Università degli Studi di Padova

CORSO DI LAUREA IN FISIOTERAPIA
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TESI DI LAUREA

Biomechanical evaluation of the lower limb in patients surgically treated for tibial plateau fracture: what is the involvement of the fascia?

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Anno Accademico 2022/2023

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ABSTRACT

Study Design: Retrospective, single-center follow-up study.

Background: In the literature, there is limited data on surgical and post-operative rehabilitation, functional outcomes (range of motion, joint stability, and pain), and there are no studies investigating the potential long-term asymmetry between the lower limbs in patients surgically treated for tibial plateau fractures. Considering the significant impact that this injury has on patients' lives, the healthcare system, and society, research should focus on trying to understand what a missing piece in the surgical and rehabilitation treatment of this type of injury might be.

The possibility of using equipment that is becoming increasingly prominent in clinical rehabilitation, such as force platforms and digital dynamometers, has raised research questions about the potential presence of asymmetry in the two lower limbs in patients treated for tibial plateau fractures (TPF).

Objective: In this context, the experimental study aims to investigate: the subjective perception, quality of life related to the pathology, the possible presence of asymmetry in: active range of motion (AROM), maximal strength, power, static and dynamic stability, and the rate of force development (RFD) between the limb operated on for TPF and the non-operated contralateral limb. Furthermore, given the new knowledge regarding objective data that can be provided by technology, the study allows us to explore the possible involvement of fascial structures in the execution of functional jumping movements that require the use of the upper limbs, in contrast to those that primarily involve the lower limbs. Finally, the data also enable us to investigate the potential impact of fascial tissue functions on the operated limb compared to the contralateral limb.

Methods: The study included patients who underwent surgery for tibial plateau fractures between 2009 and 2016 at the orthopedic-traumatological clinic of the university-hospital in Padua. 28 patients were recruited and underwent subjective evaluation (Tegner, Lyhsolm, NPRS, AKSS, KOOS-I, IKDC, and SF-36), clinical evaluation (Lachman, Pivot Shift, Jerk, anterior drawer, posterior drawer, varus-valgus stress test, Apley test, McMurray test, meniscal palpation, alignement and Peripheral Vascular and Nerve Deficits), strength, joint range of motion, and RFD evaluation using a dynamometer (DynaMo, VALD, Brisbane, Australia), and functional assessment of Single Leg Stance (SLS), Squat Jump (SJ), Countermovement Jump (CMJ), and Countermovement Jump with arm swing (CMJL) on force plates (ForceDecks, VALD, Brisbane, Australia) and a p-value ≤ to 5% ($p \leq 0,005$) was considered statistically significant.

Results: At an average follow-up time of 9,10 ± 2,33 years, follow-up visits were conducted on 28 individuals with an average age of 54,89 ± 8,89 years. They took an average of 9,71 ± 8,12 months to return to pre-injury activity levels. Subjective assessments yielded average scores of: 3,43% ± 1,17

for the Tegner Score, 83,25% ± 23,61 for the Lysholm Score, 0,68 ± 1,52 for the NPRS, 85,53% ± 23,78 for the AKSS, 77,62% ± 23,80 for the KOOS-I, 74,10% ± 18,00 for the IKDC, and 80,94% ± 17,44 for the SF-36. At the clinical examination no patients tested positive for Valgus Stress Test and Posterior Drawer Test; only one patient reported peripheral vascular and nerve deficits following the surgery; the Apley Test, McMurray Test were the ones with the highest positivity rates, but only the Valgus Stress Test showed statistically significant positivity (p=0,020).
From the dynamometer evaluations a statistically significant difference was observed in terms of knee flexion strength (p=0,001), knee extension strength (p=0,034), flexion AROM (p=0,000), and extension AROM (p=0,009). From the statistical analysis conducted for the tests performed on force platforms, it emerged that patients did not present statistically significant asymmetries in terms of average excursion and average excursion velocity of the center of mass projection: monopodal balance was not statistically different between the operated and healthy limbs. The average height achieved in the SJ was 10,30 ± 4,63, in the CMJ was 11,54 ± 5,14, and in the CMJL was 14,47 ± 6,17. The comparison between these showed a statistical difference only between SJ and CMJL (p=0,015). Furthermore, a significant increase in concentric force impulse was observed between SJ and CMJ (p=0,036) and SJ and CMJL (p=0,027). However, no significant differences were found when comparing concentric and eccentric force between SJ and CMJ (p=0,994) and CMJL (p=0,614). The SJ is the functional movement that allowed the identification of highly significant lower limb asymmetries from a statistical point of view: concentric force (p=0,006), concentric RFD (p=0.005), landing force (p=0,0016), and RFD during the landing phase (p=0,014) indicating that the injured limb is weaker. In the execution of CMJ and CMJL, no marked asymmetry between the lower limbs was identified except for concentric force expression in CMJL, where a greater weakness of the operated limb was noted (p=0,026).
Conclusion: In the long term, the patients in this study demonstrated statistically significant asymmetries in terms of joint strength and joint range between the two lower limbs. Ultimately, it cannot be excluded that fascial tissue is directly involved in the operated limb compared to the contralateral limb. However, further research is needed in this direction to better understand the underlying biological mechanisms behind what clinical observations are showing us.

Keywords: Tibial Plateau Fracture, Forcedecks, Dynamometer, Asymmetry

1. INTRODUCTION

1.1 Fascia

1.1.1 Anatomy of the Fascia

"A fascia is a sheath, a sheet, or any other aggregation of connective tissue that forms beneath the skin to attach, wrap, and separate muscles and other internal organs." This is the definition proposed by the authors Stecco and Schleip in 2016.

We can define the fascia as a connective tissue structure that forms a three-dimensional network extending throughout the body and is in continuous between all organs, muscles, and somatic structures, becoming a system that connects them rather than separating them [66]. This structure surrounds and connects visceral organs and muscles, allowing for optimal transmission of forces between different body segments, reinforcing capsule-ligamentous structures, forming a connective sheath richly supplied with blood vessels and small nerve endings [7] that surround larger nervous and vascular structures and enclosing the periosteal portions of bones and the paratenon of tendon structures [5].

Fascial tissue consists of an extracellular matrix composed of an amorphous aqueous component in which various types of glycoproteins, including collagen types I and III and elastin, are immersed, providing the tissue with suitable characteristics of strength and elasticity. Within this solution, different types of cells are irregularly and randomly arranged:

- Fibroblast cells, which produce collagen and elastin and facilitate the transmission of forces.
- Fasciocyte cells responsible for the synthesis of hyaluronic acid, which allows for sliding between different fascial layers.
- Myofibroblast cells that enable contractile activity of the fascial tissue itself, influencing fascial tension and consequently joint stability.
- Telocyte cells, special cells equipped with long, thin extensions called telopods, creating a three-dimensional network that enables intercellular communication.
- Free myelinated or non-myelinated nerve endings that allow the transmission of nociceptive information [70]: In 2020, Fede and colleagues estimated that fascial tissue contains approximately 250 million nerve endings, making it recognized as the most sensory tissue in the human body [4,71]. It is important to note that in musculoskeletal tissues, 80% of afferent nerves terminate in free nerve endings, and 90% of these correspond to slow-conducting C fibers [73].
- From recent research, it has emerged that the superficial fascia does not contain sensory corpuscles, such as Pacinian and Ruffini corpuscles [4], but in the muscle-fascia junction, defined as "dense regular collagen-connective tissue (RDCCT)," and at the anchoring site

between fascia-tendon and periosteal fascia, these corpuscles have been found along with free nerve endings, Golgi bodies, and neuromuscular spindles [72].

This composition is not uniform throughout the tissue distribution but varies depending on the area and the function it has to perform. For example, the layer of connective tissue underlying the skin must be both resistant to protect the underlying tissue and flexible and elastic to allow for movement [66,70].

Over the years, various authors have attempted to classify the connective tissue surrounding organs and the human body, with Gallaudet being the first in 1931 and Stecco in 2015.

In the second edition of "Fascia the Tensional Network of the Human Body," published in 2022, a division into four types of fascial tissue is proposed. In the human body, this tissue assumes a concentric arrangement from the outermost to the innermost, allowing for the identification of:

- Superficial fascia (or adipose tissue): It is composed of connective tissue, that connects the skin to the deep fascia, and is formed by collagen fibers and adipose cells in an irregular manner, which can vary significantly between individuals. This tissue originates from somatic mesenchymal tissue and covers the entire body surface except for orifices [67]. In 2022, Fede and colleagues conducted histological and immunohistochemical investigations of superficial fascial tissue in the abdominal and thigh areas. The studies revealed that the superficial fascia is a well-defined fibrous tissue with a thickness of 500-700 μm, composed of fibro-adipose connective tissue, where collagen fibers are irregularly arranged, mixed with adipocytes, and permeated by blood and lymphatic vessels. This tissue is richly innervated by bundles of sensory autonomic nerve fibers of small (4,8 ± 2,6 μm) and large (21,1 ± 12,2 μm) calibers. Sensory corpuscles such as Pacinian or Ruffini corpuscles were not found in it [4], but there is a significant presence of free nerve endings. The superficial fascia has recently been recognized as a specific anatomical structure, as it was initially considered a component of the hypodermis. It consists of a fibrous layer located in the hypodermis. It consists of a fibrous layer located in the hypodermis that separates superficial adipose tissue from deep adipose tissue [4].
- Deep axial fascia: This layer originates from somatic mesenchymal tissue, just like the previous one, and forms the primitive matrix from which skeletal muscles, tendons, ligaments, aponeuroses, and joint capsules originate. It also plays a role in forming the periosteum of bones, the epimysium of muscle tissue, the paratenon of tendons, and the layer of tissue covering joint capsules. It covers the body's surface and envelops axial muscles such as the oblique abdominal muscles, rectus abdominis, and the paraspinal muscles (longissimus, multifidus, iliocostalis, and scalene) but does not extend to the head. In the junction zone

between the four limbs and the axial skeleton, it intersects, modifies, and continues into what is known as the deep appendicular fascia. A study conducted by Fede and colleagues in 2019 investigated the degree of innervation in various soft structures and tissues and revealed that the deep fascia is one of the most densely innervated tissues in the human body, second only to the skin, superficial fascia, subcutaneous tissues, specific muscles (vastus lateralis and gluteus maximus), joint capsules, and tendons [7].

- Meningeal fascia: It originates from the primitive meninges that surround the nervous system during the embryonic phase of gestation. It consists of the dura mater, arachnoid, and pia mater, and it terminates in the epineurium that surrounds individual peripheral nerves, thereby covering all neural structures [67].
- Visceral Fascia: This fascia originates from splanchnic tissue and surrounds all visceral cavities, including the pleural, pericardial, and peritoneal cavities. It provides vascular and nervous branches that supply blood and innervation to the organs it surrounds. One of its fundamental characteristics is the thickening it forms at the midline, extending from the cranial base to the pelvic cavity. [67].

Each somatic organ is covered by its own protective layer of connective tissue: the fascia. Connective tissue forms a series of layers at different depths that intersect with each other and with somatic organs, creating a network capable of connecting and protecting all structures of the body [66]. This is because during the embryonic development of the human body, each organ forms within a sheath that will later become this fascia: bones develop within the embryonic mesenchymal sheath, which, upon completion of growth, will become the periosteum; muscles also develop within a sheath that will become the epimysium, and in the same way, joint capsules form from the thickening of mesenchymal fascial tissue.

As explained by Peter P. in the chapter "General Anatomy of the Muscle Fasciae" of the book "Fascia the Tensional network of the Human Body" [66], it is important to consider that each striated (skeletal) muscle is composed of muscle fibers grouped together by the endomysium, which, in turn, is surrounded by connective tissue called perimysium to form muscle fascicles. These fascicles are grouped to form the muscle, enveloped by a sheath of connective tissue called epimysium that is continuous with the tendon, allowing the muscle to attach to the bone. Recent research allows us to understand that the histological composition and the amount of fascial tissue forming the different layers of muscle tissue differ from region to region and from muscle to muscle. The authors explain that fascial tissue allows the transmission of contractile forces along the course of muscle fibers and fascicles, enabling optimal distribution of forces, coordinated contraction, and protection from excessive contractions in injured areas. Like muscle tissue, fascial tissue undergoes continuous synthesis and remodeling in response to mechanical stimuli, resulting in changes in its histological and structural characteristics.

1.1.2 Fascia of the Lower Limb

As explained by Stecco and colleagues in the chapter "Deep Fascia of the Limbs" in the second edition of "Fascia: The Tensional Network of the Human Body" [69], the myofascial organization and the relationship between fascia and muscles in the limbs are completely different compared to the trunk. In the appendicular region, each muscle is enclosed in its own layer of fascia, defining its shape and volume, known as the epimysium. Subsequently, muscles are grouped and connected to each other through a layer of fascia that envelops them, defining the various compartments of the limbs. This is the "aponeurosis", a formation of connective tissue that allows the connection of various muscles involved in the same motor pattern. In the trunk, on the other hand, the fascia adheres completely to the muscles, and only a few aponeurotic compositions can be identified. These structures are in close communication with each other, so the aponeurotic formations in the trunk allow the connection of the muscles of the trunk to the limbs and act as a "bridge" in connecting the musculature of the upper limbs to that of the lower limbs.

The authors also explain that the deep fascial connective tissue of the limbs is composed of fibrotic tissue arranged in a wavy pattern, with close connections to the periosteum, tendons, and ligaments. This tissue serves as the origin and insertion for muscles and plays a fundamental role in allowing sliding between various surfaces. Deep fasciae are structures that dissipate excessive contractile forces at the enthesis (the muscle-tendon junction) and play an important proprioceptive and coordinative role, as well as facilitating venous return.

The deep fascial portion of the lower limbs consists of a layer of connective tissue, approximately 1 mm thick, containing fibroblasts, collagen fibers, and elastin arranged in an irregular matrix. It can be easily separated from the overlying superficial fascia and the underlying muscle structures. This portion of tissue forms a structural continuum, which is called the fascia lata in the thigh and the crural fascia in the leg. The fascial structure is not uniform in thickness but is thinner in the proximal area ($0{,}541 \pm 0{,}023$ mm) and thicker near the knee ($1{,}419 \pm 0{,}105$ mm).

In the lateral portion of the thigh, there is a distinct region known as the fascia lata, which is reinforced by the presence of the iliotibial tract, a structure where fibers from the tensor fasciae latae and the gluteus maximus muscles attach. It runs along the entire length of the thigh, inserting distally on Gerdy's tubercle of the tibia and the anterolateral portion of the crural fascia, providing lateral stability and allowing bipedal stance. On the medial side, the tendons of the semitendinosus, gracilis, and sartorius muscles unite to form the pes anserinus, which inserts on the anteromedial tibia and the medial portion of the crural fascia, serving as stabilizers of the knee. The presence of these fascial structures over a biarticular extension, in addition to providing stability to the knee, allows for the coordination of movements involving the hip and knee joints. The fascial structures of the knee are reinforced anteriorly by the attachment of fibers from the vastus lateralis of the quadriceps femoris muscle, tibialis anterior, and extensor hallucis longus to the fascia lata, and posteriorly by the presence of connections between some fibers of the semimembranosus muscle and the heads of the gastrocnemius muscle with the posterior fascia.

