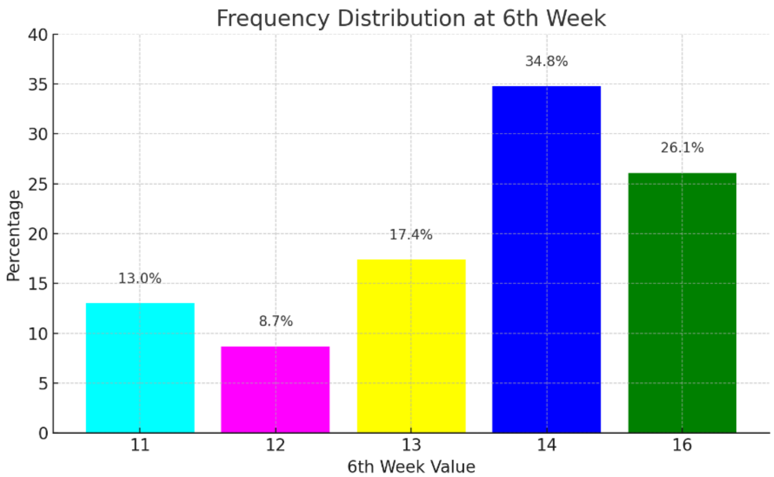
Classification	Frequency	Percent
1 column	8	34.8
2 columns	10	43.5
3 columns	5	21.7
Total	23	100.0



Interpretation:
The classification of injuries within the dataset is categorized into '1 column,' '2 columns,' and '3 columns' injuries, illustrating different levels of severity or complexity. The distribution indicates that '2 column' injuries are the most prevalent, comprising 43.5% of the cases [case series 2], suggesting they might be the most common type encountered in this particular clinical or accident scenario. This is followed by '1 column' injuries, which represent 34.8% [case series 1], indicating less complex injury patterns. The '3 column' injuries, which likely represent the most severe or complex cases, account for 21.7% of the total [case series 3].

Frequency Distribution of Rasmussen score at 6th week

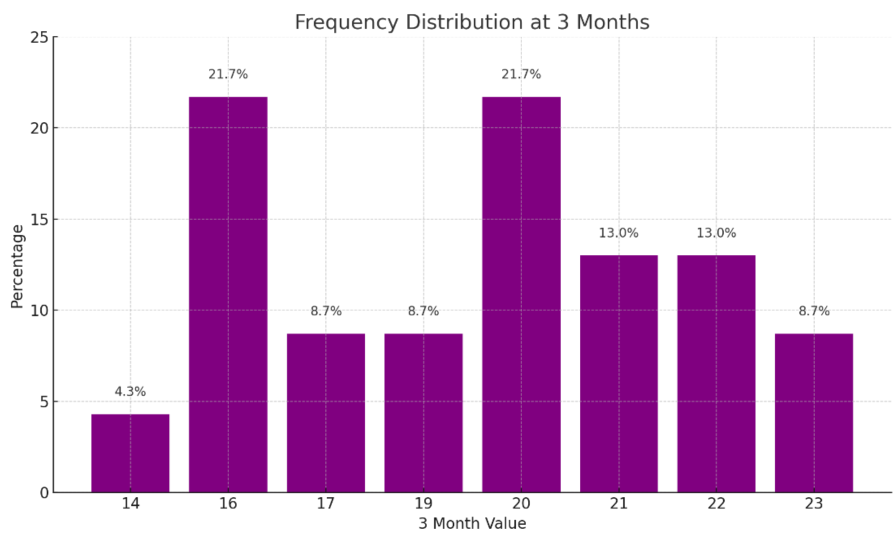
6th week	Frequency	Percent
11	3	13.0
12	2	8.7
13	4	17.4
14	8	34.8
16	6	26.1
Total	23	100.0



Interpretation:
The frequency distribution of values at the 6th week reveals a pattern indicative of progression or change over time within the cohort. The most frequently reported value at this time point is '14', accounting for 34.8% of the cases, suggesting a common outcome or status among participants at this stage. This is followed by '16', representing 26.1% of the dataset, possibly indicating a progression or improvement in the condition or response being measured. The values '11' and '13' show lower frequencies of 13.0% and 17.4%, respectively, highlighting fewer common outcomes. The value '12' is the least common, with only 8.7%, suggesting it may represent an atypical or less desirable outcome within the context of the study.

Frequency Distribution of Rasmussen score at 3 Months

3 Month	Frequency	Percent
14	1	4.3
16	5	21.7
17	2	8.7
19	2	8.7
20	5	21.7
21	3	13.0
22	3	13.0
23	2	8.7
Total	23	100.0

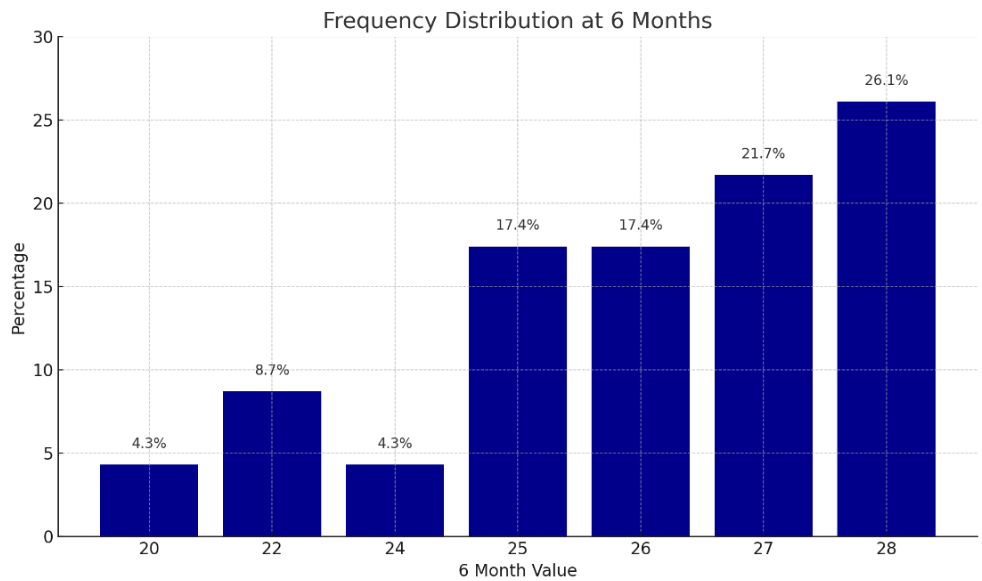


Interpretation:
The frequency distribution for the 3-months follow-up period illustrates a varied response spectrum among the subjects, emphasizing the predominant outcomes at '16' and '20', each recorded at 21.7%. These peak values suggest these are typical responses or recovery states at this juncture, potentially reflecting a stabilization phase or a critical recovery marker in the therapeutic or clinical scenario under study. Similarly, '21' and '22' both register a moderate occurrence rate of 13.0%, delineating an intermediate response range. The least common outcome is '14', at 4.3%, possibly representing an atypical or less favorable response.

