Examining Various Graft Substrates and Their Clinical Evidence in the Treatment of Tibial Plateau Fractures

Timothy R. Niedzielak[1,*], Michael Downing[2], Alexander Ting[2], Charles De la Rosa[2], Joshua Berko[2] and Nicholas Lampasona[2]

[1]*Orthopedic Surgery Resident Physician, Broward Health Medical Center, Department of Orthopedic Surgery, 1600 S. Andrews Avenue – GME, 3rd floor West Wing, Fort Lauderdale, Florida, USA 33316*

[2]*Nova Southeastern University College of Osteopathic Medicine, Fort Lauderdale, Florida, USA*

Abstract: Tibial plateau fractures (TPF) are complex injuries of the tibia that involve the articular surface and commonly have depression of subchondral and metaphyseal bone. Common sequelae of this injury include arthritis and gait disturbances. A popular surgical strategy for this fracture calls for elevation of subchondral bone to restore the joint line, in turn leaving a metaphyseal bone void; this is then commonly secured with plates and screws. Autologous bone has been the gold-standard graft option to fill these voids, but other filling agents such as allografts, biologic grafts, and xenografts are gaining popularity TPF surgery. This is because bone graft substitutes provide predictable outcomes in the treatment of TPF and avoid complications such as donor site pain, infection, increased blood loss, and increased operative time that is seen with autografts. This review explores the benefits, complications, and outcomes of clinically researched graft substrates used for TPF reconstruction. Secondarily, we aim to find potential graft candidates for future clinical research that will progress the treatment of TPF. Internet searches with specific keywords were conducted on different journal databases to find clinically researched graft options in the treatment of TPF within the last 10 years. Multiple studies of various bone graft substitutes achieved similar, if not better results than autologous bone grafts in the treatment of TPF. A summary of each clinically researched graft in this review can be found in Table **1**. Establishing a graft selection protocol remains a challenge for fracture surgeons, as well as choosing the best graft material. Future studies should aim to establish a superior graft substrate based clinical outcomes, while minimizing the cost and morbidity to the patient.

Keywords: Allograft, Autograft, Biologics, Calcium Hydroxyapatite, DBM, Synthetics, Xenograft.

INTRODUCTION

The tibial plateau is a quintessential component of the knee joint as it absorbs and distributes axial forces translated from the lower leg. Tibial plateau fractures (TPFs) are intra-articular injuries of the proximal tibia at the level of the knee joint classically described using the Schatzker Classification system. This classification system simplifies the 2 column concept into a roman numeral system, providing a standardized representation of complex fracture lines. These simplifications include one column shearing fractures (Schatzker I and II), zero column depression fractures (Schatzker III), medial column condylar fractures (Schatzker IV) as well as bicondylar fractures (Schatzker V and VI) [1]. The outcome goals for all periarticular fractures abide by the basic tenets of the AO, which in summary calls for restoration of the joint line with internal stable fixation to allow for early and functional range of motion (ROM). Major indications for surgery include a step-off of more than 2mm at the articular surface, 1cm of translational displacement at the fracture site or 10 degrees of varus/valgus angulation in the sagittal plane across the fracture site [1]. Historically, 99% of TFPs have an associated soft tissue injury; 81% were found to have a lateral meniscus injury and 77% with a concomitant complete ACL tear [1]. Given the complexity of TPFs, adequate assessment with X-ray, CT and/or MRI is essential in choosing the appropriate treatment plan. Potential complications of this injury include compartment syndrome, post-traumatic arthritis, and gait disturbances [1].

As previously noted, the main goal of surgery with these fractures is restoration of the joint line with and stable fixation to hold the reduction. This can be achieved via numerous surgical fragment-specific approaches. Nevertheless, in cases where there is articular depression, elevation of this subchondral bone often leaves a metaphyseal void. This void requires structural support to prevent postoperative collapse [1]. There are several substrates available for the elevation of depressed tibial plateau fractures: autografts, allografts, and xenografts. Each graft fosters bone healing properties through various osteogenic,

*Address correspondence to this author at the Orthopedic Surgery Resident Physician, Broward Health Medical Center, Department of Orthopedic Surgery, 1600 S. Andrews Avenue – GME, 3rd floor West Wing, Fort Lauderdale, Florida, USA 33316;
Tel: (773)218-1132 (c) and (954)712-2996 (f);
E-mail: TimothyNiedzielak@gmail.com

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osteoinductive and osteoconductive mechanisms. This study aims to compare the benefits, complications, and outcomes of all graft substrates used for TPF reconstruction.