1.1.3 Function of Fascia

Due to its anatomical and histological composition, the superficial fascia serves various functions.
It acts as a structure comparable to an exoskeleton, providing an excellent site for the insertion of certain muscles. For example, the fascia lata serves as an insertion structure for the gluteus maximus and tensor fasciae latae muscles, while the thoracolumbar fascia (TLF) connects the latissimus dorsi muscle with the gluteus maximus [74].
Fascial structures also have a proprioceptive function. As explained by Anderson et al in 1994 proprioception refers to the ability to understand the position and movement of the body or its parts in space and the force required to perform such movements [72]. In the muscle-fascia junction RDCCT, as described earlier, various organs are positioned to serve as mechanoreceptors, and considering that free nerve endings can act as proprioceptors [7,68], it is reasonable to assume that fascial tissue plays a proprioceptive and motor coordination role [4,71,72].
Another sensory interaction facilitated by fascial structures is interoception. The latest research defines "interoception" as an umbrella term used to describe the sensations that, after being decoded at the central nervous system level based on past experiences, provide us with information about what we feel with and in our body. For example, some interoceptive sensations can be recognized as warmth, cold, hunger, thirst, pain, tickling, tingling, the sensation of muscle activity, and heart activity. [73]. Considering the high density of type C nerve endings in the endomysial and perimysial fascial regions, which are activated by mechanical stimuli such as tension and pressure, a 2008 study by Olausson and colleagues used functional magnetic resonance imaging to investigate the brain region activated in response to such stimuli. The researchers concluded that stimulation of these nerve endings resulted in activation of the insular cortex, which Craig (2003, 2009) has explained as playing a fundamental role in representing the body's actual state, a crucial function for interoception [73].

Furthermore, the connective tissue under study is widely discussed in the literature for its possible nociceptive function [2,3,4]. Hoheisel and colleagues, in the chapter "Nociception: The Thoracolumbar and Crural Fascia as Sensory Organs" in the second edition of "Fascia: The Network of the Human Body" [74], explain how the thoracolumbar fascia is densely innervated by sensory and sympathetic fibers. Indeed, in situations of inflammation affecting fascial tissue, researchers have found high concentrations of fibers containing Substance P (SP) and fibers containing the calcitonin gene-related peptide (CGRP), which are neuropeptides that make up fibers that induce neurogenic inflammatory processes and play an important role in nociceptive function. These recent findings allow researchers to hypothesize that the fascial structure may play a fundamental role in situations of pain perception, particularly in nonspecific low back pain. Other current research has assessed the presence of fascial thickening and reduced joint flexibility in patients with chronic pain [3], aiming to demonstrate that fascial structures play a fundamental role in musculoskeletal conditions where pain is considered "nociplastic," meaning it is subject to maladaptive processing referred to as "central sensitization" [7]. Finally, a very important function that researchers are investigating is the possible transmission of forces by fascial structures. As explained by Huijing P. A. in the chapter "Force Transmission and Muscle Mechanics: General Principles" in the second edition of "Fascia: The Network of the Human Body" [99], muscle force is derived from the sum of forces created by the contraction of sarcomeres arranged in parallel, while the velocity of muscle contraction is derived from the sum of the velocities at which sarcomeres arranged in series contract. The same author, in the chapter "Epimuscular Myofascial Force Transmission: an introduction" of the same book [100], explains how muscular force transmission depends on two mechanisms: myotendinous for the transmission of forces in series and myofascial for forces in parallel. Furthermore, muscular force must be transmitted to adjacent structures, and this is defined as epimuscular force transmission. This is carried out by myofascial and connective structures, and if they have adequate rigidity, they allow the transmission of force between synergistic muscles for a movement, enabling intermuscular transmission, and to vascular and nervous structures, hence extramuscular transmission.

The author also explains that fascial structures, even those not rich in collagen, can be elements that contribute to the transmission of forces. An example of this is the fact that the force and length at the proximal and distal insertion points of a muscle are not equal: there is stiffness along the length of the muscle, resulting in different lengths and local forces. Another example comes from experiments conducted on cadavers, which have identified an increase in the length and force on a muscle tissue connected to the same synergist when the first one was stretched, compared to the length achieved on the same agonist if it was not connected to the synergist. The fascial connection between two synergistic tissues allows for a summation of forces that is not observed in two unconnected tissues. Additionally, the author mentions experiments in which changing the load applied to fascial structures while maintaining the length of the muscle-tendon tissue resulted in a variation in the force expressed by the muscles themselves.

Regarding the transmission of forces, an interesting study is Lesondak D.'s chapter "Myofascial Chains: A Review of Different Models" in the second edition of "Fascia The Network of the Human Body" [101], where its explained how myofascial structures in the human body form myofascial chains (such as the posterior-medial, anterior-medial, posterior-lateral, anterior-lateral, and posterior-anterior chains). In doing so, they enable the transmission of forces between distant body parts and between synergistic muscles for the same functional movement. Fasciae, therefore, allow our body to coordinate. Thanks to them, the human body naturally does not move in isolation from a muscle but in synergy between the activation of an agonist muscle and its synergists, while simultaneously reducing the activation of antagonistic muscles. In the same volume, author Myers T. W. in the chapter "Anatomy Trains: Myofascial Force Transmission in Postural Patterns" [102], also introduces the concept of "anatomical trains," explaining how neural tissue that is arranged at the fascial level allows for physical connections between functionally related muscles.

1.2 Tibial Plateau

1.2.1 Anatomy of the Tibial Plateau

The tibia is the second-largest bone in the body after the femur and, together with the fibula, forms the anatomical region known as the leg, which extends between the knee and ankle joints [57].

The proximal tibial articular surface and the associated soft tissues serve two functions: they provide joint stability to the knee by maintaining the femoral condyles in their natural positions and allow the transmission of weight and forces from the knee to the ankle [32,57,60].

The proximal epiphysis of the tibia is characterized by the presence of two columns: a medial column and a lateral column, corresponding to the two homonymous condyles of the femur, which are covered with articular cartilage. Although they have almost flat surfaces, they differ in shape. The medial condyle is typically concave and covers a larger area than the lateral condyle, which is convex in shape [60].

The two tibial condyles are separated by an intercondylar spine that follows an anteroposterior axis. This spine has irregular portions that serve as attachment sites for the cruciate ligaments and menisci [60]. Each condyle is partially covered by the respective meniscus, with the medial meniscus overlying the medial condyle and the lateral meniscus overlying the lateral condyle. Menisci are fibrocartilaginous structures with a crescent shape, designed to create a larger surface area for accommodating the rounded femoral condyles on the nearly flat tibial plateaus, reduce compressive stress on the femorotibial joints, and lubricate the articular cartilage. In some anatomical studies it has been reported that the medial meniscus covers 51-74% of the medial tibial plateau, while the lateral meniscus covers 75-93% of the lateral tibial plateau [65]. The medial meniscus has a typical "C" shape and contributes more to the anteroposterior stabilization of the knee, while the lateral meniscus, due to its location on a convex surface, has a more wrap-around "O" shape and plays a more significant role in stabilizing rotational movements of the joint [32,60]. These characteristics allow the menisci to distribute load differently, with the medial meniscus transmitting 50% of the forces acting on the medial femorotibial joint, while the lateral meniscus carries 70% of the forces on the lateral compartment [65].

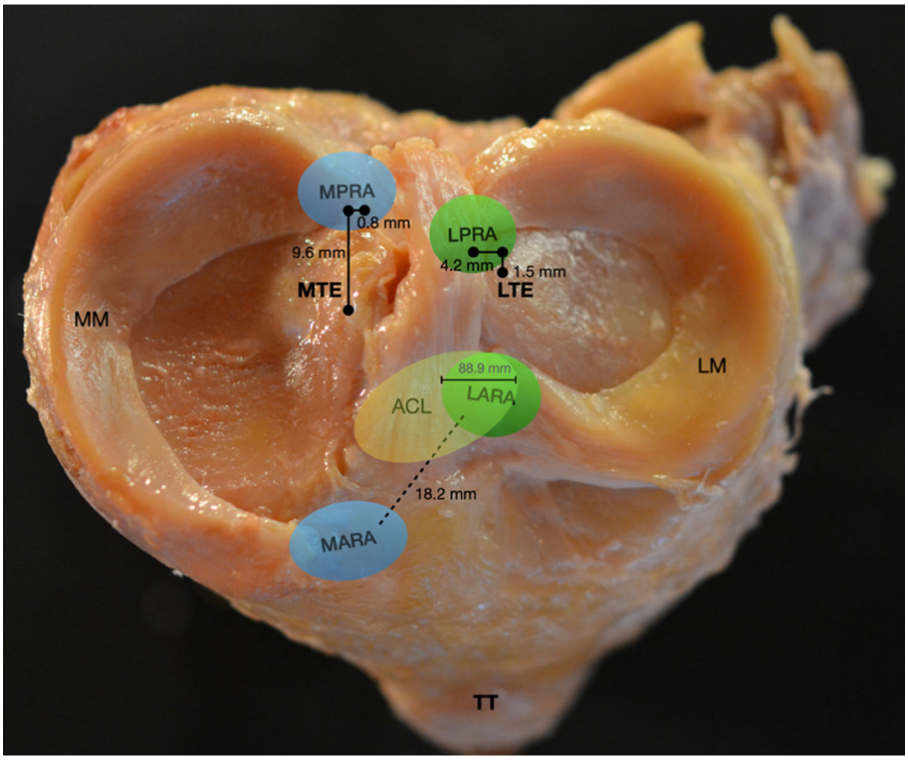

*Figure 1 – **MARA**: insertional zone of the anterior horn of the medial meniscus, **LARA**: insertional zone of the anterior horn of the lateral meniscus, **MPRA**: insertional zone of the posterior horn of the medial meniscus, **LPRA**: insertional zone of the posterior horn of the lateral meniscus, **MM**: medial meniscus, **LM**: lateral meniscus, **MTE**: medial tibial eminence, **LTE**: lateral tibial eminence, **ACL**: anterior cruciate ligament, **TT**: tibial*

Menisci have close connections with various bony, capsular, tendinous, and ligamentous structures that provide the knee with an optimal balance of movement freedom and stabilization. Both menisci are connected by the transverse ligament, the medial meniscus is in continuity with the medial collateral ligament, and both are, to varying degrees, attached to the capsule via coronary ligaments.

Additionally, the quadriceps and semimembranosus muscles insert on both menisci, while the popliteus muscle inserts only on the lateral meniscus [60].

Anterior to the insertion site of the anterior horn of the medial meniscus (indicated as MARA in figure 1) and posterior to the insertion of the anterior horn of the lateral meniscus (LARA) on the tibia, there is a portion of the intercondylar eminence from which the anterior cruciate ligament (ACL) originates. The tibial insertion areas of the ligament can have varying shapes, including elliptical, triangular, or "C"-shaped [64], with a surface area ranging from 100-160 mm^2 [61,62,63].

Posteriorly and near the insertion sites of the posterior horns of the menisci (MPRA and LPRA), it is possible to recognize the distal insertion site of the posterior cruciate ligament (PCL). This insertion area is characterized by a typical trapezoidal shape, covering approximately 160-220 mm^2. This surface is located in a specific groove called the "PCL facet," situated at the mid-lateral axis that divides the tibial plateau into anterior and posterior portions. It is possible to identify this area as it is delimited posteriorly by the "champagne glass" shape of the bone, which is easily recognizable in radiographs [59].

The proximal-lateral portion of the tibia articulates with the head of the fibula in a posterior area relative to the medio-lateral plane that divides the tibia into anterior and posterior portions (See Figure 4 A).

The tibia is influenced by various muscles that originate or insert on it. At the proximal level, it is possible to recognize the areas of insertion of the tendon terminations of:

- Tensor fasciae latae, which inserts distally onto Gerdy's tubercle on the tibia
- Quadriceps femoris, which inserts distally through the patellar tendon onto the tibial tuberosity
- Sartorius, gracilis, and semitendinosus, which form the pes anserinus tendon and insert into the anteromedial proximal tibia
- Semimembranosus, which inserts on the medial tibial condyle
- Popliteus, which inserts on the posterior tibia at the soleal line
- Extensor digitorum longus, which originates from the anterior portion of the lateral tibial condyle
- Soleus, flexor digitorum longus, and tibialis posterior, which originate from the posterior portion of the tibia along the soleal line

The innervation of the tibial plateau is provided by the deep femoral nerve and the tibial nerve, which carry motor and sensory information for the knee joint. The tibial nerve is a terminal branch of the sciatic nerve, which is the largest nerve branch in the body. The sciatic nerve originates from the nerve roots of L4-S3, exits the pelvis through the greater sciatic foramen below the piriformis muscle, and runs posteriorly to the hip, positioning itself deep to the biceps femoris muscle but superficial to the adductor magnus muscle. The nerve descends posteriorly in the thigh and a few centimeters caudal to the popliteal fossa it bifurcates into the tibial nerve and the common fibular nerve. The tibial nerve continues its course in the posterior compartment of the leg [58].

Blood supply to the tibial epiphyseal and metaphyseal regions is provided by periosteal branches of the tibial artery, while the blood supply to the diaphyseal and distal regions of the same bone is facilitated by the nutrient artery. Venous return is ensured by the anterior and posterior tibial veins[57].

1.2.2 Tibial Plateau Fractures (TPF)

Tibial plateau fractures (TPF) are a severe intra-articular injury that is often treated by orthopedic traumatologists [8,9]. They account for approximately 1-2% of all fractures in the body and represent 9,2% of tibia fractures [1,10,12,29,30,36], with an incidence rate of 10,3-13,3 per 100,000 people per year [11,34]. These fractures typically result from trauma, such as motor vehicle accidents, pedestrian accidents, falls from significant heights, or high-impact injuries in contact sports [41].

TPF is more commonly observed in the male population than in females, particularly in adults between the ages of 40 and 60. These injuries are typically seen in two populations:

1. Young males who experience high-impact injuries, such as road traffic trauma (64%).
2. Older females with weaker bone density who sustain lower-impact trauma (35%) [1,8].

At the time of injury, several factors can influence the geometry and degree of deviation of the fracture. Factors to be considered include:

- Magnitude of the Impact: The force applied must be sufficient to cause a bone fracture, and greater force results in more extensive bone damage.
- Direction of the forces that have acted on the joint: Fractures with joint involvement typically result from the application of shearing and compressive forces to the joint. Specifically, a force applied in varus typically leads to a fracture of the medial tibial plateau, while a force applied in valgus leads to a fracture of the lateral tibial plateau. Torsional forces usually result in diaphyseal fractures with involvement of the periarticular soft tissues.
- Degree of Knee Flexion: If the knee is flexed at the time of trauma, it results in a fracture involving the posterior portion of the tibial plateau. Conversely, if the trauma occurs with the knee extended, the fracture will affect the anterior portion of the tibial plateau.
- Bone Quality: This is the most significant influencing factor. In younger individuals, bone fragments tend to be larger and have a typical wedge shape. In contrast, in the older population

with lower bone density, fractures more commonly result in depression of the affected tibial plateau [28,32].