Frequency Distribution of Rasmussen score at 6 months

6 Month	Frequency	Percent
20	1	4.3
22	2	8.7
24	1	4.3
25	4	17.4
26	4	17.4
27	5	21.7
28	6	26.1
Total	23	100.0

NO OF PATIENTS	FUNCTIONAL OUTCOMES
1 (4.4)	Fair
11 (47.8)	Good
11 (47.8)	Excellent

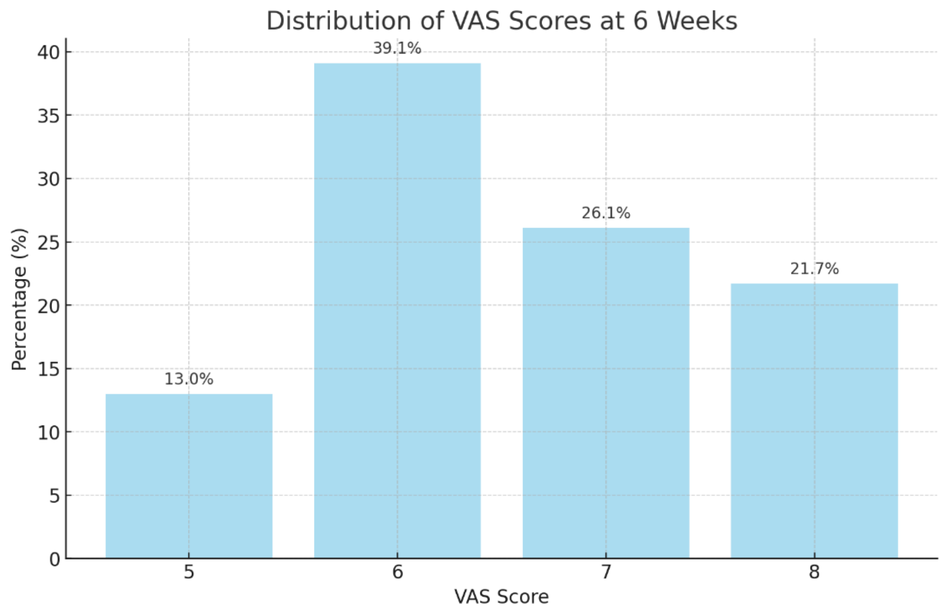


Interpretation:

The frequency distribution at the 6-month milestone reveals an interesting progression in patient responses, with a significant portion of the patients achieving higher evaluation scores. The peak frequency is observed for the value '28', representing 26.1% of the participants, suggesting a favorable outcome or optimal response at this time point. This is followed closely by the value '27', which accounts for 21.7%, indicating that a majority of the cohort is converging towards higher levels of recovery or improvement. The values '25' and '26' each constitute 17.4%, further underscoring a trend towards substantial improvement among the subjects. In contrast, the lower values ('20', '22', and '24'), each with minimal frequencies (4.3% and 8.7%), indicate less common outcomes.

Frequency Distribution of VAS score at 6 weeks

VAS Score	Frequency	Percent
5	3	13.0
6	9	39.3
7	6	26.0
8	5	21.7
Total	23	100.0

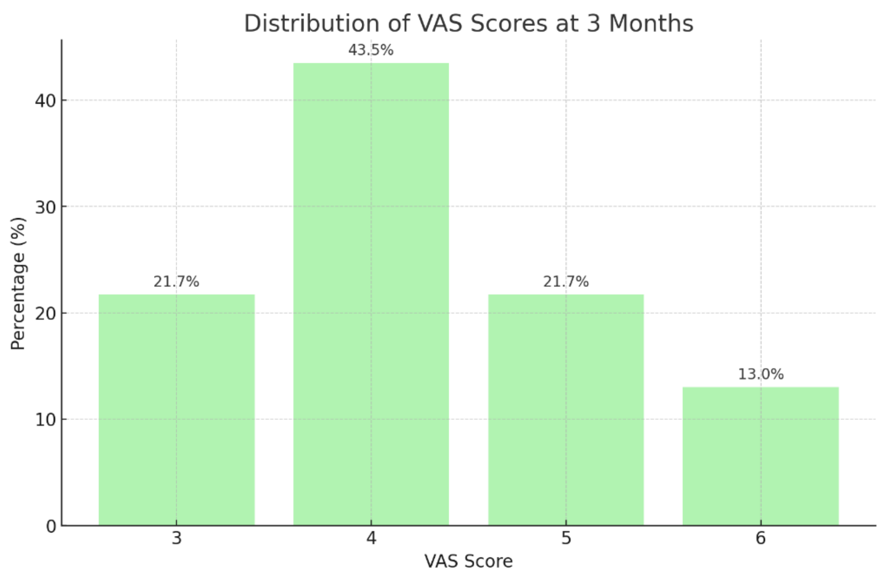


Interpretation:

The bar chart illustrates the distribution of Visual Analog Scale (VAS) scores at 6 weeks. Scores ranged from 5 to 8, with the highest frequency observed at a VAS score of 6, comprising 39.1% of the responses. This was followed by a score of 7 (26.1%), a score of 8 (21.7%), and the least frequent being a score of 5 (13.0%). The chart effectively captures the predominance of moderate to high scores, suggesting that a significant proportion of individuals experienced notable discomfort or pain at this time point. This distribution provides a quantitative basis for understanding the initial severity of symptoms post-intervention

Frequency Distribution of VAS score at 3 months

VAS Score	Frequency	Percent
3	7	30.6
4	8	34.7
5	5	21.7
6	3	13.0
Total	23	100.0

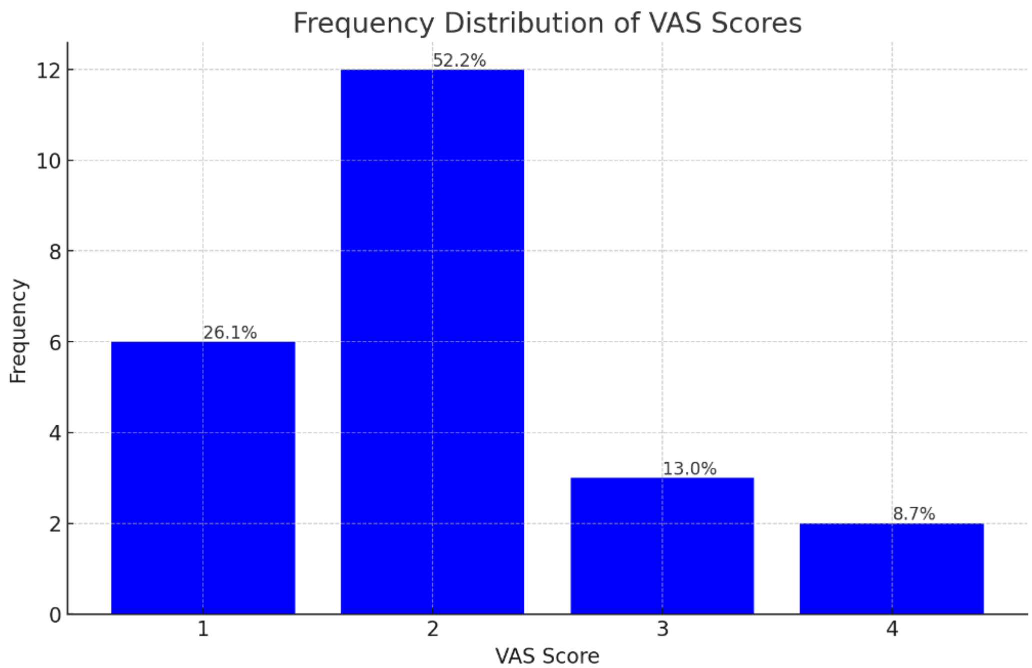


Interpretation:

The bar chart displays the distribution of Visual Analog Scale (VAS) scores at 3 months. At this juncture, the scores reveal a downward shift compared to the initial 6-week assessment. The most common score was 4, representing 43.5% of the responses, indicating a moderate level of discomfort or pain. This was followed by scores of 3 and 5, each accounting for 21.7% of the participants. The least frequent score was 6, comprising only 13.0% of the responses. This distribution signifies an overall decrease in symptom severity, suggesting an improvement in the condition being monitored, likely due to ongoing treatment or natural progression of recovery

Frequency Distribution of VAS score at 6 months

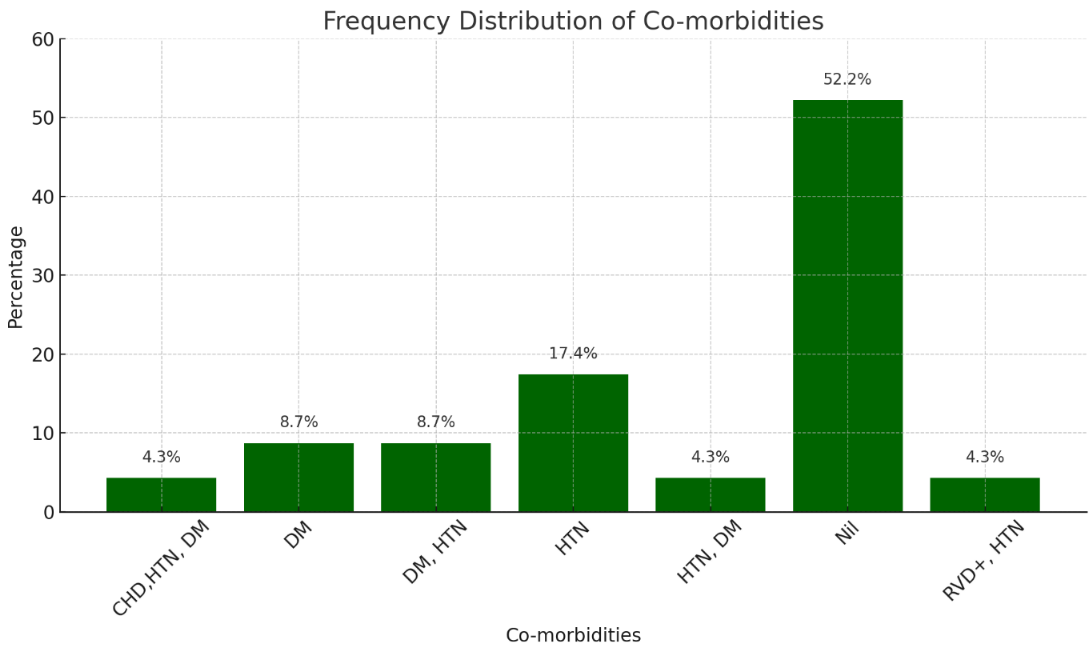
VAS Score	Frequency	Percent
1	6	26.1
2	12	52.2
3	3	13.0
4	2	8.7
Total	23	100.0



Interpretation:
The bar chart illustrates the frequency distribution of Visual Analog Scale (VAS) scores, revealing a predominant clustering of lower scores within the sample. The majority of participants (52.2%) reported a VAS score of 2, underscoring a mild perception of pain or discomfort. The scores of 1 and 3 were less frequent, representing 26.1% and 13.0% of the responses, respectively, while a VAS score of 4 was the least common, observed in only 8.7% of cases. This distribution suggests that most participants experience mild to moderate levels of the assessed condition, with a smaller proportion encountering more severe manifestations.

Frequency Distribution of Co-morbidities

Co-morbidities	Frequency	Percent
CHD, HTN, DM	1	4.3
DM	2	8.7
DM, HTN	2	8.7
HTN	4	17.4
HTN, DM	1	4.3
Nil	12	52.2
RVD+, HTN	1	4.3
Total	23	100.0

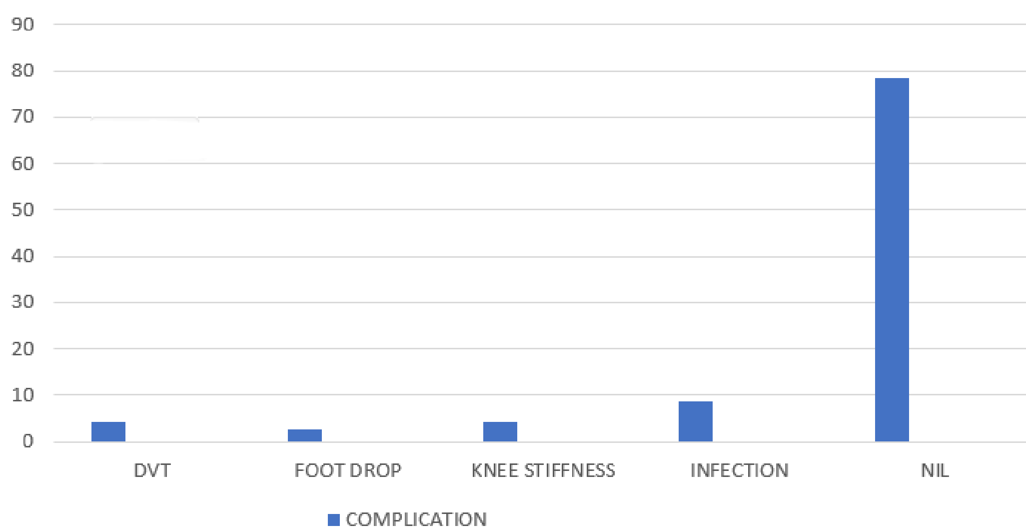


Interpretation:

The frequency distribution of co-morbidities in the study cohort reveals a predominant absence of additional health conditions, with 52.2% of participants reported as having no co-morbidities ('Nil'). This significant majority underscores the potential for the primary condition under investigation to be assessed without the confounding effects of other chronic illnesses, providing a clearer understanding of the direct impacts and outcomes. Among those with co-morbid conditions, hypertension (HTN) alone is the most common, seen in 17.4% of cases, reflecting its prevalence as a common chronic condition. The combinations of diabetes mellitus (DM) and HTN, either alone or in combination, represent smaller proportions, each ranging from 4.3% to 8.7%. The rarest is the combination of coronary heart disease (CHD), HTN, and DM, also reflecting a complex but less frequent health profile.

Frequency Distribution of Complications

Complication	Frequency	Percent
DVT	1	4.3
Foot drop	1	4.3
Knee stiffness	2	8.7
operated site got infected after 8 months	1	4.3
Nil	18	78.4
Total	23	100.0



Interpretation:
The frequency distribution of complications post-treatment in this cohort reveals a significant predominance of patients experiencing no complications, with 78.4% reported as 'Nil'. This substantial majority indicates a high level of efficacy and safety associated with the treatment or intervention provided. Among the recorded complications, 'Knee stiffness' emerges as the most common, albeit at a low rate of 8.7%, reflecting a relatively mild and manageable issue following interventions. Other complications such as 'DVT' (Deep Vein Thrombosis), 'Foot drop', and an 'Infection after 8 months' each occurred in only 4.3% of cases, demonstrating their rarity but highlighting critical areas for vigilant monitoring and preventive care.