MATERIALS AND METHODS

A systematic database search was performed using a combination of specific keywords, which was always preceded by “Tibial Plateau Fracture”. This was followed by another keyword depending on the graft being examined. These keywords included: “autograft;” “allograft;” “synthetic grafts;” “calcium hydroxyapatite;” “biologics;” “DBM;” and “xenograft.” For example, a search for synthetic grafts was done by inputting “tibial plateau fractures synthetic graft.” The search was repeated with these word combinations across 3 separate databases: PubMed, Mendeley, and Google Scholar. Inclusion criteria included graft substitutes directly relating to tibial plateau fracture treatment. Only abstracts and full-text articles published after 2005 were included to review the most current treatment strategies. Articles that were found to report on any fracture other than TPF were excluded. Studies that used animal subjects were also excluded.

RESULTS

This systematic review yielded 221 abstracts. 103 abstracts were found to discuss fractures other than the tibial plateau and were thus excluded. 48 studies included animal subjects in the article and were excluded. This left 70 articles for full-text review. After full-text review, 27 articles were included for data analysis.

Autografts

Autografts are recognized as the gold standard for use in tibial plateau fractures. Autologous bone promotes bone healing properties in fractures and provides scaffolding support for TPF reconstructive surgery. It exhibits three properties: osteogenesis, osteoinduction, and osteoconduction. The iliac crest is the most common autologous harvested site for reconstructive orthopaedic surgery as it can provide both cancellous and cortical grafts that provide superior osteoconduction and structural support, respectively [2]. Another benefit of autologous bone grafting is that it is not immunogenic, offering more predictability than alternative graft options. Potential complications of autograft harvesting include donor site pain, infection, increased blood loss and increased operative time. In a retrospective review of iliac crest bone graft procedures, major complications included chronic postoperative donor site pain, hematoma, neurological injuries, fractures, and superficial skin infections [2].

A retrospective study done in Greece by N.K. Sferopoulos compared 18 patients with TPF treated with open reduction and internal fixation (ORIF) and autografts taken from the ipsilateral femoral condyle versus 17 patients with TPF treated with ORIF and allografts. This study found a shorter average time to bone union in the autograft group compared to the allograft group (14 weeks vs 18 weeks). The autograft group only required an average of an additional 5 minutes of operative time, while also encompassing a lower average cost than the allograft group (1,276 euros vs 2,978 euros) [3]. This study demonstrates ipsilateral femoral condyle autologous grafts are an acceptable alternative option to the traditional iliac crest autograft for TPF repair.

A study by Mohammed *et al* compared autografts harvested from the contralateral proximal tibia with autografts taken from the iliac crest in the treatment of depressed tibial plateau fractures. 16 patients received the iliac crest graft, while 18 received the contralateral proximal tibia graft. No differences in time of healing (14 weeks) or functional knee score was recorded between groups [4].

Allografts

Allograft is an adequate alternative for bone substitution in the treatment of TPFs. It involves harvesting and processing cadaveric bone to reduce disease transmission and immunogenic properties. Processing involves the debridement of the soft tissue, using ethanol to remove viable cells that could possibly mount an immunologic response and gamma radiation to sterilize bacteria and viruses [5]. Allografts lack the osteogenic properties that autografts provide due to the irradiation of cells during graft processing, making them less attractive than autografts. They do however maintain osteoconductive and osteoinductive properties.

Types of allografts include fresh allograft, frozen allogeneic spongy bone graft, and freeze-dried cancellous allograft. Fresh and frozen allografts provide osteoinductive properties. Fresh allograft is rarely utilized today for TPF reconstruction, due to an increased risk of disease transmission and immunogenicity. Frozen allograft is less immunogenic than fresh allograft, but more immunogenic than the freeze-dried alternative. Graft screening procedures evaluate for evidence of HIV, HBV, HCV, HTLV-1, and syphilis [6]. Freeze-dried allograft is the least immunogenic and has the lowest likelihood of adverse viral transmission among the subtypes of allografts. As the bone morphogenetic proteins are depleted, freeze dried allograft is purely osteoconductive [7].

One study compared autografts and allografts in arthroscopic treatment of TPF. 58 patients received freeze-dried cortico-cancellous allograft and 23 patients received autogenous bone grafts. Clinical and radiological assessment was performed using the modified Rasmussen clinical criteria. The mean clinical score for autograft and allograft was 18.65 and 18.55 respectively, both of which are deemed “excellent” per this criteria. The mean radiological score of the autograft and allograft was 15.65 and 15.68 respectively, also considered “excellent.” These results show no statistically significant difference between the allograft and autograft groups. Complication rates were also equivocal: two infections in the allograft group, one infection in the autograft group, with articular surface collapse seen in one patient in each group [8].

Another study examined 22 patients with TPF and treatment with deep frozen and irradiated bone allograft. The Rasmussen score system was used for clinical evaluation during follow-up, and radiographic evaluation was examined at 1-, 3-, 6-, and 12 month post-op encounters. The Rasmussen score was “excellent” or “good” in 88.9% of cases. Radiographic evaluation showed 20 of the 22 bone allografts well incorporated into host bone, while 2 grafts exhibited resorption. One complication of infection was noted during the study [9].