The application of a force with the appropriate intensity and direction to the proximal tibial articular surface results in the detachment of a wedge-shaped bone fragment. As the force continues to be applied, this fragment becomes depressed and displaced relative to the center of the joint. The wedge-shaped fragments created can be defined by three points indicating where the bone's continuity was disrupted: two points located on the plane of the tibial plateau (A and P) and one in the meta-epiphyseal area (M). These three points form a virtual plane that indicates the fracture's position (see Figure 2).

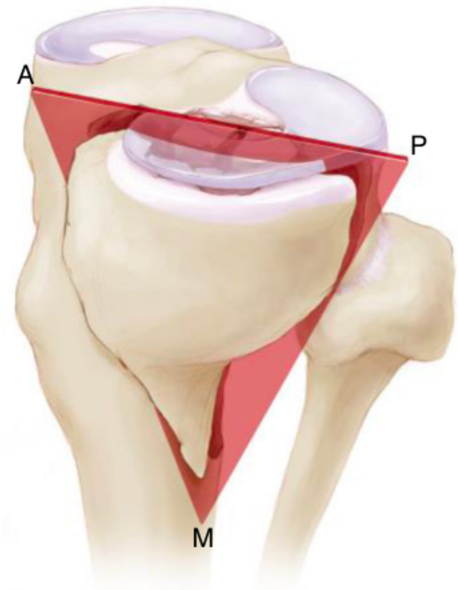

*Figure 2 representation of a typical fracture involving the lateral hemi plate and the virtual plane that describes it. **A**: position of the fracture on the tibial plane in the anterior portion. **P**: position of the fracture on the tibial plane in the posterior portion. **M**: position of the fracture in the meta epiphyseal portion.*

Compressive forces are also responsible for the degree of fragmentation of the detached bony portion.

In cases of lower-intensity trauma on less dense and more osteopenic bones, articular depression fractures are more likely to occur [32].

The majority of injuries (55-70%) occur in the lateral condyle, isolated medial condyle fractures occur in 10-23% of tibial plateau fractures, while more complex fractures that can be classified as bicondylar occur in 10-30% of cases [10].

Tibial plateu injuries are typically mentioned in the literature because they have a significant negative impact on the quality of life, preventing people from working and reducing their level of activity, affecting functional integrity and knee stability, and potentially leading to early development of secondary arthritis, ligament injuries, pain, and disability [10,29,30]. It's worth noting that less than one in five patients is able to regain a level of activity similar to what they had before the injury, with long-term sequelae that may include pain, joint stiffness, instability, and fear of re-injury [8].

1.2.3 Classification of Tibial Plateau Injuries

The treatment of tibial plateau fractures (TPF) and the subsequent long-term outcomes depend closely on how they are assessed, classified, and ultimately treated [31,36].

In 1939, Marchant proposed a differentiation system for TPF into three types: split, depressed, and combined [33,34]. However, until the 1950s, there were no surgical guidelines for the reduction of bone fractures. Initially, plaster casts were used for the treatment of these injuries, but they did not allow for the restoration of optimal bone lengths. Traction was then employed, but it often resulted in ligamentous laxity and soft tissue problems, leading to poor long-term outcomes. It was only in the 1960s when the AO/OTA Classification System published treatment guidelines for fractures that careful attention was paid to achieving anatomical reduction of articular surfaces and correction of axial deformity. However, the inability to recognize bone fragments resulting from fractures hindered the ability to obtain optimal joint stability. Therefore, significant attention was given to evaluating different types of fractures [32].

Over the years, 38 different evaluation systems for tibial plateau fractures have been developed in the literature [30]. Currently, the most used evaluation scales among orthopedic surgeons are the Schatzker classification and the AO/OTA Classification System [28,31,33,36].

According to the Schatzker classification, initially proposed in 1974 based on two-dimensional imaging, tibial plateau fractures were divided into six grades based on the extent of the injury. The first three groups corresponde to lower-severity fractures, usually resulting from low-intensity trauma leading to a fracture of the lateral tibial plateau, which is less dense and resistant than the medial plateau and joint stability is relatively preserved. Articular stability is relatively preserved in these grades. In contrast, Grades IV, V, and VI indicate progressively worse damage typically resulting from high-intensity trauma, with fractures involving the medial plateau and the possibility of ligamentous disruption or joint subluxation. These injuries often involved damage to capsuloligamentous structures and soft tissues, leading to severe joint instability [10,12,31].

Furthermore, the classification divides injuries based on the tibial plateaus involved, with the first four categories indicating a lesion to a single plateau and the last two indicating injuries to both plateaus [30]. The association between force intensity and the degree of plateau involvement stems from the fact that the medial plateau has denser trabecular bone compared to the lateral plateau, requiring greater forces to fracture [31].

Specifically, the different types of fractures are as follows (see Figure 3):

I. Isolated detachment of the lateral tibial plateau, typical in young individuals with good bone density, resulting in only bone detachment. This fracture results from a traumatic mechanism involving shear and valgus forces.

II. Isolated detachment of the lateral tibial plateau associated with depression of the same, resulting from a similar traumatic mechanism as the previous one but in an older population with lower metaphyseal bone density.

III. Isolated depression of the lateral tibial plateau, often with the metaphyseal cortex remaining intact, preserving joint stability.

IV. Isolated fracture of the medial tibial plateau, resulting from high compressive force and varus, often associated with knee dislocations and potential neurovascular damage. This type of fracture has the poorest prognosis among isolated condyle fractures.

V. Bicondylar fracture without diaphyseal and metaphyseal involvement of the tibia.

VI. Bicondylar fracture with diaphyseal and metaphyseal involvement resulting from very high-intensity trauma [28,30,31].

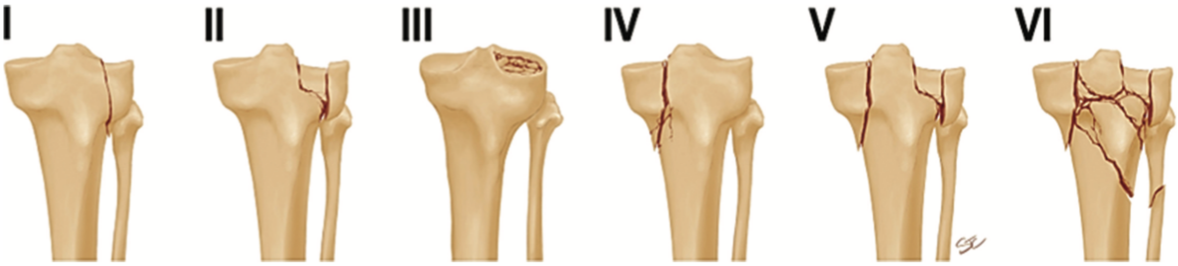

Figure 3 - Schatzcker Classification for TPF

With the advent of computed tomography (CT), the study of bone fractures in three dimensions became possible. This diagnostic capability led researchers to better identify bone fractures. Kfuri and colleagues in 2018 [31] aimed to revise the Schatzker classification for tibial plateau fractures by introducing elements that provide greater precision in the three-dimensional location of tibial plateau lesions. In addition to the initial division between medial (M) and lateral (L) plateau, the authors added a subdivision into anterior (A) and posterior (P) portions to provide a coronal plane assessment. This subdivision is achieved by drawing a virtual horizontal line from the insertion of the lateral collateral ligament on the head of the fibula to the superficial portion of the medial collateral ligament at its insertion on the medial tibial crest. This line delineates the wider anterior and narrower posterior portions of the tibial plateau. In summary, the tibial plateau is divided into quadrants: anterolateral

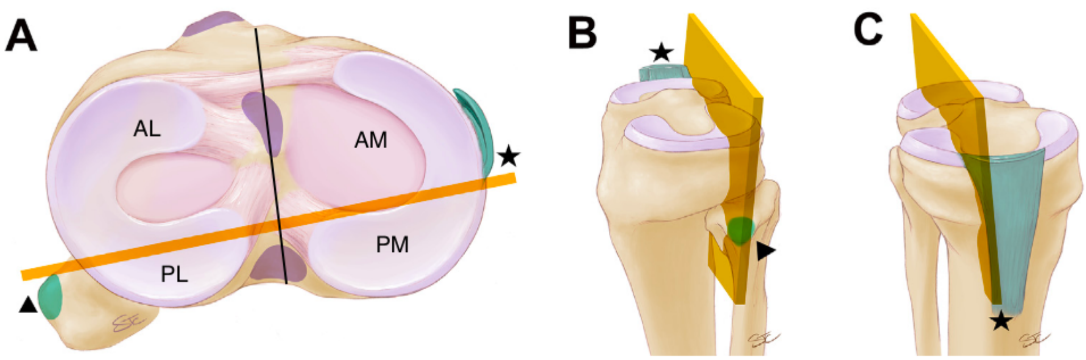

*Figure 4 In yellow is represented the virtual plane that delineates the anterior and posterior portions of the tibial plateau. In black, the axis with an anteroposterior direction dividing the profiles of the medial and lateral hemi plates is depicted. In green, the superficial portion of the medial collateral ligament at its tibial insertion (**star**) and the lateral collateral ligament at its fibular surface insertion (**triangle**) are represented. **A**: representation of the division of the tibial plateau into anterior, posterior, medial, and lateral portions. **B**: representation of the sagittal plane dividing the tibial plateau into anterior and posterior portions with a lateral view. **C**: representation of the sagittal plane dividing the tibial plateau into anterior and posterior portions with a medial view.*

(AL), anteromedial (AM), posterolateral (PL) and posteromedial (PM), allowing for the specification of the area of interest in the fracture (see Figure 4).

This classification allows for a more detailed identification and classification of tibial plateau fractures, with a particular focus on fractures with characteristic wedge-shaped bone detachment [31]. These types of fractures typically assume a shape that can be virtually reduced to a two-dimensional triangle, with two of the three apices on the tibial plateau and the third in the metaphyseal area (as shown in figure 2). This classification allows the delineation of these three apices, enabling a better understanding of the actual position of the bone fracture lines and the plane on which they extend, providing essential elements for optimal surgical access and intervention. This evaluative interpretation allows determining the position of the fracture apices in the different quadrants of the tibial plateau, specially indicating if they are located in the anterior (a) or posterior (p) portion. Additionally, the third apex is indicated with the abbreviation: ax if located in the anterior position or px if located in the posterior portion of the tibial metaphysis. Various fractures and their classifications are illustrated in Figures 5, 6, and 7 [31].

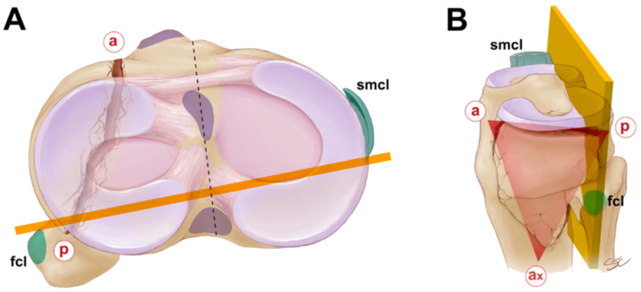

*Figure 5 - Fracture involving the lateral hemi plate with extension into the anterolateral and posterolateral quadrants. **A**: axial view. **B**: lateral view. fcl: fibular collateral ligament. smcl: superficial medial collateral ligament.*

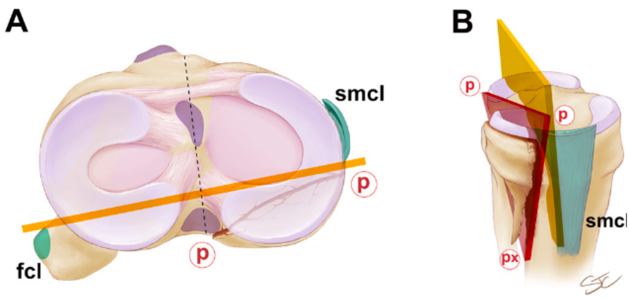

*Figure 6- Isolated fracture involving the medial hemi plate in the posteromedial quadrant. **A**: axial view. **B**: medial view. fcl: fibular collateral ligament. smcl: superficial medial collateral ligament.*

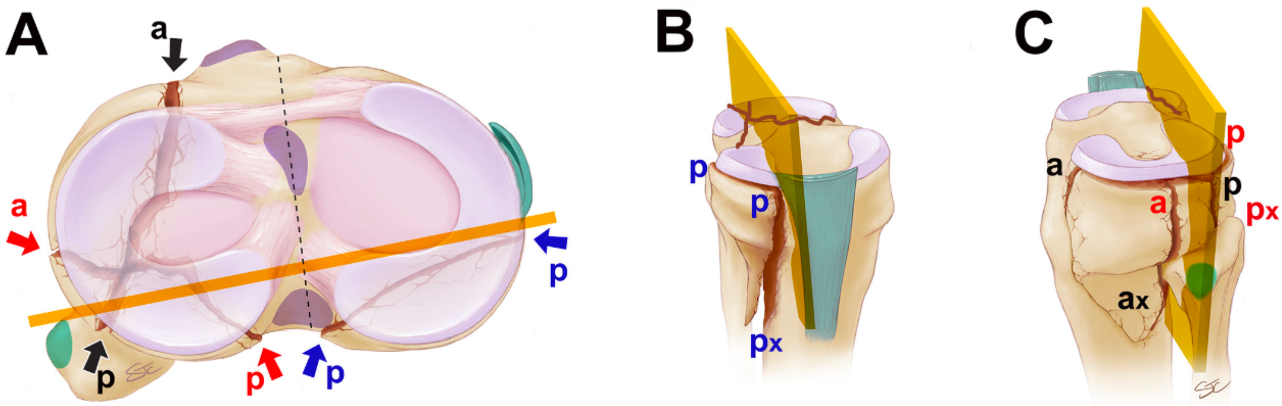

*Figure 7- Comminuted bicondylar fracture of the tibial plateau with differentiation of the three different fracture lines and their positions (the black fracture extends from anterior to posterior and its inferior apex is located anteriorly, the red fracture extends in the same way, but the inferior apex is located posteriorly, and the blue is located posteriorly). **A**: axial view. **B**: medial view. **C**: lateral view.*

Another classification system that is important to mention is the AO/OTA Classification System, an alphanumeric system that distinguishes and evaluates all types of fractures. According to this classification, each bone segment is assigned a specific numerical code. The fractures discussed here fall under code 41, indicating proximal tibia fractures [33,35]. Then, there is a further subdivision to determine whether the fracture occurred in an extra-articular (A), partially articular (B), or completely articular (C) portion of the bone [33]. Each subgroup identified by a letter is subject to further numerical subdivision based on the severity grade. For example, B1 indicates a fracture with only a bone fragment detachment, B2 indicates a sole depression of the fractured bone fragment, and B3 indicates a combination of the previous two. Similarly, C1 denotes a simple meta-epiphyseal articular fracture, C2 indicates a simple multifragmentary meta-epiphyseal articular fracture, and C3 indicates a meta-epiphyseal articular fracture [35].
In general, fractures can be categorized under classification 41B when only one plateau is involved and 41C when both plateaus are involved. (See Figure 8)

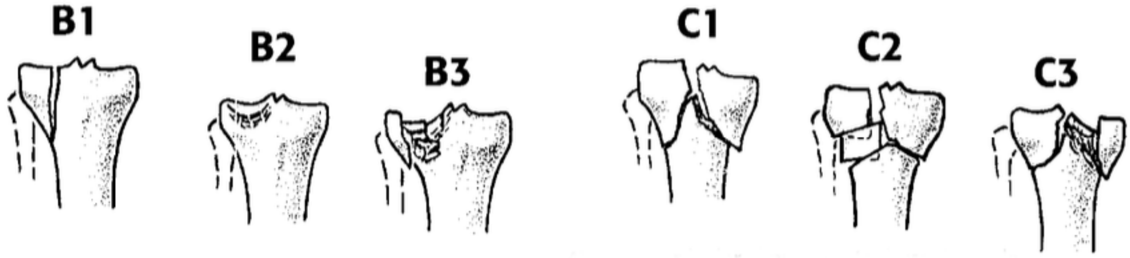

Figure 8 - AO Classification for TPF

Remembering the earlier observations, the comparison with the classification system devised by Schatzker is easily understood (see Figure 9) [28].