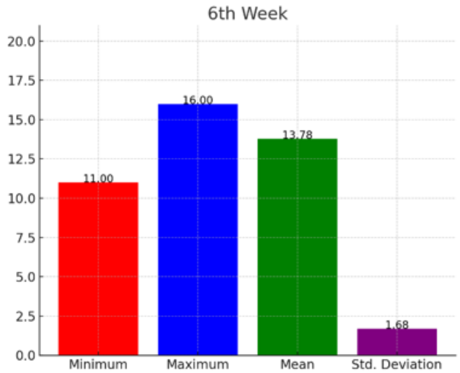
Statistical comparison of variables of Modified Rasmussen Score and VAS score.

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Rasmussen score at 6 weeks	23	11	16	13.78	1.678
Rasmussen score at 3 months	23	14	23	19.17	2.640
Rasmussen score at 6 months	23	20	28	25.87	2.181
VAS score at 6 weeks	23	5	8	6.56	0.99
VAS score at 3 months	23	3	6	4.17	1.03
VAS Score at 6 months	23	1	4	2.04	1.164

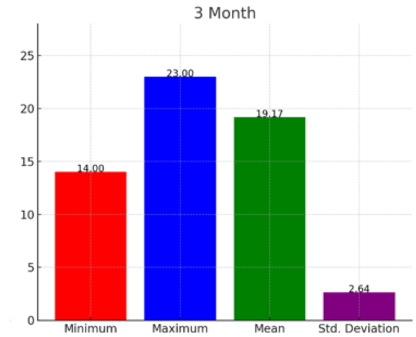
Interpretation:
In our study, when we compare mean, maximum and mean scores over a period of time, it reveals a progressive increase in mean values from the 6th week to the 6th month, indicating a trend of improvement or escalation in the measured parameters. At the 6th week, the mean value is 13.78, with a relatively narrow range from 11 to 16, reflecting early outcomes or responses. By the 3rd month, the mean increases significantly to 19.17, with a wider maximum of 23, suggesting continued improvement or progression in patient conditions. The 6th month sees a further rise in the mean to 25.87, approaching the upper boundary of 28, which illustrates substantial advancements or recovery. The VAS score, at 6 weeks shows mean values of 6.56 and 4.17 at 3 months highlighting the significant recovery from pain. At 6 months, averaging 2.04 with a range from 1 to 4, highlights the subjective patient-reported outcome regarding pain or satisfaction, maintaining a standard deviation of 1.164, which denotes relatively consistent patient experiences across the cohort.

Statistical comparison of variables of Modified Rasmussen Score and VAS score.

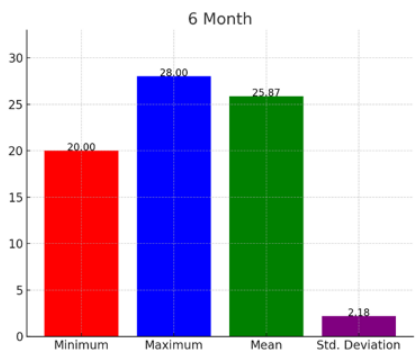
Modified Rasmussen Score at 6 weeks



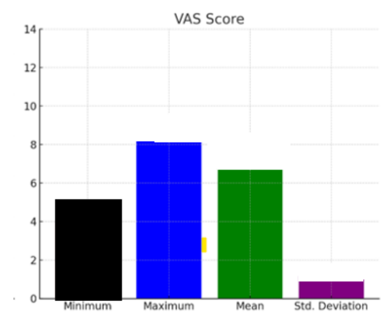
Modified Rasmussen Score at 3 months



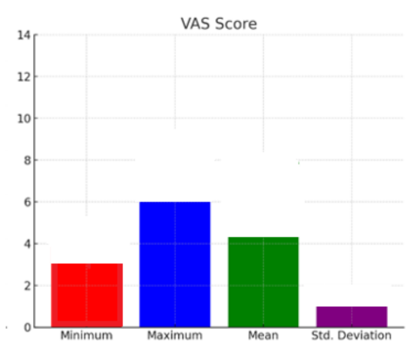
Modified Rasmussen Score at 6 months



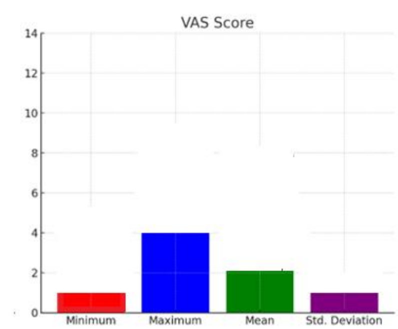
VAS score at 6 weeks



VAS score at 3 months

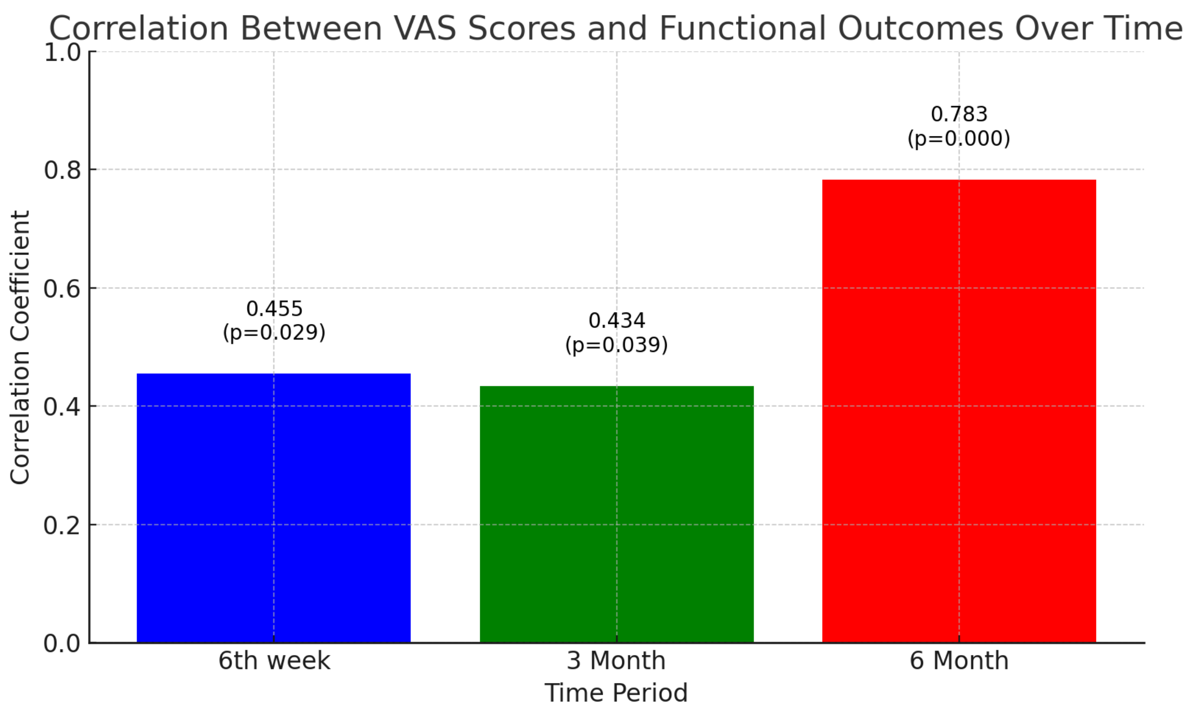


VAS score at 6 months



Correlation Between VAS Scores and Functional Outcomes

6th week	Correlation	0.455*
	P value	0.029
3 Month	Correlation	0.434*
	P value	0.039
6 Month	Correlation	0.783**
	P value	0.000



Interpretation:

The correlation analysis between VAS scores and functional outcomes over time illustrates a progressively strengthening relationship. Initially, at the 6th week, the correlation coefficient is 0.455 with a significant p-value of 0.029, indicating a moderate positive association. This relationship slightly weakens at the 3-month mark, with a correlation of 0.434 and a p-value of 0.039, still indicating a positive but lesser association. However, by the 6th month, the correlation substantially increases to 0.783, accompanied by a highly significant p-value of less than 0.001, suggesting a strong positive correlation.