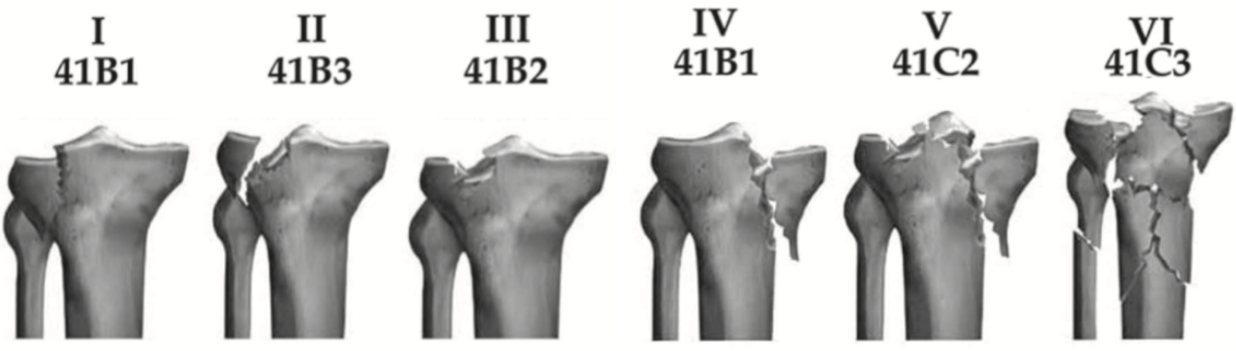

Figure 9 - Correlation between the Schatzker classification and AO classification.

It's important to note, however, that in this type of injury, damage rarely affects only the bone structure. Therefore, it's crucial to mention the recent review conducted by Thürig and colleagues in 2023, which highlighted that in the literature, it is reported that at least one ligamentous or meniscal injury is present in 93% of TPF. The authors suggest that, in addition to a careful analysis of routine imaging investigations for identifying bone damage and providing a classification (X-rays and CT scans), preoperative magnetic resonance imaging (MRI) is essential, as it is a non-invasive tool that can identify soft tissue injuries. However, the recent review did not establish a clear relationship between the Schatzker classification grade and the need for preoperative MRI [29]. The field of research is therefore open.

1.2.4 Surgical Techniques and Surgery

The goals of surgery for tibial plateau fractures (TPF) are generally to restore the anatomical joint congruity to enable the recovery of knee stability, articulation, and function, as well as to achieve optimal lower limb alignment [9,12,29,30,32]. Surgical treatment and, consequently, the prognosis for recovery depend on five factors: the degree of articular depression, the extent and distance of the condyle fracture lines, the degree of fragmentation, the presence of metaphyseal dissociation and the integrity of soft tissues [10].

Historically, the most used surgical technique for reducing this type of fracture was open reduction and internal fixation (ORIF), which involved exposing the fracture site through a large medial incision. However, this approach often led to significant soft tissue damage and compromised blood supply to the bone, resulting in suboptimal outcomes [9]. Advances in surgical techniques and the use of appropriate materials have significantly reduced postoperative complications and improved long-term outcomes [9]. Today, treatment techniques for TPF include ORIF, closed reduction and percutaneous fixation, arthroscopically assisted reduction and internal fixation (ARIF), and external fixation (EF) techniques, often combined with bone grafting [1,10]. Internal fixation techniques may involve the use of cannulated screws or fixation plates, depending on the type of fracture [41].

In the literature, several types of bone grafts can be used. For example, Polat B. and colleagues mentioned the following in their 2019 study: autologous grafts from cortical or cancellous bone, grafts from donors, artificial grafts using calcium phosphate bone cement, and grafts using calcium sulfate bone cement. They stated that in patients with Schatzker grade 2 to 6 fractures, the use of grafts led to better outcomes than not using them [38].

It's important to note a recent review published by Tripathy S.K. and colleagues in 2021, emphasizing the importance of using an external fixation technique as a preliminary treatment. Its use in patients with comminuted fractures, severe soft tissue injuries, or in patients unable to withstand prolonged surgery times has shown excellent clinical outcomes. The authors suggest that this technique should always be considered as it reduces the risk of bleeding and infections that can result from prolonged surgery times [12].

Although there is no unanimous consensus in the literature on the best interventional technique [37], currently, the most used technique is ORIF. This technique involves using plates that allow for optimal anatomical reconstruction, lower limb alignment, and increased joint stability [11]. However, the choice of surgical technique, as explained by Robertson and colleagues, largely depends on the type and severity of the fracture being treated. In their 2017 review, they suggest that the ARIF technique appears to provide better long-term outcomes than other techniques, but it can only be used for less complex fractures resulting from low-intensity trauma [41].

Surgical treatment should primarily aim to provide joint stability to the fracture, so the surgical technique used must follow specific logical processes: first, it is necessary to identify which bone fragments (or the bone fragment) are responsible for joint stability, which determines the patient's positioning and surgical access; then, the most appropriate surgical technique should be performed to achieve anatomical reduction that restores the anatomical relationships of the joint surface, repositioning the fragments that have moved away from the center of the joint and have been subjected to depression, and if necessary, bone grafting will be performed. Subsequently, the actual reduction is performed, involving the application of plates and screws. In cases where the fracture extends in a diaphyseal direction, this portion of the fracture is also reduced and fixed [32].

Grade 1 fractures, involving the lateral tibial plateau, are treated using either an anterolateral or posterolateral approach depending on the position of the fracture, whether it extends anteriorly or posteriorly. Anatomical reduction can be achieved using screws or Kirschner wires, and if necessary, a plate can be placed for stabilization. If the displacement is minimal, percutaneous reduction can be performed. Often, in this type of fractures, the lateral meniscus, especially its anterior horn, is also injured, so it may be necessary to treat the meniscus if it is involved.

Grade 2, where the fracture extends into the lateral tibial plateau, is treated with an anterolateral or posterolateral approach. First, the bone depression is reduced, and the bone fragment is realigned and fixed with Kirschner wires. Bone grafting is performed if needed, followed by reduction using screws and the possible placement of a plate.

Grade 3, which involves depression of the lateral tibial plateau, may be treated conservatively in older patients without joint instability. However, in younger patients with severe instability, surgery is required. It involves an anterolateral or posterolateral approach and addressing the fracture with bone grafting and screw fixation, or in cases of severe instability, a plate may be used.

Grade 4 fractures, which involve a medial injury, are treated cautiously due to the possibility of encountering nerve and vascular damage, which can lead to complex regional syndromes. Treatment typically involves either an anteromedial or posteromedial approach, and reduction may require the application of a plate to stabilize the joint and screws to secure the fragments. Surgical repair of the capsular and ligamentous tissues is often necessary as well.

Grade 5, where both tibial plateaus are affected, may require initial immobilization of the limb with an external fixator to allow for initial soft tissue healing. Subsequent surgery follows an approach that follows the positions of the fracture lines in the tibial quadrants (according to the Kfuri classification) and involves the placement of single or multiple plates and screws.

Grade 6, like grade 5, often requires initial placement of an external fixator or Ilizarov technique. Surgery is performed only when adequate soft tissue healing has occurred. The surgical aim is to maintain proper tibial axis alignment and restore knee joint alignment. The surgical technique involves reduction through an approach that depends on the extension of the fracture lines and includes the placement of proximal tibial plates and screws and long plates to reduce extensive diaphyseal fractures [28,31,32,38]. Generally, after surgery, antibiotic prophylaxis is used to reduce the risk of infection, and antithrombotic prophylaxis should continue for 10-15 days to reduce the risk of deep vein thrombosis [28].

1.2.5 Rehabilitation

The postoperative treatment of patients undergoing surgery for tibial plateau fractures is also of high importance. In fact, the postoperative complication rate affecting these patients ranges from 4-27%, with issues such as surgical failure, recurrent dislocations, nonunion, or the onset of infection [40].

Long-term outcomes after surgical treatment depend on the severity of the fracture, the surgical reduction performed, as well as the severity and extent of soft tissue injuries, including tendons, ligaments, cartilage, the joint capsule, and menisci, and possible damage to blood vessels or nerve structures [29,32].

Generally, the initial rehabilitation goal should be to regain joint mobility without pain. Therefore, passive mobilization and active-assisted and active joint mobilization should be initiated as early as the first day after surgery. The aim is to reduce the risk of joint stiffness, synovial adhesions, capsular contractures, and improve cartilage healing [28]. However, there is no unanimous consensus in the literature on the exact timing when the patient should start moving the knee [38]. Still, it has been shown that prolonged immobilization and the use of braces for more than two weeks after surgery lead to worse outcomes [8].

The timing of weight-bearing remains a widely debated topic in the literature [38, 40]. For instance, a Dutch survey conducted among orthopedic surgeons showed that nearly 90% of them do not adhere to protocols for weight-bearing after tibial plateau reconstruction surgery [40].

Considering that during daily life activities, the knee is subjected to forces ranging from 220-350% of body weight [40], and during walking, ground reaction forces (GRF) can reach values ranging from double to five times body weight and can even reach twenty-four times body weight during running [27], the timing of weight-bearing should be carefully considered and investigated.

According to Arbeitsgemeinschaft für Osteosynthesefragen (AO), the standard rehabilitation after tibial plateau fracture reduction surgery dictates no weight-bearing or limited weight-bearing with toe-touching for a period ranging from 6-8 to 10-12 weeks post-surgery [10,40]. However, this period may be further extended if the injury has resulted in significant bone depressions. Recent literature, however, explains that earlier partial weight-bearing does not lead to different clinical outcomes compared to late weight-bearing [11]. On the other hand, other studies suggest that weight-bearing starting after 12 weeks post-surgery is a prognostically negative factor and leads to poor long-term outcomes [8,38].

In summary, passive, active-assisted, and active mobilization, as well as partial weight-bearing, should be initiated early, as no differences have been observed in the long term in terms of pain, quality of life, and complications in patients who undergo early rehabilitation treatment [8,10,28,38,40].

However, the rehabilitation process should not only focus on the early return to normal locomotor function but should also be oriented towards returning the injured person to their pre-injury condition, respecting their interests and wishes. It should be noted that tibial plateau fractures are considered a risk factor for the development of post-traumatic arthritis, which occurs in 9% to 44% of patients. Given that the majority of patients who sustain these injuries are active, the incidence of arthritis significantly affects their quality of life, return to work, and participation in sports [1]. In fact, less than one in five patients returns to pre-injury activity levels, often experiencing pain, joint stiffness, instability, and a fear of reinjury [39]. It is clear that both surgical treatment and the subsequent rehabilitation of this type of injury should be further investigated to improve long-term outcomes and enhance the function and quality of life of patients.

1.3 Biomechanical Assessment

1.3.1 Stiffness and Stretch Shortening Cycle (SSC)

The ability to withstand external tensile forces is defined in the literature as "stiffness" [85,86,87,92,93]. Specifically, it refers to the capacity of an elastic tissue, such as the muscle-tendon junction and aponeurosis [86], to resist the stretching it undergoes and return to its original shape and volume once the external stimulus is removed [3,86,92,93]. The concept of stiffness can be translated into the mechanical capacity of the tissue to store elastic potential energy [86,87], which is crucial for performing functional activities of daily living [90] that require a stretch-shortening cycle (SSC) in biarticular muscles [89].

Although the underlying mechanism of energy storage and release in movements involving SSC is not well understood in the literature [87,88,90], it is known that a movement including a first phase of eccentric contraction, immediately followed by a concentric contraction, allows greater force to be generated compared to a movement with a latency phase (isometric contraction) between the lengthening and shortening phases or a movement with only a concentric phase [89,90]. In other words, when a muscle contracts eccentrically, during the lengthening phase, and is immediately followed by a concentric contraction, it produces more force compared to when the concentric contraction is preceded by an isometric contraction or a movement that includes a latency phase (such as an isometric contraction) between the lengthening and shortening phases [87,88,92,93], or a movement that involves only a concentric phase [89,90,98].

Throughout the research, these considerations are fundamental because studies demonstrate that greater stiffness is positively associated with greater heights in the execution of squat jumps (SJ) and countermovement jumps (CMJ) [83,92,93].

The ability of SSC movements to generate greater force can be attributed to various factors: muscle pre-activation, stretch reflex, the release of passive elastic energy by the tendon tissue, and the phenomenon known as transient force enhancement (FE) [87,90]. The FE phenomenon explains that in a movement with SSC, compared to one without, the difference in the amount of energy released is greater the faster the eccentric muscle contraction occurs. Therefore, in the initial eccentric phase, there is a significant increase in force, which tends to decrease as the eccentric contraction progresses. This late enhancement phase is slower and is referred to as residual force enhancement (RFE). It has been recently associated with the SSC phenomenon and is thought to occur in the titin protein rather than the muscle-tendon or aponeurotic structures [87,90].

In a study conducted by Grober and colleagues in 2021, it was reported that as the length of the muscle-tendon unit decreases, the RFE developed during the lengthening phase decreases, and it increases as the amplitude of the SSC increases [90].

Aging results in a decrease in muscle mass, strength, and the ability to produce power [91]. This is clinically defined as sarcopenia, but it involves a greater impact on the ability to produce power, i.e., a certain force in a shorter time, more than the production of maximal force itself [89]. Therefore, it is understandable how there is a reduction in the ability to develop RFE with aging.

1.3.2 Rate of Force Development (RFD)

As explained in the review by Maffiuletti and colleagues in 2016, another crucial measure that has been increasingly investigated in the assessment and monitoring of explosive functional movements, such as in sports activities and daily life tasks, which involve fast contractions, is the Rate of Force Development (RFD) [94,97]. This measure allows the evaluation of the capacity of athletes, the elderly, and patients to generate maximal voluntary activation in an explosive contraction. It reflects the ability to recruit motor units maximally rather than the speed at which they are contracted and is assessed by the ratio between force expressed and the time during which it is exerted, measured in N/s (Newton per second) [94]. RFD can provide valuable data for monitoring athletic preparation, the condition of patients during rehabilitation, functional capacity in the elderly population, individuals with chronic illnesses, and those with neurodegenerative conditions [96,97]. It is also relevant for assessing fatigue, neuromuscular function [94,95,96] and, as explained by Lomborg S. D. at al in their review conducted in 2022, if compared to the assessment of muscle strength, it is a more sensitive measure for monitoring neurodegenerative diseases indicating that it could be a useful indicator of the nerve-muscle interaction [97].

The ability to generate a high amount of force in a short time can be improved through programs involving explosive exercises and rapid muscle activation. In the aforementioned reviews, Maffiuletti and Lomborg and colleagues explain how this type of measurement is optimal for monitoring functional capacities in daily life and sport-specific tasks. It helps identify changes in neuromuscular function, making it a valuable tool not only in athletic preparation for achieving optimal performance but also in the rehabilitation field, aiming to enhance motor capacity and postural control while reducing the risk of injury and falls.

The study of Maffiuletti explains how a reduced ability to recruit motor units optimally, resulting in a relatively low RFD value, can be influenced by several factors, including:

1. The inability of the primary motor cortex to create an output signal in a short period.
2. Inefficiencies in the synergistic activation of muscles used in the specific movement.
3. Muscle structure in terms of fiber distribution, pennation, and fiber length.
4. Muscle size in terms of volume.
5. Muscle architecture, as muscles primarily composed of fast-twitch (type II) fibers have been shown to exhibit higher RFD.
6. Elements that significantly influence muscle force and stiffness, such as the muscle-tendon junction and fascial structures [94].

1.3.3 Force Platforms

Force platforms (also called forcedecks) are tools that allow the measurement of the force exerted by a person on the ground during a movement and the contact time of the person with the ground [83].

Specifically, the equipment used in this study consists of two force platforms produced by VALD: instruments composed of strain gauge load cells that undergo relative distortion (imperceptible to the naked eye) when a force is applied to them. In this sense, these platforms enable the calculation of Ground Reaction Forces (GRF), which are forces of equal intensity and opposite direction exerted by the ground on individuals when they make contact with the ground [83]. These forces and the contact time are then transmitted as raw data to the specialized software developed by the same company and used on a Windows-based device. They are then interpreted on a force-time curve. With the data provided by this curve, knowledge of the value of gravitational acceleration, and the laws of Newtonian physics, namely:

1. Law of Inertia: If the sum of forces acting on an object is zero, the object remains at rest; if it is in motion, it will continue to move at a constant velocity
2. Proportionality Principle: The force acting on an object is directly proportional to its acceleration and shares the same direction and sense: $F = m * a$ (Force equals mass times acceleration)
3. Action-Reaction Principle: If an object A exerts a force on an object B, object B exerts an equal force in the opposite direction on object A,

the software can interpret these values and calculate other measurements such as body weight and mass, impulse, acceleration, velocity, and power. Furthermore, this data can be further analyzed by the software, allowing for the quantification of movement-related data such as the start of movement, eccentric phase, braking phase, deceleration phase, concentric phase, take-off, landing, and end of the movement.

This type of technology has long been used in athletic training and beyond because it allows for the measurement of an athlete's ability to express maximal isometric force (as in the execution of tests like the isometric mid-thigh pull test, squat test, or bench press test) [83], as well as maximal isoinertial force (as in squat jumps). This, in turn, helps in understanding the Dynamic Strength Deficit. In the context of sports, this measure helps identify whether an athlete needs to improve their strength or their ability to convert maximal strength into power. Power is defined as the product of force and the time required to express that force [84], and in athletic terms, it translates to the execution of ballistic movements, i.e., the ability to perform a movement as quickly as possible. All of this is done to tailor training programs to the specific needs of the athlete and to monitor the changes induced by training itself [21,22].

Another use of force platforms lies in their ability to assess the previously mentioned RFD [94]. By using two force platforms, it is also possible to evaluate the potential presence of asymmetry in force expression between the two lower limbs and, consequently, any differences in RFD expressed in specific movements by the two limbs [83]. This is highly important because lower limb force asymmetry is widely recognized in the literature as a predictor for the risk of ligamentous injury and the early development of arthritis [23,24,25,26]. In this regard, they also have significant utility in monitoring patients undergoing rehabilitation or nearing a return to sports after anterior cruciate ligament reconstruction surgeries [23,27,81].

In recent years, these tools have found extensive use in other patient populations, such as those with motor and postural control issues (as in people with neurodegenerative diseases or elderly [98]), as they allow for the identification of postural control, static and dynamic balance, and any lower limb asymmetries when performing specific tasks [80]. It is important to note that a study conducted by Merrigan explains how the presence of limb length discrepancy could be a factor influencing this type of evaluation [83]. This was investigated in patients, and only one patient reported a 1 cm discrepancy.

As explained by Chen B. and colleagues in 2021 [80], the center of mass (CoM) refers to the imaginary point where the entirety of body weight can be expressed. The center of gravity (CoG) is the perpendicular line connecting the CoM to the ground, while the center of pressure (CoP) is the point of foot-ground contact where GRFs exerted by the CoM on the support surface can be reduced. As explained by Kozinc and colleagues in their 2020 review, the single-leg stance test is widely used by many clinicians to assess balance, even in older populations, as it is the best for assessing the risk of falls: larger variations in CoP displacement are correlated with a higher risk of falling and allow for optimal patient screening to identify the need for a targeted rehabilitation program aimed at reducing the risk of falls [82].

Through this technology, the countermovement jump has been investigated. Some authors (Merrigan 2020) explain that this functional gesture is widely used not only for its practicality but also for its particular reliability in monitoring training adaptations, fatigue resistance, presence of asymmetry and the risk of injury [83]. These authors also explain that this specific task allows for the isolation and investigation of the Stretch-Shortening Cycle (SSC), helping to identify its influence or absence in an individual's ability to use the elastic force accumulated at the muscle-tendon junction [85,88].

1.3.4 Dynamometer

One of the purposes of this study is to investigate the potential presence of muscle strength and active range of motion (AROM) asymmetry in the lower limbs, specifically focusing on the muscles acting on the knee. As explained by Trivedi and colleagues in their 2020 review, muscle strength refers to the force generated during a voluntary contraction against resistance [84]. To assess these capabilities, a commonly used tool in clinical practice was adopted, which allows for the measurement of force and the range of motion produced in a specific movement by a patient: the dynamometer. This is a device widely used in various fields and has been introduced into clinical rehabilitation and prevention practices for several decades, as well as in the world of physical athletic training because it is an instrument that allows for the identification of the force applied to it [75,76,77,78,79,84].

In the execution of the study, the device used was a dynamometer produced by VALD, a digital instrument that allows for the measurement of force, time required to reach maximum force, the Rate of Force Development (RFD) [94], and AROM through specific procedures explained in the standardized protocols provided by the manufacturer. It consists of a sensor that converts the applied force measurement into either traction or compression, and when used, it can provide objective data related to the resistance it is subjected to. The same device is equipped with a digital inclinometer that allows for the assessment of the degrees of range of motion. Therefore, when this device is attached to a body extremity, it can evaluate an individual's ability to move a joint and objectively measure the degrees of movement.

This hardware device was used in conjunction with software developed by the same manufacturer, available as an application on an iOS-based device.

2. AIMS OF THE STUDY

In the literature, there is limited information regarding surgery and post-operative rehabilitation for patients who have undergone surgery following injuries resulting in fractures of the tibial plateau [1,8]. Furthermore, there are few studies that report long-term functional outcomes (range of motion, joint stability, and pain) and the development of secondary arthritis in this type of patients. This type of injury has a significant impact on the quality of life of patients and the healthcare system, as these patients cannot return to work before 3-4 months post-operation, leading to high direct costs (healthcare expenses) and indirect costs (lost productivity when the patient is absent from work) for both the patient and society [1,8,11].

Considering these types of patients, the fact that in the literature there are no studies investigating the possible presence of long-term asymmetry in the two lower limbs and the possibility of using new instruments that are increasingly gaining importance in the clinical rehabilitation field (such as force plates and digital dynamometers), a few research questions were raised. In this context the aim of our study was to respond to the following questions:

1. Are there asymmetries in terms of active range of motion (AROM), maximal strength, power, static and dynamic stability, and rate of force development (RFD) between the limb operated on for tibial plateau fracture and the contralateral limb?
2. Can we hypothesize or exclude a possible involvement of fascial structures in the execution of functional jumping movements that involve the use of the upper limbs compared to those that primarily involve the lower limbs?
3. Given the new knowledge regarding objective data that can be provided by technology, can we hypothesize or exclude an involvement of fascial tissue in the operated limb in this type of patients?

3. MATERIALS AND METHODS

3.1 Surgical Technique Used

All patients who participated in the study underwent the same decision-making algorithm for the evaluation and treatment of tibial plateau fractures and were operated on by a team of orthopedic and traumatology specialists at the Padua Hospital, following these steps:

Step 1

All anesthetic procedures were performed with peripheral nerve blocks using an ultrasound-guided technique with atropine injections in combination with analgosedation. For isolated lateral tibial plateau fractures, a double peripheral nerve block was used, targeting the femoral nerve and saphenous nerve. For fractures involving the medial tibial plateau or both plateau areas, an adductor canal block was used with ultrasound guidance, or deep sedation was administered using a laryngeal mask. Patients were placed in a supine position on the operating table with the injured knee flexed at approximately 60°. Postoperative antithrombotic therapy with enoxaparin was initiated on the same evening after the operation and continued until weight-bearing was achieved. During surgery, an intensifier of images was used to allow for reduction and alignment that best preserved the anatomy. In cases where soft tissue damage did not allow for definitive internal fixation, a temporary external fixation technique was used.

Step 2

Approach and exposure: For lateral plateau fractures, a straight anterolateral incision or a peri-patellar hockey stick-shaped incision was used for fracture exposure. Reduction of the medial plateau was performed first, with a medial incision starting from the posteromedial edge of the tibial metaphysis or a more anterior incision centered on the tibial tuberosity. For fractures involving both tibial plateaus, a double incision was made: a posteromedial incision (approximately 1 cm from the posterior tibial edge) and an anterolateral incision in the peripatellar area. In both groups, the surgical procedure continued according to standard protocols through the subsequent steps.

Step 3

Reduction and stabilization: The knee joint was opened through sub-meniscal arthrotomy to assess fracture characteristics and the possible presence of ligament and meniscus injuries. Kirschner wires were used to reduce fragments and provide temporary fixation. Depressed fragments were lifted and supported with a compression clamp or temporary Kirschner wires to achieve anatomical reduction, while any bone defects were filled with synthetic tricalcium phosphate or autologous bone grafts from the iliac crest.

Step 4

Internal fixation: Depending on the type of fracture, single or double locking plates (LCP DePuy Synthes) were used to achieve definitive osteosynthesis.

Step 5

Postoperative protocol: All patients followed the same postoperative protocol and were monitored by the same trauma team according to standard procedures. Active and passive knee mobilization was initiated from the day after surgery to regain joint range of motion. For the first 4-6 postoperative weeks, partial weight-bearing on the toes of the operated leg was advised with the use of crutches, gradually progressing to full weight-bearing at 3 months after surgery.

3.2 Study Sample Inclusion and Exclusion Criteria

Between July 21, 2023, and September 22, 2023, patients who had undergone surgery for tibial plateau fractures at the Orthopedic and Traumatology Clinic of the University Hospital of Padua between 2009 and 2016 were contacted by phone. All patients under the age of 68 at the time of the study were included to investigate the presence of alterations in a physically active population. A total of 70 patients were contacted, and the study's objectives were explained to them. Twenty-eight patients volunteered to participate. Each patient underwent a visit at the hospital's outpatient clinics, during which a medical history was collected, a clinical evaluation was conducted by an orthopedic and traumatology resident to investigate possible capsular, meniscal, and ligamentous knee damage, force evaluations were performed on VALD force plates, and joint mobility and knee strength were assessed using a digital dynamometer. The subjective assessment scales and clinical tests used to evaluate each patient are presented below.

3.3 Subjective Evaluation Scales

- Tegner Activity Score (TAS)

The Tegner Activity Scale is a test that provides standardized assessment of the level of work and sports activities of patients who have undergone treatments such as ligament reconstruction in the knee joint, meniscal repair, meniscectomies, microfractures, tibial osteotomy, realignment and stabilization of the patella, osteochondritis dissecans, and traumatic injuries [16].

This test was created as a complement to the Lysholm Knee Scoring Scale since it was observed in the Lysholm scale that limitations in the functional section score could be caused by a decrease in the individual's level of physical activity. The test consists of a list of 11 items, where activities are listed progressively from 0 to 10, including actions of daily living, recreational activities, amateur sports, and professional sports in order from least to most physically demanding. The patient is then required to indicate the level of activity they feel capable of participating in.

A score of 0 represents a condition of mild illness or disability caused by knee problems, while a score of 10 describes patients participating in national and international competitions. Scores between 6 and 9 are descriptive of individuals participating in recreational or competitive sports activities.

- Lysholm Knee Scoring Scale

The Lysholm test is primarily used for evaluating the outcomes of reconstructive surgery for ligament injuries in the knee. However, in the literature, it is also indicated as a widely used assessment scale for monitoring conditions such as patellofemoral dysfunction, meniscal injuries, knee cartilage injuries, osteochondritis dissecans, traumatic knee dislocation, patellar instability, patellofemoral pain, and knee osteoarthritis, as it is optimal for evaluating symptoms like instability [16].

The test consists of 8 questions that inquire about the following: the presence of any limp, the need for support during walking, the presence of joint blocks, instability, pain, swelling, difficulty in climbing stairs, and difficulty in squatting. Each item is assigned a score ranging from 0 to a maximum, which varies depending on the importance of the item. The final test score is obtained by summing the values of each item, resulting in a final score ranging from 0, indicating complete disability, to 100, indicating the complete absence of symptoms. More specifically, in the literature, a score between 100-95 is considered excellent, good if between 94-84, fair if between 83-65, and poor if below 65 [16].

- Numeric Pain Rating Scale (NPRS or NRS)

To date, it represents one of the most well-known unidimensional outcome measures for assessing the intensity of pain: the NPRS scale is a validated measurement system that allows the subjective expression of the severity of acute or chronic pain that is perceived. It corresponds to a segmented and numerically divided version of the Visual Analog Scale (VAS). The assessment involves asking the patient to verbally or graphically indicate on a scale from 0 to 10, where 0 indicates no pain and 10 the worst pain imaginable, the intensity of the pain perceived by the patient at the time of assessment. As with the VAS scale, no translation barriers have been identified with the NPRS scale, making it an optimal measurement system in all populations [14].

- American Knee Society Score (AKSS)

The American Knee Society Score (AKSS) is a validated questionnaire widely used in the literature to evaluate degenerative issues affecting the knee joint and the outcomes of knee joint replacement [17]. The evaluative questionnaire consists of two parts: one that is operator-dependent, focusing on the clinical examination of the knee joint being assessed, and a subjective part that assesses the knee's functional capacity in daily activities. The maximum score is 100 points for each of the two sections, with higher scores indicating better functional capacity. The clinical section includes the evaluation of pain, range of motion, anteroposterior and mediolateral stability, where higher scores indicate better functionality. The presence of flexion contracture, extension deficit, and varus-valgus alignment issues, if present, result in a negative score and reduce the final score. In this evaluation part, a score between 80-100 points indicates excellent functionality, 70-79 points are considered good, 60-69 points are acceptable, and below 60 points are considered poor. The second part of the questionnaire is completed by the patient and assesses their abilities in daily activities, specifically walking and climbing stairs, where a maximum of 50 points can be obtained for each activity. Additionally, the need for walking aids is evaluated, with a maximum negative score of -20 points if aids are required. In the study, only the second part of the evaluation scale was used.