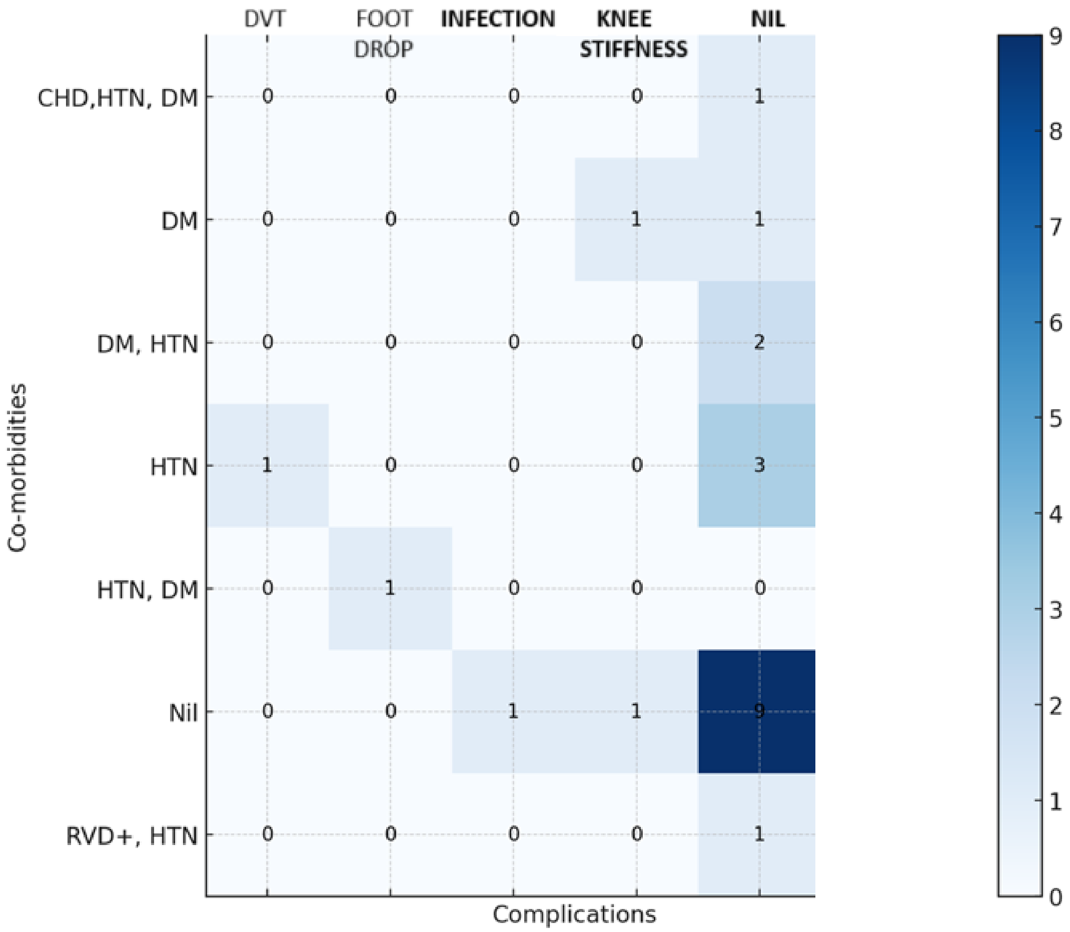
Association Between Co-Morbidities and Complications

	Complication					Total
Co-morbidities	DVT	Foot drop	Knee stiffness	Nil	operated site got infected after 8 months	
CHD, HTN, DM	0	0	0	1	0	1
DM	0	0	1	1	0	2
DM, HTN	0	0	0	2	0	2
HTN	1	0	0	3	0	4
HTN, DM	0	0	0	0	0	1
Nil	0	1	1	9	1	12
RVD+, HTN	0	0	0	1	0	1
Total	1	1	2	17	1	23
Pearson chi-square = 34.556, p-value = 0.259						

Interpretation:
The heatmap illustrates the association between various co-morbidities and the occurrence of complications among study participants. This visual representation highlights that most complications are isolated incidents across different co-morbid conditions, with 'Nil' co-morbidities showing a spread across different complications including 'Foot drop', 'Knee stiffness', and an 'Infection after 8 months'. Notably, 'HTN' alone is associated with the single occurrence of 'DVT'. The predominant condition of 'Nil' co-morbidities with no complications in many cases (9 instances) underlines the general health resilience against complications among participants without additional health burdens.

Despite these associations, the Pearson chi-square value of 34.556 with a p-value of 0.259 indicates no statistically significant association overall between the types of co-morbidities and the complications that occurred, suggesting that in this sample, co-morbidities did not predict the type of complication experienced.

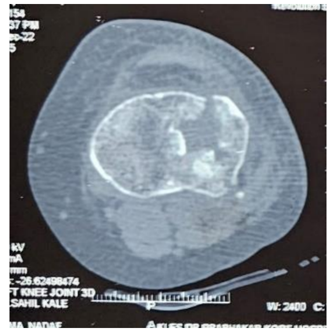
Association Between Co-Morbidities and Complications



RESULTS : CASE SERIES - I

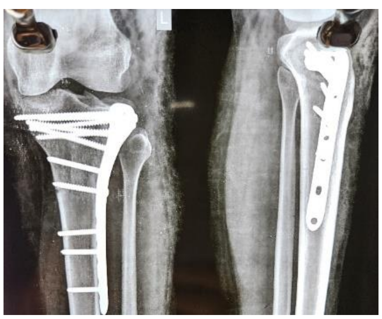
Pre-op X-ray

Schatzker's type 2 fracture



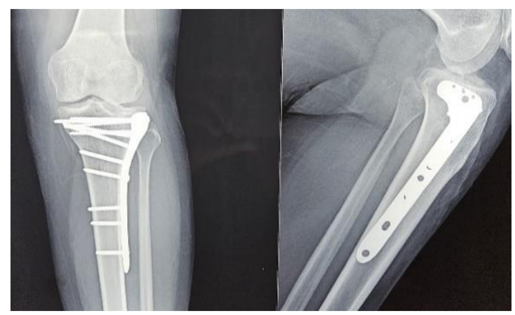
Pre-op CT axial view

Luo's 1 column fracture



6 weeks follow up

3 months follow up

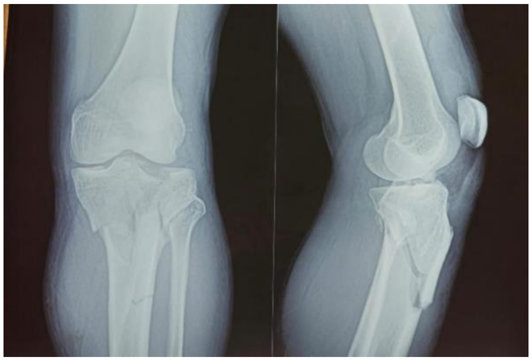


6 months follow up

Functional outcome at 6 months

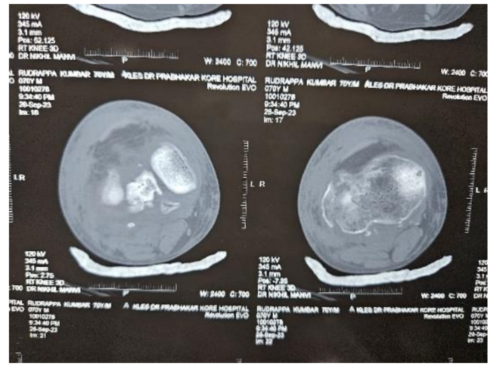
Functional outcome at 6 months

CASE SERIES - II



Pre - op X-Ray

Schatzker's type 4 fracture



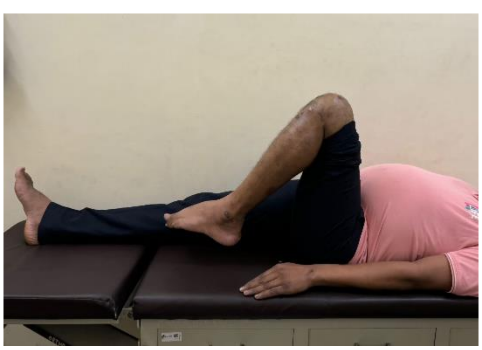
Pre – op CT axial view

Luo's 2 column fracture

Post op X-ray

3 months follow up

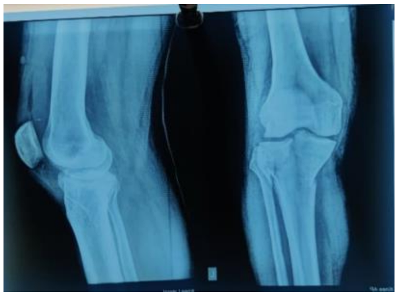
6 months follow up



Functional outcome at 6 months

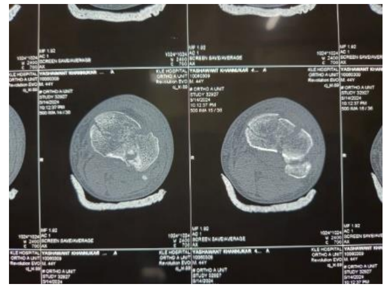
Functional outcome at 6 months

CASE SERIES- III



Pre-op X-ray

Schatzker's type 5 fracture



Pre-op CT axial view

Luo's 3 column fracture

6 weeks follow-up

3 months follow-up

6 months follow-up

Functional outcome at 6 months

Functional outcome at 6 months

DISCUSSION

Proximal tibial fractures pose a notable challenge for orthopaedic surgeons due to the need for stable fixation, restoration of alignment, and preservation of soft tissues. The concept of column-specific fixation has gained traction, emphasizing targeted stabilization of the lateral, medial, and posterior columns according to fracture morphology [46]. Early work on high-energy tibial plateau fractures underscored the frequency of complications when managing bicondylar patterns via a single approach, prompting strategies that consider separate columns for optimal articular restoration [47]. Many authors have supported the importance of accurate articular reduction and stable fixation to prevent joint collapse and late osteoarthritis, especially in multi-column injuries [48]. Although conventional lateral locking plates suffices for some fracture types, more complex patterns often demand dual or triple plating to ensure stability across all involved columns [49]. The present investigation focused on functional outcomes in patients treated with these column-specific approaches, documenting clinical scores, pain levels, and complications at standardized follow-up intervals.

In our study of 23 patients, aged ranged from under 40 to over 50 years were included, mirroring many clinical reports where the fourth to sixth decades show a higher incidence of these fractures [50]. As old aged individuals often have poorer bone quality and a risk of comorbidities, careful surgical planning can mitigate complications and promote satisfactory healing across all age groups [51]. The sample was predominantly male 82.6%, a pattern frequently noted when road traffic accidents constitute the primary mechanism of injury [52]. Indeed, 82.6% of fractures here resulted from high-energy trauma, aligning with evidence that RTAs often generate multi-column or bicondylar patterns demanding robust fixation constructs [53]. If a patient has underlying osteoporosis leading to more fragile bone, patient requires locking plates or augmented fixation [54].

Fracture distribution was categorized into one-column, two-column, or three-column. Approximately 34.8% of patients had one column involvement and 43.5% had two-column while 21.7 % had three column involvement, reflecting the commonly encountered bicondylar pattern in which both condyles are compromised [56]. The absence of classification for posterior column fractures could lead to inadequate surgical planning and sub-optimal results. As per Hong Wei Chen. et al in a study done on 38 patients, it was found that 28.8 % of the patients had posterior tibial plateau fracture and the similar incidence rate was reflected in our study with 21.7%. This result emphasizes the role of CT based classification as these fractures could not be identified on plain radiographs [57].

Biomechanical studies have shown that insufficient fixation of these posterior fragments can lead to angular deformities and hardware failure [58,59]. The principle of addressing each column is supported by prior clinical series demonstrating improved alignment and range of motion when the posterior condyle is stabilized, rather than relying solely on a lateral locked plate [61].

Functional outcomes progressed significantly over time. By six weeks postoperatively, scores reflected early pain, stiffness, and restricted weight-bearing. At three months, patients had notably higher functional ratings, coinciding with partial or full weight-bearing protocols and more advanced rehabilitation exercises [62]. By six months, the mean functional score was 25.87 (±2.181), indicating that most patients approached pre-injury activity levels. These gains are consistent with staged recovery patterns in tibial plateau fractures, where the first three months focus on controlled mobilization and the subsequent months emphasize strengthening and gait training [63]. Research by Yao et al. demonstrated that the three-column classification allows for more tailored surgical planning, leading to better alignment and joint stability postoperatively. This aligns with our findings, where patients treated using the three-column approach showed superior Modified Rasmussen Score of 47.8% at the end of 6 months when compared to those managed with the traditional Schatzker-based methods.

Furthermore, column-specific fixation reduces soft tissue injury and improves recovery, especially in complex fractures, according to a systematic analysis by Berei et al [46] that examined the results of different fixation procedures. Our study corroborates those results, showing that targeted fixation of individual columns results in better functional recovery and fewer post-surgical complication.

Patients showed good results in our study on proximal tibial fractures treated with column-specific fixation based on the three-column classification. The mean VAS score for pain was 2, which indicates little discomfort, and the average Modified Rasmussen Clinical Score was 26, which indicates "good" knee function where 47.8 % had “excellent”,47.9% had “good” and 4.3% had fair results. In contrast, Yin et al. used the Modified Rasmussen Clinical Score to evaluate 40 patients who had proximal tibial fractures. According to their findings, 54.2% of patients had "excellent," 38.7% had "good," and 7.1% had "acceptable" results [64].

In comparison to patients treated with the Schatzker classification, patients treated with the three-column classification system had considerably lower VAS pain scores after surgery, according to a study by Yin et al [64]. This is supported by our results, which shows that patients with column-specific fixation had higher satisfaction and better pain alleviation, which were associated with superior functional outcomes as determined by the Modified Rasmussen Score.

Comorbidities such as hypertension or diabetes did not show a statistically significant association with increased complication rates in our series, but individuals with diabetes or immunocompromise can be predisposed to wound healing issues or delayed union [65]. In our study, 73.9% of participants had no complications. Those who did experience adverse events encountered knee stiffness, foot drop, deep vein thrombosis, or late infection. Knee stiffness, though uncommon here, has been widely documented as a frequent issue after periarticular fractures, especially when early motion is deferred.