- Italian version of the Knee injury and Osteoarthritis Outcome Score (KOOS-I)

The KOOS-I questionnaire is an evaluative questionnaire, translated and validated in the Italian language from the original English version, which allows the investigation of various subjective parameters in patients who have undergone ligament reconstruction surgery, reparative surgery for meniscal tears, early osteoarthritis, osteochondritis dissecans, microfractures, tibial osteotomy, and knee prosthetic surgeries [16,18]. This assessment places great emphasis on the symptoms and the patient's subjective perception of the injured knee and how these factors influence the patient's quality of life. The major areas investigated include knee symptoms and stiffness (7 items), pain (9 items), functioning in activities of daily living (17 items), functioning in sports and recreational activities (5 items), and quality of life in relation to knee function (4 items). The questionnaire consists of 42 items, and the patient completing it must provide a response (by checking a box) on a five-point scale regarding which situation most accurately reflects their own. From the sum of the scores for each subscale, a result is obtained, which is then transformed into a percentage scale, allowing for evaluation from 0 to 100, where 0 corresponds to extreme difficulties, and 100 corresponds to a healthy knee [16,18,20].

- International Knee Documentation Committee (IKDC)

The evaluation using the IKDC questionnaire allows for an understanding of the patient's subjective perception of the function of the injured knee and thus assess any improvements or worsening of symptoms. This questionnaire is used for the study of many knee joint-related conditions such as ligament reconstruction, meniscal repair, cartilage injuries, conditions of patellofemoral pain syndrome, tibial osteotomy, traumatic injuries, and osteochondritis dissecans [16,20]. The assessment is divided into three domains and investigates: symptoms, function in sports and daily life activities, and a comparison with knee function before and after the injury.

The questionnaire requires the patient to rate 18 items. The response options vary: three items are rated on a scale from 0 to 10, fourteen on a scale from 0 to 4, and one requires a dichotomous yes/no response.

The result is obtained by summing the scores for each item, which is then transformed into a percentage value. The final evaluation is thus on a scale ranging from 0 to 100, where the maximum value indicates the absence of symptoms and limitations in daily life and sports activities.

- The Short Form 36 (SF-36)

The SF-36 questionnaire is a validated and widely used tool in the literature to quantify the physical health status and related quality of life of the patients who complete it. Through 36 items, the questionnaire measures the overall quality of life. The different items are divided into two major components, allowing the distinction between physical health status, represented by the Physical Component Summary (PCS), and mental health status, represented by the Mental Component Summary (MCS), thus measuring the impact of an illness on different aspects of quality of life [1,14].

The SF-36 assesses: physical functioning (10 items), limitations due to physical health (4 items), limitations due to emotional problems (3 items), energy and fatigue (4 items), emotional well-being (5 items), social activities (2 items), pain (2 items) and general health perception (5 items). The thirty-sixth item evaluates changes in health status compared to the previous year. Each of these items is assessed separately on a scale from 0 to 100, where lower scores indicate worse functionality [15].

3.4 Clinical Evaluation Scales

Every clinical test, such as the anamnesis collection, was performed by an orthopedic resident of the hospital-university of Padua (R.I.).

The clinical tests selected were performed to identify the possible presence of ligamentous, capsular or meniscal lesions. The tests conducted were:

- Lachmann Test

Among the tests used to assess the integrity of the anterior cruciate ligament (ACL), this one is considered the most reliable in the literature [50]. Confirming this there are two reviews both from 2022, one realized by Tanaka S. and colleagues and the other by Sokal P.A. and colleagues, which describe the diagnostic accuracy data of this test. They affirm that its sensitivity values are of 79% and 81% and its specificity values are of 91% 85%. This test is performed with the patient in a supine position, the knee to be examined flexed at 15°-20°. The examiner places one hand on the distal femur and stabilizes it while using the other hand to grip the proximal tibia. Subsequently, a force is applied in the posterior-anterior direction with the hand holding the tibia. The test is considered positive if there is an increased translation of the lower limb where there is suspicion of ACL injury, compared to the contralateral limb. According to some authors, the perception of a soft end-feel, in conjunction with an increase in excursion, may be indicative of an injury [43].

- Pivot Shift Test

This is the most suitable test to confirm the presence of an ACL (Anterior Cruciate Ligament) injury, as it assesses the combined movement of internal rotation and anterior translation of the tibia on the femur, thereby examining the rotational stability of the knee. This test is performed with the patient in a supine position. Specifically, the examiner must grasp the patient's tibia at the distal level with one hand and place the other hand under the popliteal fossa. At this point, the clinician induces a progressive flexion of the knee to 90 degrees while simultaneously inducing internal rotation of the tibia. In the case of a positive test, subluxation of the tibia will occur while the knee is flexed, and it will gradually return to the extended position of the joint. The test has a very high specificity (94-96% according to colleagues Sokal and Tanaka), and it can predict the injury in 94-98% of cases. However, it has a very low sensitivity (estimated in the literature at 55%), so in case of a negative result, it is not possible to exclude the presence of an injury with adequate certainty [43].

- Jerk Test

The test in question can be considered a variation of the test described earlier, as it is performed in a supine position and follows the same principles as the Pivot-Shift test. However, it differs from the previous test in that, instead of starting from a knee extended position, the clinician applies a valgus-internal rotation force, beginning with the knee in flexion and progressing towards extension. This test has diagnostic accuracy values of 98% for specificity and 28% for sensitivity [54].

- Anterior Drawer Test

This test is performed to investigate the presence of a possible injury to the anterior cruciate ligament (ACL). It is conducted with the patient in a supine position, and the knee to be examined is flexed at 90 degrees. The clinician immobilizes the foot of the examined limb by sitting on it and grasping the tibia with both hands. The thumbs are placed on the tibial joint line on either side of the patellar tendon, and the index fingers are placed on the hamstring tendons. The examiner then applies a force in the posterior-anterior direction, and the test is considered positive if there is increased anterior translation of the tibia on the femur compared to the contralateral side.

However, this test has limitations in patients who have suffered an acute injury for three reasons: the presence of intra-articular effusion limits achieving the 90-degree knee flexion position, possible muscle spasm may restrict anterior translation of the tibia and performing the test could compress the posterior horn of the medial meniscus against the posterior edge of the medial femoral condyle, limiting tibial excursion. According to the two 2022 reviews by Sokal P.A. and Tanaka S., the test has a sensitivity of 83-78% and a specificity of 85-91% [43].

- Posterior Drawer Test

This test is performed in the same manner as described for the Anterior Drawer Test, but the clinician applies force in the anterior-posterior direction. This allows for the stress of the posterior cruciate ligament (PCL) to assess its integrity. If increased posterior translation of the tibia compared to the healthy side is observed, it may suggest a posterior cruciate ligament (PCL) injury [49].

- Apley Test

The Apley test is performed during the objective evaluation phase, following a medical history assessment, to evaluate the possible presence of a meniscal injury. It is conducted with the patient in a prone position, the hip in anatomical position (0 degrees of extension), and the leg to be examined with the knee flexed at 90 degrees. The examiner secures the thigh to the examination table by placing their knee on it, and then applies an axial traction force to the tibia while inducing both internal and external rotation to rule out issues with the capsular structures. In the presence of inflammation or damage to the capsule, this can exacerbate painful symptoms.

If this test does not cause pain, the meniscal stress test can be performed. In this test, an axial force is applied to the heel (perpendicular to the examination table), followed by internal rotation to stress the lateral meniscus and external rotation if the medial meniscus is to be examined.

The diagnostic accuracy of this test is somewhat uncertain. There is no unanimous consensus in the literature regarding its ability to include or exclude the sought-after pathology. A 2009 review by Hing W. and colleagues explains that the specificity values of the test range between 77% and 93%, and sensitivity values vary from 41% to 83% when considering both menisci. However, the test generally shows better values when examining the medial meniscus specifically [44,45,46,48].

- McMurray Test

The McMurray test is often performed in conjunction with the previously described test to investigate the presence of a possible meniscal injury. The patient is in a supine position, and the examiner must hold the heel of the limb with one hand while stabilizing the knee to be examined with the other hand. Subsequently, the examiner must induce maximum knee flexion, followed by internal rotation (using the hand holding the heel) to stress the lateral meniscus and then external rotation to highlight any damage to the medial meniscus. Finally, passive knee extension is provoked while maintaining the rotations, bringing the knee to 90 degrees of flexion. The test is considered positive, indicating damage to the examined meniscus, if a click or pain is perceived during the execution.

Like the previously described test, the McMurray test has widely variable diagnostic accuracy values in the literature. However, it allows for more accurate diagnostic criteria when it comes to detecting injuries to the lateral meniscus. The 2009 review by Hing W. reports specificity values ranging from 29% to 96% and sensitivity values from 27% to 70,6% [44,45,46,47,48].

- Meniscal Palpation

The meniscal palpation test is one of the examinations that can be performed during the objective evaluation to search for or exclude the possible presence of meniscal injuries. The examination is conducted with the patient in a supine position and the knee to be tested flexed at 90 degrees. The examiner must position themselves at the patient's foot to stabilize the lower limb and then place their hands on the knee joint line. At this point, the clinician uses their index finger to palpate the entire joint line, both medially (to assess the medial meniscus) and laterally (for the lateral meniscus). If the patient reports the onset or worsening of common pain, the test is considered positive.

Like other clinical tests for evaluating the presence of meniscal injuries, the meniscal palpation test also has conflicting diagnostic accuracy values in the literature. Sensitivity values range from 55% to 92%, and specificity values range from 29% to 94% [44,46].

- Varus Stress Test

The Varus Stress Test is performed to assess the possible presence of an injury to the lateral collateral ligament (LCL), which is the primary stabilizing structure of the knee during varus (inward) movements. The test is conducted with the patient in a supine position, with the knee flexed at 30 degrees. The clinician must grasp the examined limb with one hand at the distal medial aspect of the femur and the other hand at the distal lateral aspect of the leg. The test is carried out by applying a varying force to the knee. An increase in the opening of the joint space compared to the healthy side is indicative of an injury to the lateral collateral ligament. The test should also be performed with the knee fully extended, and the presence of joint space opening in this position may suggest a more complex and extensive injury [51,52].

- Valgus Stress Test

The Valgus Stress Test is performed to investigate the possible presence of damage to the medial collateral ligament (MCL), which is the primary stabilizer of the knee against forces that act in valgus (outward) stress. The test is conducted using the same procedures as the previous one, with the patient in a supine position, the knee flexed at 30 degrees, and the examiner's hands placed, one on the distal medial aspect of the femur and the other on the distal leg, allowing them to apply a valgus force to the knee. The test is considered positive if there is an increase in the opening of the joint space compared to the healthy side. Like the previous test, this one should also be performed with the knee fully extended [53].

- Alignment

Furthermore, the alignment of the lower limbs was also assessed to identify any differences in terms of varus or valgus alignment and leg length between the healthy limb and the limb that underwent reconstruction surgery for a tibial plateau fracture.

- Peripheral Vascular and Nerve Deficits (PVND)

Finally, the potential occurrence of post-operative complications and the development of peripheral vascular and nerve-related conditions were investigated.
Each clinical test, except for the assessment of alignment and peripheral vascular and nerve deficits, followed a grading system with three stages: a score of 0 indicates a negative result compared to the contralateral limb, a score of 1 indicates a mild positivity to the test compared to the healthy side, and a score of 2 indicates a marked positivity to the test compared to the other lower limb. The assessment of alignment was scored on a dichotomous scale: 0 for congruent alignment with the non-operated limb and 1 for the presence of alignment differences. The evaluation of the presence of peripheral vascular and nerve deficits received a score of 0 for the absence of these associated disorders or 1 for their presence.

3.5 Dynamometer Assessment

The dynamometer evaluation was conducted following the protocols provided on the dedicated VALD website to measure the knee's range of motion (AROM) in flexion and extension while in the prone position. The measurement of the range of motion was carried out by placing the dynamometer at the distal third of the leg, secured with a specialized velcro strap (provided with the device). The measurement of knee extension degrees in the prone position, as explained in the manufacturer's protocols, begins from a knee flexion position of 90 degrees. The patient is then asked to extend the knee as far as possible. Similarly, the measurement of flexion degrees starts from the knee's extended position, and the patient is subsequently asked to flex the knee as much as possible, waiting for the device to stabilize the maximum flexion angle (see Figure 10 C).

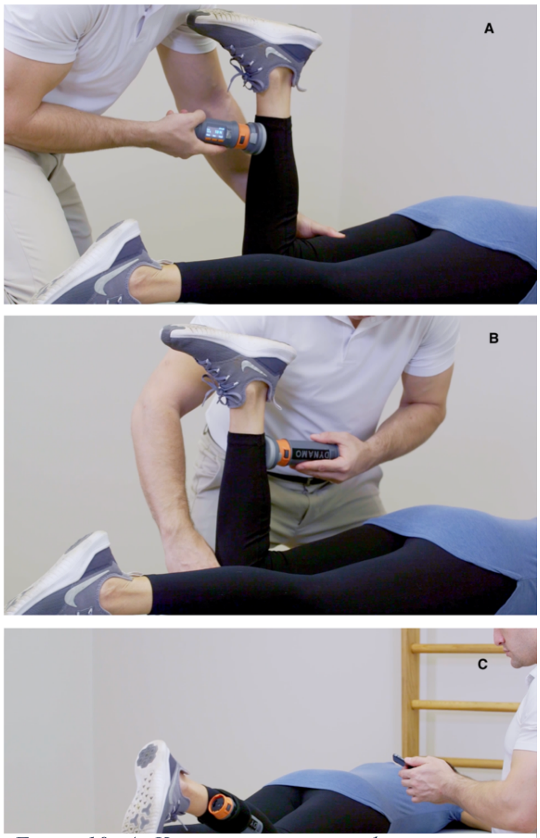

*Figure 10- **A**: Knee extension strength measurement, **B**: Knee flexion strength measurement, **C**: Knee active range of motion (AROM) measurement.*

The manufacturer provides several methods for measuring maximum force for knee flexion and extension movements. The measurement was carried out as per the manufacturer's protocols for push dynamometer tests in the prone position. The decision to conduct the tests in this manner was driven by the desire to achieve maximum knee stabilization and avoid compensations at the hip [75] to reduce the risk of bias. Additionally, literature studies have shown that tests for measuring maximum isometric force performed with handheld dynamometer stabilization do not demonstrate differences compared to measuring the same force with an isokinetic dynamometer [77]. Therefore, after attaching a specialized head to the device, the dynamometer is manually held by the operator on the opposite leg's portion during the movement: for extension, the dynamometer is placed on the front portion of the leg (Figure 10 A), and for flexion, it is placed on the rear portion (Figure 10 B). Each patient was systematically instructed to maintain the prone position with their upper limbs extended along the sides and the knee under examination at a 90-degree flexion position, keeping it attached to the examination table surface during the test to obtain a standardized procedure and further reduce the risk of bias [76]. Subsequently, patients were instructed to exert maximum isometric force against the resistance offered by the dynamometer. In case of compensation where hip flexion occurred, the test was repeated. Each test was performed three times for each lower limb, with a five-second rest between each maximum contraction.