According to research by Johnson et al [66], postoperative knee stiffness was more common in patients treated with classic Schatzker-based fixation than in those treated with column-specific procedures. Similar to this, our study found that individuals treated with the three-column classification had lower rates of knee stiffness, most likely as a result of improved anatomical alignment and less soft tissue damage. This emphasises how crucial accurate fracture classification and customised fixation are to reducing joint stiffness and maximising mobility following surgery. Foot drop raises concern for intraoperative or traction-related nerve injury; such incidents highlight the need for meticulous surgical dissection. A late infection at eight months underscored the possibility of low-grade chronic infection, hardware irritation, or hematogenous seeding, all of which can undermine fixation. Fortunately, the overall complication rate was relatively modest, in line with series reporting 24% complication rates for similar high-energy proximal tibial fractures [46].

Our study's observed rates of complications also exhibit significant comparisons with previous research. The overall complication rate of 21.8% of which 8.7% of patients developed knee stiffness, 4.3% had DVT, foot drop and operative site infection respectively were in line with results from related studies. For instance, Zhang et al. found that deep infections were the most frequent complication, with an overall complication incidence of 22.4% for 88 patients having tibial plateau fracture osteosynthesis where 8.78% of the patients developed knee stiffness, 3.40% had DVT, 5.68% of infection and 4.54% had hardware prominence [65].

Our protocol employed a case-by-case strategy using lateral locked plates or dual plates if the posterior column was severely compromised. This individualized approach aligns with the principle that no single technique suits all fracture patterns; rather, each column must be addressed based on its displacement and comminution [48].

While the short-term functional recovery in our study appeared promising, limitations should be acknowledged. The sample size of 23 patients restricts the power to detect small differences among subgroups. Follow-up of six months may be insufficient to capture the onset of post-traumatic osteoarthritis, which can manifest years after injury [51]. Moreover, the study lacked comprehensive radiological scoring systems that might more precisely gauge articular congruity [53]. Rehabilitation protocols varied based on individual factors, possibly confounding the relationship between fixation strategy and final outcome. Nonetheless, the consistent observation of improved scores from six weeks to six months suggests that structured physiotherapy—initiated early when possible—plays a pivotal role.

Furthermore, advanced classification systems have refined surgical approaches, and robust open fracture protocols remain crucial when the soft tissue envelope is significantly compromised [67], particularly for fractures that align with Gustilo-Anderson criteria [68]. Emerging frameworks like the Marsh OTA classification offer standardized assessments and enhance interobserver reliability [69]. Additionally, modern internal fixator systems have evolved to optimize periarticular fracture management while limiting soft tissue disruption, contributing to improved outcomes [70]. These developments highlight how technology and rigorous classification can complement column-specific fixation to further reduce complications and enhance recovery.

SUMMARY

The current study was done to assess the functional outcomes and overall efficacy of column-specific fixation in proximal tibial fractures. Proximal tibial fractures are notorious for complex fracture patterns and need to achieve rigid stability against the delicate balance of preserving the soft tissue envelope. Classification of these fractures into single-column, two-column, and three-column categories allows surgeons to adapt their fixation strategies to restore articular congruity and to support effective yet safe rehabilitation. These patients underwent a combination of meticulous preoperative planning, modern implant technology, and close postoperative monitoring to maximize the chances of returning the knee joint to near normal or normal function.

In our study, 82.6% of the patients were males and road traffic accidents [82.6%] were the major cause of injury. 34.8% of the patients had 1 column fracture while 43.5 % of them had two column and 21.7% had three column fracture respectively. By the end of 6 months 47.8% of the subjects had 'Excellent' outcome, 47.8% of the patients had 'Good' while only 4.34% of the patients had 'Fair' outcomes as per Modified Rasmussen Scoring System. 78.2% of the patients experienced 'Mild' and 21.7% had 'Moderate' pain levels as per VAS score and had resumed their pre-injury activities.

Complications, such as knee stiffness 8.7%, post-operative infection being 4.3%, and nil instances of implant prominence or failures and 82.6% had no complications. As per our study, comorbidities do not have any influence on overall functional outcome.

Functional assessments were performed at 6 weeks, 3 months, and 6 months after surgery. Consistent progressive improvement in the scores was observed. This underlines the role of time, management of pain, and structured rehabilitation in restoring mobility of the knee and autonomy in patients. In most patients at 6 months, near complete return of joint range of motion was observed, along with decrease in the severity of pain. This trajectory follows known recovery patterns but also emphasizes the critical interaction between appropriate implant selection—especially in multi-column fractures—and long-term stability of the tibial plateau.

The complications appeared relatively infrequent but serious, including knee stiffness, foot drop, infection, and one case of DVT. Although a statistical analysis could not establish a robust connection in terms of comorbidities and complications, vigilance in medical optimization for patients with conditions like diabetes or hypertension can further minimize risks. The majority of patients with no comorbidities sailed through recovery without major setbacks, although individual variations in pain tolerance, postoperative compliance, and physiotherapy involvement played a role in overall recovery quality.

When compared to other published work on proximal tibial fractures, the results support that focused, column-specific fixation creates a stable mechanical environment that fosters timely bone healing and functional recovery. It helps overcome the specific challenges presented by multiple columns of fracture, thereby avoiding some of the pitfalls that include varus or valgus collapse and secondary osteoarthritis. It identified early mobilization protocols, robust pain control, and patient-tailored rehabilitation programs as the cornerstones to optimize the outcome and prevent complications.

Key Points from the Study

In our study, about 21.7% of the patients had 3 column fractures which could not be identified in radiographs (Schatzker's classification). This demonstrated the significance of CT based column fixation. Through this study, it is found that column-specific fixation is adaptable to diverse fracture patterns, aiding in precise reduction of the articular surface as majority of patients reached near-complete functional recovery by 6 months, underscoring the importance of rigid internal fixation and systematic rehabilitation.

Low VAS pain scores were significantly correlated with good functional scores, emphasizing pain management as a critical component of recovery. Although comorbidities did not directly predict complications, tailored perioperative care remains paramount for patients with DM, HTN, or other conditions. The successful outcomes in both one-column and multi-column fractures highlight the versatility and efficacy of well-planned, individualized surgical approaches.

CONCLUSION

Our study emphasises the significance of accurate anatomical classification and customised surgical techniques in the treatment of proximal tibial fractures through the functional outcome analysis of column-specific fixation. The three-column classification provides a more thorough comprehension of the fracture morphology, allowing for a more focused and biomechanically stable fixation technique, even if the Schatzker classification is still frequently utilised due to its historical significance and simplicity. In our study, about 21.7% of the patients had 3 column fractures which could not be identified in Schatzker's classification. This demonstrated the significance of CT based column fixation.

The results of our study show that, especially in complex fracture patterns, column-specific fixation, guided by the three-column classification, improves functional outcomes. By strategically stabilising specific columns, this method reduces soft tissue injury and improves recovery after surgery. The Schatzker classification, on the other hand, may not fully handle the complex nature of multi-fragmentary and comminuted fractures, despite its effectiveness in simpler fracture patterns. This could result in a higher likelihood of malalignment and more severe than ideal functional outcomes.