For both maximum strength evaluation and active range of motion (AROM), the maximum values reached within the three measurements were considered, along with the corresponding time required to reach that strength or range of motion. This approach assessed the maximum capacity for strength and AROM expression to analyze the best performance. Regarding the rate of force development (RFD) value, the average data obtained from the tests was studied in order to study the mean capacity of muscle recruitment and not the best performance.

Although the publication by Larson and colleagues [79] in 2022 explains that measuring maximum force in the adult population using a clinician-stabilized push dynamometer offers excellent reference values for both inter and intra-personal comparisons, other studies like the one conducted by Gonzalez and colleagues in 2021 [78] explains that this type of test has reduced interpersonal validity for high forces compared to the same measurement performed with a pull dynamometer, which is fixed to the operator's body. For this reason, to minimize bias, it was decided to have all measurements conducted by the same clinician (S.P.), beginning with the AROM measurement followed by the measurement of maximum force, first for knee flexion and then for extension. The tests were started with the right lower limb and followed by the left limb, regardless of which limb was injured.

The figures provided were taken from the VALD manufacturer's website, where the utilized protocols are demonstrated [55].

3.6 Force Platforms Assessment

Among the many tests provided in the protocols of the manufacturer of the used equipment, specific tasks were chosen for each patient. Specifically, during the assessment, each patient was instructed on the execution of each functional task and was then asked to perform them.

The functional movements that were examined included:

- Single Leg Stand Test (SLS)

In this test, the patient was asked to keep their hands on their hips and balance on one leg for 15 seconds while the other lower limb remained at 0° hip extension and knee flexion (see Figure 11). This exercise allowed the identification of total center of pressure (CoP) displacement, the average speed of CoP movement within the support base, the maximum medial, lateral, anterior, and posterior CoP displacement, and performing the test with both lower limbs allowed the assessment of any asymmetry between the two sides in the previously mentioned parameters.

Figure 11 - Single Leg Stance (SLS)

- Squat Jump Test (SJ)

The execution of this test involved keeping hands on hips, reaching the squat position holding it for 2 seconds (3^{rd} image from the left in figure 12), and then performing a jump. This gesture allowed the identification of concentric mean force, maximum force at take-off, jump height and time, maximum power, and asymmetry between the two sides in the expression of mean concentric force, maximum force at take-off, maximum force at landing and their relatives RFD (see Figure 12).

- Countermovement Jump Test (CMJ)

For the execution of this test each patient was asked to keep their hands on their hips, descend into the squat position, and perform a jump as high and as quickly as possible without maintaining the squat position for 2 seconds. This functional movement is widely used and discussed in the literature as it allows the identification of maximum eccentric force, jump height and time, duration of the eccentric and concentric phases and any asymmetry in the eccentric and concentric phases, maximum force at take-off, maximum force at landing and the concentric, eccentric and landing RFD [23] (see Figure 12).

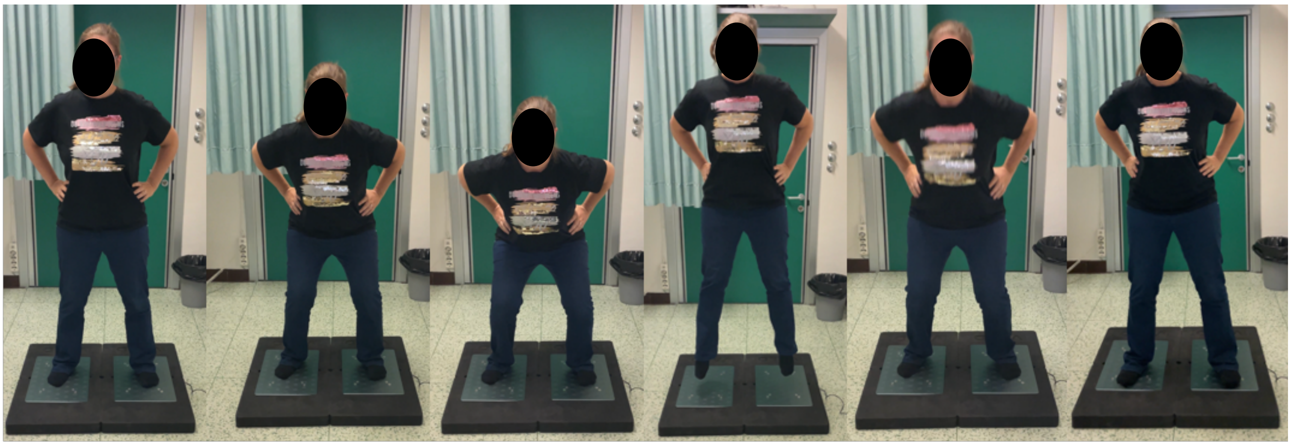

Figure 12 - Squat Jump (SJ) and Countermovement Jump (CMJ)

- Countermovement Jump Loaded (CMJL)

This test was performed in the same way as the previous one, but the patient was asked to take the leap using both upper limbs, which were no longer constrained by a hold on the hips (see Figure 13). Compared to the previous test, this is known because it allows an increase in the load on the lower limbs, consequently increasing ground reaction forces (GRF), enabling jumps up to 38% higher [81]. It also increases concentric impulse, force, and power. As explained by Heishman A.D. and colleagues in their 2020 publication, compared to the previous test, this one provides less reliability in monitoring lower limb function but offers greater accuracy in assessing fatigue level and neuromuscular function, making it a better screening tool for evaluating sport-specific activities [103].

Figure 13 – Countermovement Jump Loaded (CMJL)

The testing procedures were standardized, with each patient receiving explanations of the test procedures in the same manner by the same operator. The tests were conducted by the patients without footwear and in the order described. During the execution of the various tests, the patient was verbally guided by the same operator for correct execution of the functional movement. Each test was performed with the patient completing three repetitions per leg for the Single Leg Stand Test (SLS) and three times for each functional movement and patients were asked to maintain a static position for 2-3 seconds between each repetition. The statistical analysis was conducted on the mean values calculated from each test in order to study the mean capacity in every test and functional movement.

4. RESULTS

The data obtained from subjective assessments, clinical evaluations, dynamometer examinations, and forcedecks examinations were subjected to statistical analysis using the SPSS program run on an iOS operative system by a doctoral student at the University of Padua (X.Z.). A t-test was conducted, and values equal to or less than 5% ($p \leq 0,05$) were considered statistically significant.

4.1 Patient Characteristics

The group of patients who were evaluated consisted of 28 individuals, comprising 13 females (46,4%) and 15 males (53,6%). Among them, 13 (46,4%) individuals had sustained a fracture to the tibial plateau of the left lower limb, while the remaining 15 (53,6%) had fractures in the right lower limb. Subsequently, it was possible to identify that the follow-up was carried out at an average distance of 9,10 ± 2,33 years from the intervention. The patients showed an average age of 54,89 ± 8,89, and on average, they had to surpass a period of 9,71 ± 8,12 months to return to pre-injury activity level. Finally, the average height was found to be 172,46 ± 11,12 cm, and the average weight 76,70 ± 19,58 kg. Through the measurement of these, it was possible to calculate the BMI, which on average showed values of 25,28 ± 5,37 (kg/cm^2). (See Table 1).

4.2 Subjective Evaluation

The patients underwent subjective assessment, and the statistical analysis allowed us to identify that the average values recorded are: 3,43% ± 1,17 for the Tegner Score, 83.25% ± 23,61for the Lyhsolm Score, 0,68 ± 1,52 for the NPRS, 85,53% ± 23,78 for the AKSS, 77,62% ± 23,80 for the KOOS-I, 74,10% ± 18,00 for the IKDC and 80,94% ± 17,44 for the SF-36 assessment. (See Table 1).

Characteristic	***N statistic***	***Range Statistic***	***Minimum Statistic***	***Maximum Statistic***	***Mean Statistic ± Standard Deviation***
Age [years]	28	31,00	35,00	66,00	54,89 ± 8,89
Years From Intervention	28	7,00	7,00	14,00	9,10 ± 2,33
Months to return to preinjury activity level	28	34,00	2,00	36,00	9,71 ± 8,12
Height (cm)	28	36	154	190	172,46 ± 11,12
Weight (kg)	28	77	44	121	76,70 ± 19,58
BMI (kg/m^2)	28	27,49	14,70	42,19	25,28 ± 5,37
Tegner Score	28	6,00	0,00	6,00	3,43 ± 1,17
Lyhsolm Score	28	92,00	8,00	100,00	83,25 ± 23,61
NPRS	28	6,00	0,00	6,00	0,68 ± 1,52
AKSS2	28	80,00	20,00	100,00	85,53 ± 23,78
KOOS-I	28	87,20	12,80	10,00	77,62 ± 23,80
IKDC	28	73,60	21,80	95,40	74,11 ± 18,00
SF-36	28	55,30	42,20	97,50	80,94 ± 17,44

Table 1 - Statistical Analysis of the Characteristic and Subjective Evaluations

4.3 Clinical Evaluation

The clinical evaluation was conducted to investigate the possible presence of damage at ligamentous, menisci or capsule structures. To evaluate the ACL integrity, the following tests were performed: Lachman Test, Pivot Shift Test, Jerk Test and Anterior Drawer Tests. To assess the integrity of the PCL, the Posterior Drawer Test was conducted. The Varus Stress Test was used to assess the integrity of the LCL, and the Valgus Stress Test for the MCL. Subsequently, to investigate the potential presence of meniscal injury, clinical tests including Apley Test, McMurray Test, and Meniscal Palpation were performed. Finally, Alignment in the frontal plane and the secondary development of peripheral vascular nerve deficits were evaluated. It was found that only one patient (3,6%) reported peripheral nerve deficits and that only, the Posterior Drawer Test and the Valgus Stress Tests were the only two which always resulted negative, the Meniscal Palpation and the Alignment were the tests which showed more positivity (21,4%) and that the Varus Stress Test showed a statistical correlation with a p-value of 0,020 ($p<0,05$). (See Table 2).

Clinical Test	*Test Results*			*P-value*
	0	*1*	*2*	
Lachman Test,	25 (89,3%)	1 (3,6%)	2 (7,1%)	0,110
Pivot Shift Test	25 (89,3%)	3 (10,7%)	0 (0%)	0,645
Jerk Test	26 (92,9%)	2 (7,1%)	0 (0%)	0,182
Anterior Drawer Tests	24 (85,7%)	2 (7,1%)	2 (7,1%)	0,062
Posterior Drawer Test	28 (100%)	0 (0%)	0 (0%)	-
Varus Stress Test	24 (85,7%)	4 (14,3%)	0 (0%)	0,020*
Valgus Stress Test	28 (100%)	0 (0%)	0 (0%)	-
Apley Test	23 (85,2%)	4 (14,3%)	0 (0%)	0,883
McMurray Test	23 (85,2%)	5 (17,9%)	0 (0%)	0,104
Meniscal Palpation	22 (78,6%)	4 (14,3%)	2 (7,1%)	0,152
Alignment	22 (78,6%)	6 (21,4%)	-	0,279
PVND	27 (96,4%)	1 (3,6%)	-	0,362

Table 2 - Statistical Analysis of the Clinical Evaluation

4.4 Dynamometer Assessment

The dynamometer evaluation allowed the identification of asymmetries in the lower limbs. The assessment revealed that, on average, patients flexed the operated limb with a mean strength of 106,93 ± 6,53, extended it with a mean force of 190,68 ± 15,02, flexed the healthy side with 121,63 ± 8,82 and extended it with a mean force of 206,93 ± 14,03, showing a significant correlation. The p-value was respectively calculated at 0,001 and 0,034 when comparing flexion and extension movements between the limbs ($p<0,05$). The two limbs also showed a statistical correlation as the operated limb flexed a mean of 116,03 ± 3,51(°) and the healthy flexed in mean 125,45 ± 2,72 (°). Also they extended respectively 2,71 ± 2,07 (°) and 7,89 ± 1,10 (°). The p-value was calculated to be respectively 0,000 for flexion and 0,009 for extension. Finally, the statistical analysis showed no

Variables	*Mean ± SD (n=27)*	*P-value Injured vs. Health*
Peak F flx injured [N]	106,93 ± 6,53	0,001*
Peak F flx healthy [N]	121,63 ± 8,82	
Peak F ext injured [N]	190,68 ± 15,02	0,034*
Peak F ext healthy [N]	206,93 ± 14,03	
Rom flx injured [°]	116,03 ± 3,51	0,000*
Rom flx healthy [°]	125,25 ± 2,72	
Rom ext injured [°]	2,71 ± 2,07	0,009*
Rom ext healthy [°]	7,89 ± 1,10	
RFD flx injured [N/s]	173,26 ± 11,21	0,411
RFD flx healthy [N/s]	180,28 ± 12,57	
RFD ext injured [N/s]	262,78 ± 24,49	0,209
RFD ext healthy [N/s]	283,86 ± 20,72	

Table 3 - Statistical Analysis of the Dynamo Assessment

difference and statistical correlation in terms of flexion RFD and extension RFD between the lower limbs (respectively: p-value =0,411 and p-value=0,209). (See Table 3).

4.5 Force Plate Assessment

It's important to mention that one patient couldn't perform the clinical-functional tests, so the analysis was conducted on the results obtained from 27 patients. The analysis of data obtained from the Single Leg Stand test (SLS) showed that when patients maintained the balance on the operated limb, their center of mass moved on average within an area of 924,76 ± 491,45 mm^2 and at a velocity of 61,66 ± 32,76 m/s and when they maintained the balance on the healthy limb, they're projection of the center of mass moved on average within an area of 901,709 ± 627,22 mm^2 at a velocity of 60,61 ± 42,22 m/s. In conclusion we can affirm that there is no significant difference in terms of total excursion and velocity of the projection of the center of mass during the SLS: the p-value obtained from the comparison of the lower limb was respectively of 0,662 and 0,762 (p>0,05). (See table 4)

Variables	*Mean ± SD (n=27)*	*P-value Injured vs. Health*
Total Excursion injured leg [mm^2]	924,76 ± 491,45	
Total Excursion health leg [mm^2]	901,709 ± 627,22	0,662
Velocity injured leg [m/s]	61,66 ± 32,76	
Velocity health leg [m/s]	60,61 ± 42,22	0,762

Table 4 – Statistical Analysis of the SLS test

The data collected from the forcedecks during the functional tests were evaluated and statistically analyzed to investigate the potential presence of differences in terms of performance and asymmetry. From the statistical analysis, it emerged that the only statistically significant measures (p-value<0,05) in terms of performance were:

- The difference in concentric force during the SJ, CMJ, and CMJL phases. In the first movement, concentric force was significantly lower than in the second (p=0,036) and the third (p=0,027) movements. However, no statistical difference was identified when comparing the concentric force between CMJ and CMJL (p=0,994).
- The difference in height reached during the SJ and CMJL: p=0,015, while this difference was not observed in the correlation between SJ and CMJ (p=0,673) and comparing CMJ and CMJL (p=0,116).