For proximal tibial fractures, precise classification and column-specific fixation are essential to obtaining the best possible functional results. Compared to the conventional Schatzker approach, the three-column categorisation offers a more thorough and efficient framework for handling complex fracture patterns, improving stability, alignment, and recovery.

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ANNEXURE 1: ETHICAL CLEARANCE

K.L.E. ACADEMY OF HIGHER EDUCATION AND RESEARCH
(Deemed – to- be- University)
Accredited 'A+' Grade by NAAC in (3rd Cycle) Placed in Category 'A' by MHRD (GoI)

JNMC INSTITUTIONAL ETHICS COMMITTEE
JAWAHARLAL NEHRU MEDICAL COLLEGE,
NEHRU NAGAR, BELAGAVI-590010 (KARNATAKA-INDIA)

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Ref No.MDC/JNMCIEC/ 124 **Date: 21/03/2023**

To,
BL0122003
PG Student in Orthopaedics
J. N. Medical College,
BELAGAVI.

Sub: Institutional Ethical Clearance for the study.

With reference to the above, we wish to inform you that your proposed research project titled **"FUNCTIONAL OUTCOME ANALYSIS OF COLUMN SPECIFIC FIXATION IN THE MANAGEMENT OF PROXIMAL TIBIAL FRACTURES"**, is ethical and justifiable. The proposed research project has been cleared by the JNMC Institutional Ethics Committee.

(Dr. Smita Sonoli)
Member Secretary
JNMC Institutional Ethics Committee
J.N.Medical College, Belagavi.

(Dr. Harsha Hegde)
Chairman,
JNMC Institutional Ethics Committee
J.N.Medical College, Belagavi

ANNEXURE 2 : INFORMED CONSENT

“FUNCTIONAL OUTCOME ANALYSIS OF COLUMN SPECIFIC FIXATION IN THE MANAGEMENT OF PROXIMAL TIBIAL FRACTURES”

Registration number of the student: BL0122003

Objective: To prospectively study the functional outcome of proximal tibial fractures fixed using three column concept after a follow up period of 6 months by modified Rasmussen score.

Introduction: Complex tibial fractures usually have complicated fracture pattern, often associated with severe soft tissue injury. Dual column plating based on conventional x-ray for such fractures may not address the multiplanar comminution. CT based evaluation will allow direct visualization and anatomical reduction in such fractures.

Therefore, we propose to explore the effects of surgical treatment guided by the three-column classification method on knee joint function and postoperative complications in patients with proximal tibial fractures.

Explanation of procedure: Treatment method will be decided after classifying the type of fracture and displacement and surgery will be done as early as possible. It will be done under c-arm guidance and post operatively functional and radiological outcome will be analyzed by periodic x-rays at the interval of 6 weeks, 3rd month and at 6th month respectively.

Withdrawal from participation in the study: Participation in this study is voluntary. You will be free to decide whether to participate in this study or continue participation once enrolled. In case you decide to withdraw your participation, you are free to do so. However, please convey the decision to the principal investigator.

Possible benefits from participating in the study: You will/will not have nor get any benefits by participating in this study. The data gathered will help the population at large.

Possible risks from participating in the study: There are no risks involved in participating in this study.

Privacy and confidentiality: The information collected from you will be coded, to prevent any person from identifying you. Your identity will never be revealed. The data collected from you will be kept confidential and only processed or aggregated data will be used for publication.

Financial incentives: You will not receive any payment for participating in this study.

Authorization for publication of aggregated data: Results obtained after processing of the aggregated data will be published for scientific purposes and or presented to scientific groups. However, your identity will never be revealed.

ANNEXURE 3: PROFORMA

FUNCTIONAL OUTCOME ANALYSIS OF COLUMN SPECIFIC FIXATION IN THE MANAGEMENT OF PROXIMAL TIBIAL FRACTURES

PATIENT NO: IP NO:

NAME:

AGE: SEX:

ADDRESS:

OCCUPATION:

X-RAY NO: MODIFIED RASMUSSEN SCORE:

CT NO: VAS SCORE:

DOA: DOD:

ANNEXURE 4: MODIFIED RASMUSSEN SCORE

Subjective	Points
A. Subjective complaints	
a. Pain	
No pain	6
Occasional pain	5
Constant pain after activity	4
Significant rest pain	0
b. Walking capacity	
Normal walking capacity (in relation to age)	6
Walking outdoors for at least 1 h	4
Short walks outdoors for >15 min	2
Walking indoors only	1
Wheel-chair/bedridden	0
B. Clinical signs	
a. Extension	
Normal	6
Lack of extension (0–10°)	4
Lack of extension > 10°	2
b. Total range of motion	
≥140°	6
≥120°	5
≥90°	4
≥60°	2
≥30°	0
c. Stability	
Normal stability in extension and 20° of flexion	6
Abnormal instability 20° of flexion	5
Instability in extension < 10°	4
Instability in extension > 10°	2
Maximum	30
Excellent	27–30
Good	20–26
Fair	10–19
Poor	<10

ANNEXURE 5: MASTER CHART

Sl No	Age / Sex	IP No	Site	Classification	RASMUSSEN SCORE AT 6 WEEKS	RASMUSSEN SCORE AT 3 MONTHS	RASMUSSEN SCORE AT 6 MONTHS	VAS SCORE AT 6 WEEKS	VAS SCORE AT 3 MONTHS	VAS SCORE AT 6 MONTHS	Co-morbidities	Complication
1	57 / M	1175388	Left	1 column	13	20	25	7	4	2	HTN	DVT
2	50 / M	1183995	Right	2 column	14	19	27	6	4	2	Nil	
3	64 / M	1186516	Left	1 column	14	20	26	6	5	3	HTN, DM	
4	45 / M	1183061	Left	2 column	14	19	27	5	4	2	Nil	
5	32 / F	1160052	Left	1 column	16	23	28	5	3	1	Nil	operated site got infected after 8 months
6	37 / M	1183241	Right	3 column	12	17	20	8	6	4	Nil	Foot drop
7	49 / F	10010589	Right	1 column	11	14	28	6	4	1	DM, HTN	
8	68 / M	10010189	Left	2 column	11	16	25	7	5	3	DM	
9	70 / M	10010278	Right	3 column	13	16	24	8	6	4	DM,	Knee stiffness
10	48 / M	10021350	Right	2 column	14	20	25	6	4	2	Nil	
11	48 / M	10034873	Right	1 column	16	21	28	7	4	1	Nil	
12	64 / M	10036423	Right	1 column	14	22	27	6	3	2	HTN	
13	61 / M	10011631	Right	3 column	11	16	22	8	6	2	CHD,HTN, DM	
14	64 / F	10021426	Left	1 column	16	20	27	5	3	2	DM, HTN	
15	32 / M	10032082	Right	2 column	16	21	28	6	4	1	Nil	
16	48 / M	10033741	Left	2 column	14	22	28	7	4	2	RVD+, HTN	
17	43 / M	10036973	Right	3 column	12	16	22	7	5	3	Nil	
18	57 / M	10041419	Left	1 column	14	23	27	6	3	1	HTN	
19	44 / M	10060309	Left	3 column	13	17	26	8	5	2	Nil	
20	40 / F	10064698	Left	2 column	16	22	28	7	5	2	Nil	
21	52 / M	10069009	Right	2 column	13	16	26	6	4	2	HTN	
22	19 / M	10069105	Right	2 column	14	20	29	8	3	1	Nil	
23	33 / M	10077715	Left	2 column	16	21	28	6	4	2	Nil	