Lastly, no statistical differences were observed in terms of eccentric force between CMJ and CMJL, and it was not possible to identify significant differences in terms of power and RFD during the concentric phase of the different functional movements. (See Table 5).

Performance	*SJ*	*Min*	*Max*	*CMJ*	*Min*	*Max*	*CMJL*	*Min*	*Max*	*SJ-CMJ p-value*	*CMJ-CMJL p-value*	*SJ-CMJL p-value*
CONC mean F [N]	986,074±230,00	581,00	1439,00	1189,04±297,02	645,00	1719,00	1197,74±347,64	645,00	1740,00	0,036*	0,994	0,027*
ECC mean F [N]	-	-	-	778,37±188,01	455,00	1208,00	750,30±217,50	318,00	1208,00	-	0,614	-
Height [cm]	10,30±4,63	4,60	21,10	11,54±5,14	3,60	24,30	14,47±6,17	4,30	28,80	0,673	0,116	0,015*
Peak Power [W]	1985,76±646,47	928,00	3030,00	2095,74±728,36	661,00	3214,00	2361,41±944,66	451,00	3773,00	0,864	0,430	0,189
CONC RFD [N/s]	1794,15±951,77	476,00	4617,00	2626,89±1926,29	426,00	7275,00	1930,15±1579,08	238,00	5812,00	0,122	0,226	0,944

Table 5 – Statistical Analysis of Performance Data of SJ, CMJ and CMJL

Asymmetry	*SJ*	*Injured-Healthy p-value*	*CMJ*	*Injured-Healthy p-value*	*CMJL*	*Injured-Healthy p-value*	*SJ-CMJ p-value*	*CMJ-CMJL p-value*	*SJ-CMJL p-value*
CONC F Injured [N]	467,18±115,60		585,22±143,96		638,89±190,26		0,005*	0,561	0,001*
CONC F Healthy [N]	512,5±125,98	0,006*	603,67±177,33	0,458	722,04±259,11	0,026*	0,096	0,149	0,001*
ECC F Injured [N]	-	-	386,04±104,26		374,18±86,86		-	-	-
ECC F Healthy [N]	-	-	392,33±98,81	0,673	398,15±121,87	0,208	-	-	-
CONC RFD Injured [N/s]	815,43±466,64		1315,19±1062,12		922,79±702,93		0,089	0,302	0,875
CONC RFD Healthy [N/s]	950,57±506,76	0,005*	1311,63±967,88	0,977	930,00±1068,88	0,971	0,249	0,425	1,000
Landing RFD Injured [N/s]	14310,32±9727,34		15686,48±10498,19		15251,75±10627,67		0,942	0,998	0,980
Landing RFD Healthy [N/s]	17869,71±11604,47	0,014*	14386,78±11284,17	0,514	16228,79±11804,15	0,351	0,597	0,911	0,936
Peak Landing F Injured [N]	1281,86±554,59		1403,44±626,17		1309,29±590,19		0,830	0,918	0,997
Peak Landing F Healthy [N]	1510,11±659,41	0,016*	1348,22±603,23	0,565	1423,71±773,68	0,176	0,716	0,969	0,958
Injured Limb Stiffness [N/m]	-	-	38116.23±14723.12		7330.04±16792.88		-	0.285	-
Healthy Limb Stiffness [N/m]	-	-	43098.08±171492.459	0,313	9151.37±23407.57	0,168	-	0.313	-
ECC Deceleration Injured RFD [N/s]	-	-	1633,48±903,18		1631,15±1040,11		-	-	-
ECC Deceleration Healthy RFD [N/s]	-	-	1675,33±1420,63	0,842	1903,46±1471,89	0,164	-	-	-

Table 6 – Statistical Analysis of Asymmetry Data of SJ, CMJ and CMJL

Subsequently, data were analyzed to investigate any possible limb asymmetry. They were subjected to statistical analysis, including concentric strength and concentric RFD expressed by both limbs in the various tasks, eccentric strength and its relative RFD in CMJ and CMJL, maximum force exerted by the limbs in the landing phase of jumps, and the relative RFD and stiffness of the limbs during CMJ and CMJL movements. From the correlational analysis, the following findings emerged:

- During the SJ and CMJL, the injured limb exhibited significantly lower concentric strength compared to the healthy limb, with p-values of 0,006 for SJ and 0,026 for CMJL. However, this difference was not significant when compared with the concentric force of the CMJ (p=0,458).
- Concentric strength expressed by the injured limb was significantly lower in SJ compared to CMJ (p=0,005) and also compared to CMJL (p=0,001). There was no statistical significance when comparing both limbs between CMJ and CMJL (p=0,561 for the injured limb and p=0,149 for the non-operated limb). Similarly, the non-operated limb did not show statistical significance in SJ and CMJ movements (p=0,096).
- The RFD expressed by the two lower limbs in the concentric phase and landing phase of SJ were significantly different, with the operated limb showing lower values. The respective p-values were 0,005 and 0,014. However, the same parameters were not significant in CMJ and CMJL.
- The force exerted by both limbs in the landing phase of SJ was significantly lower in the injured limb compared to the healthy one (p=0,016), while there was no significant difference in CMJ and CMJL.
- Finally, no statistical correlation was found for concentric strength in CMJ, eccentric strength in CMJ and CMJL, RFD in the concentric and eccentric phases of CMJ and CMJL, as well as the force expressed in the landing phase and stiffness in CMJ and CMJL. (See Table 6).

5. DISCUSSION

Fractures of the tibial plateau are considered a risk factor for the development of post-traumatic arthritis, which is observed in 9%-44% of patients. Given that the majority of patients who experience these injuries are active, the incidence of arthritis significantly impacts their quality of life, return to work, and sports participation [1]. In fact, less than one in five patients return to pre-injury activity levels, often experiencing persistent pain, joint stiffness, instability, and fear of reinjury [39]. It has been shown that approximately 45% of individuals who have sustained a tibial plateau fracture with joint involvement may develop secondary post-traumatic arthritis, and 10-20% of these patients may require prosthetic reconstruction in the future [42]. For example, Robertson and colleagues, in their review, stated that the return-to-sport rate after tibial plateau fractures is significantly lower compared to other injuries, and in another study, Kraus and colleagues found a significant decrease in sports activity in these patients two years after surgical treatment [8]. It is noteworthy that, although none of the patients in our recruited population have undergone knee replacement surgery, Wasserstain and colleagues noted that 10 years after the operation, 7,3% of patients underwent total knee replacement, which is 5,3 times higher than the healthy population [13].

In this context, an experimental study was conducted to investigate several aspects: the subjective perception and quality of life related to the condition, the potential presence of asymmetries in active mobility (AROM), maximum strength, power, static and dynamic stability, and rate of force development (RFD) between the operated tibial plateau and the non-operated side in the long term. Furthermore, with the advancement of technology and its ability to provide objective data, the study allows for an inquiry into the possible involvement of fascial structures in the execution of functional jumping movements that utilize only the lower limbs, as opposed to those involving the upper limbs. Finally, the data collected also enable hypotheses and investigations into the potential functions allowed by fascial tissue in the operated limb compared to the non-operated limb.

Therefore, at an average follow-up time of 9,10 ± 2,33 years, follow-up visits were conducted on patients who had undergone tibial plateau fracture surgery. A total of 28 individuals with an average age of 54,89 ± 8,89 years were evaluated, and they took an average of 9,71 ± 8,12 months to return to activity levels similar to those before the injury showing a similar timeframe as reported in the literature by Biz C. in 2019, Ilipoulos E. in 2020 and Alves D.P.L. in 2020 [1,8,10]. Subjective assessments yielded average scores of: 3,43% ± 1,17 for the Tegner Score, 83,25% ± 23,61 for the Lysholm Score, 0,68 ± 1,52 for the NPRS, 85,53% ± 23,78 for the AKSS, 77,62% ± 23,80 for the KOOS-I, 74,10% ± 18,00 for the IKDC, and 80,94% ± 17,44 for the SF-36. These results, compared to those found in the literature [14,15,16,18,20], indicate that, on average, patients achieved good-to-acceptable scores in the evaluation using the Lysholm Knee Scoring Scale, which falls within the range of 65-94 and a good-to-excellent condition according to the American Knee Society Score (the mean score falls within the range of 70-100). Additionally, according to the Tegner Activity Scale, they achieved a mean score within the range that allows for physical activities like swimming and recreational walking.

In the clinical examination, none of the patients showed significant positive findings in the Valgo Stress Test and Posterior Drawer Test. Only one patient reported peripheral vascular nerve deficits following the surgery, experiencing reduced tactile sensitivity and hypoesthesia in the fourth and fifth rays of the operated foot. Moreover, tests assessing the integrity of capsular and meniscal structures showed more positive results: four patients testing positive on the Apley Test, five on the McMurray Test and six during meniscal palpation. Statistical analysis revealed that only the Varo Stress Test exhibited statistically significant positivity with a p-value of 0,020, indicating a higher likelihood of lateral collateral ligament involvement in patients with tibial plateau fractures compared to the medial collateral ligament, cruciate ligaments, and meniscal structures.

Among the evaluated patients, one individual was unable to perform the required tests for SJ, CMJ, and CMJL but succeeded in the SLS, while another was unable to perform the SLS but completed the other tests. Both individuals were evaluated using a digital dynamometer.

From the assessments conducted with the dynamometer, a statistically significant difference emerged in the strength expressed during knee flexion (p=0,001) and extension (p=0,034). This indicates that the operated limb is weaker in terms of extensor and flexor muscle strength. Furthermore, the same limb exhibited a highly significant difference in terms of AROM: the operated knee showed reduced mobility in both flexion (p=0,000) and extension (p=0,009) compared to the healthy contralateral limb. Additionally, when examining the data presented in Table 3, it is possible to observe that RFD expressed during flexion and extension movements, as evaluated with the dynamometer, was lower in the operated limb compared to the healthy limb but not statistically significant. This suggests that in the studied population, this data may not have statistical relevance but does not rule out the possibility that it may be limited by the small number of patients in the study.

The statistical analysis conducted for the tests performed on force platforms revealed that patients did not exhibit statistically significant asymmetries in terms of average excursion and average velocity of center of mass projection during the examination where they were required to maintain balance on one leg for fifteen seconds. However, it should be noted that this data may be influenced by limb dominance.

Continuing the analysis of the collected data and comparing the heights reached in different jumps, it can be concluded that, on average, patients experienced an increase in jump height showing consistency with what has been reported in the literature by Labban W. in 2021 and Heisman A.D. in 2020 [81,103]. The mean height reached in the SJ was 10,30 ± 4,63, in the CMJ it was 11,54 ± 5,14 and in the CMJL it was 14,47 ± 6,17. However, it is important to note that the comparison between the heights achieved in the SJ and CMJ (p=0,673) and between the CMJ and CMJL (p=0,116) was not statistically significant, while the comparison between SJ and CMJL was significant (p=0,015). Furthermore, there was a significant increase in concentric force impulse between SJ and CMJ

(p=0,036) and SJ and CMJL (p=0,027). This was not the case when comparing concentric and eccentric force in CMJ and CMJL, where p-values were (p=0,994) and (p=0,614), respectively.
In conclusion, it can be observed that the evaluations performed with the dynamometer and force platforms led to data that are not easily interpretable. RFD calculated for each limb, through the dynamometer and CMJ and CMJL tests, indicates that there is no statistical correlation suggesting an asymmetric difference. However, this value is statistically significant when calculated for the SJ. Additionally, a highly significant difference was identified in terms of concentric force expressed by the two limbs when assessed with the dynamometer, SJ, and CMJL, but not in the CMJ. Similarly, there was no difference in eccentric force expressed during CMJ and CMJL movements.
As previously explained, the SJ is a movement that does not involve the stretch-shortening cycle (SSC), meaning it does not require the function of the muscle-tendon junction. From the data, it can be observed that the RFD relative to the SJ has a statistically significant value, indicating that the operated lower limb may be deficient in all variables influencing RFD, including 1) the inability of the primary motor cortex to generate an output signal in a short period of time, 2) inefficiency in the synergistic activation of muscles used in the specific movement, 3) muscle structure in terms of size, volume, distribution, pennation, and fiber length, 4) muscle architecture, as it has been demonstrated that muscle structures predominantly composed of type II fast-twitch (white) fibers allow for a higher RFD expression, and 5) elements that can significantly affect muscle force and stiffness, such as the muscle-tendon junction and fascial structures as explained by Maffiuletti in 2016 [94]. So considering what was explained by Huijing P.A in the chapter "Force Transmission" in the second edition of "Fascia: The Network of the Human Body" [99,100], that the myofascial structure is responsible for the transmission of forces in parallel, allowing for massive recruitment of motor units, that fascia permits the epimuscolar transmission between synergistic muscle and the fact that RFD consists of the ability to recruit these units massively rather than quickly (Maffiuletti 2016 [94]).
In CMJ and CMJL, the phenomenon of the SSC is observable, meaning that the movement involves the participation of local and global myofascial and tendinous structures, including the thoracolumbar fascia in CMJL. In these cases, no significant asymmetry was identified between the lower limbs, except for a significant difference in concentric force expression in CMJL, indicating greater weakness in the operated limb (p=0,026).
In summary, the evaluations conducted with the dynamometer and force platforms yielded data that are not easily interpreted. The RFD value didn’t show significant difference between the limbs when measured with the dynamometer and when evaluating global movements, such as CMJ and CMJL. However, it exhibited statistically significant differences in the SJ. This difference may be masked,

because the global movements involve myofascial and tendinous structures at both local and global levels and that whit the dynamometer is difficult to get a contraction as quickly as possible. Finally, it is logically reasonable to hypothesize that fascial structures may be strongly involved in increasing the RFD value and that in the population studied it's not possible to exclude that fascial structures are directly involved in the operated limb compared to the contralateral limb.

Considering the data and hypotheses put forth by this study, future research should be aimed at understanding the underlying biological mechanisms behind RFD, its involvement in people who undergo surgery for TPF and what's the involvement of fascia during actions that involve the combination of movements of the upper and lower limbs.

6. LIMITATIONS AND STRENGHTS OF THE STUDY

Among the limitations of this study, we can include the fact that subjective assessment scales in English (Tegner, AKSS and IKDC) were translated in Italian by the clinician during administration and that the clinical evaluation with the dynamometer was conducted and that the assessment using the dynamometer, although standardized, was conducted and repeated in case of an error, as observed by the clinician. On the other hand, the strengths of the study include its originality, as there are no existing studies in the literature that have investigated potential differences between the two limbs of a person operated on for TPF using a dynamometer and force platforms, the originality of the tests used in the force plate assessment and the hypotheses proposed by the study regarding the fascial involvement in the development of RFD.

7. CONCLUSIONS

In conclusion, it can be stated that:

1) In the long term, the patients in this study showed statistically significant asymmetries in terms of strength and AROM between the two lower limbs but didn't showed difference in terms of static and dynamic stability.
2) These findings also revealed an increase in jump height in CMJL compared to CMJ, potentially providing support for fascial theories underlying biomechanical function.
3) Ultimately, in light of the new knowledge regarding the role of fascial tissue, it cannot be excluded that the role of fascial tissue is directly involved in the operated limb compared to the contralateral limb.

However, further research is needed in this direction to better understand the underlying biological mechanisms behind what clinical observations has shown us.

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