Veitch *et al.* used morselized bone grafting with fresh-frozen allograft for the treatment of TPF on a series of 8 patients. Reduced tibial plateau height was maintained to less than a 2mm depression or “excellent” in 7/8 patients. Complications reported in this study included 1 patient with decreased knee ROM at 3 months post-op and 1 patient with painless valgus deformity requiring corrective osteotomy at 15 months post-op [10].

In a 2017 study, Gracitelli *et al*. examined osteochondral allograft in fractures about the knee. Of the 39 total fractures, 29 patients sustained a TPF. A sub-group analysis for these 29 patients showed that 13 of them had additional surgery; 6 of these 13 were due to osteochondral allograft failure. Of the 23 that had the allograft in-situ at the latest follow up, the Modified Merle d’Aubigne and Postel assessment showed statistically significant improvement postoperatively [11].

Berkes *et al.* conducted a retrospective study comparing 77 Schatzker Type II TPF treated with ORIF and one of two structural bone allografts. 29 patients received Plexur P Allograft (*Medtronic, Minneapolis, MN)*, while 48 received a fibular allograft. No patients experienced postoperative tibial plateau depression of > 2mm, which showed statistical significance when analyzed against previously published rates for autogenous iliac crest (30.3%, $P < 0.0001$) and calcium phosphate cement (8.7%, $P= 0.0099$). Complications in this population included fracture malreduction in 9 of the 77 patients. No significant differences were found between Plexur P and the fibular allograft [12].

Biologics

Demineralized bone matrix (DBM) has become increasingly popular in orthopaedics. Its use currently comprises 50% of all allografts used in the United States [13]. DBM can be applied as an allogenic additive for autografts in axial, appendicular, and craniofacial surgical procedures [14]. DBM has osteoinductive and osteoconductive properties and consists of an acid-extracted organic matrix that accelerates and facilitates osteogenesis. DBM works synergistically to enhance the therapeutic effects of autografts and allografts. The origin for all DBM clinical products is bone from a cadaveric donor, which undergoes processing to eliminate viable cells and potential infectious agents. There is a paucity of sound evidence in regards to the use and indications of DBM in tibial plateau fractures, though its application seems relevant. Newman *et al.* examined the results of ORIF augmented with a mixture of DBM and corticocancellous allograft chips in 41 patients that had tibial plateau fractures with bone loss. During follow-up, all fractures achieved bony union at an average time of 4.4 months. Subsidence occurred in 4 patients, ranging from 2.5 to 5.7mm. A single complication of osteomyelitis was reported in 1 patient. Overall, this study reports that a DBM corticocancellous mixture provides sufficient structural support and that DBM provides a safe and efficacious option in the treatment of tibial plateau fractures [15]. Nota *et al.* reported a complex TPF treated with ORIF and DBM application at the tibial plateau which may have lead to heterotopic ossification of Hoffa’s fat pad and the patellar tendon; this HO subsequently required surgical excision. This relationship of DBM and heterotopic ossification has not been firmly established. More data is needed regarding the use and applications of DBM in TPFs [16].

Synthetics

Synthetic graft substrates include porous metals, synthetic polymers (*i.e*., hydroxyapatite), and calcium phosphates/sulphate/carbonates. These compounds have also been examined for use in TPF treatment. A meta-analysis by Goff *et al.* found that synthetic substitutes demonstrated less secondary articular collapse as compared to biologics: 70 cases vs. 414 cases, respectively [17].

A prospective study by Iundusi *et al*. examined 24 patients with TPFs treated with ORIF and CERAMENT (*Bonesupport*, Lund, Sweden). CERAMENT is an injectable biphasic bone substitute consisting of a hydroxyapatite and calcium sulfate. Patients were followed for 3 years, with an average follow-up of 44 months. Radiographic evaluation showed satisfactory joint alignment. Rasmussen knee function score had an average of 26.5 (14 patients deemed excellent results and 10 with good results) [18]. Hofmann *et al*. completed a prospective and randomized study comparing CERAMENT with autologous grafting in 135 patients with acute depression and split-depression fractures of the proximal part of the tibia across 20 hospitals in Germany. There was significant reduction of blood loss and pain levels at postoperative day 1 in the CERAMENT group. Short Form-12 version 2 Physical Component Summary (SF-12 PCS) and visual analog scale (VAS) scores were examined and demonstrated no significant differences in either metric at 26 weeks post-op. There were no significant differences in rates of fracture healing, defect remodeling, and articular subsidence. This study demonstrates Level 1 evidence that CERAMENT produces non-inferior results to autologous bone graft in the treatment of TPF [19].

Zhou *et al.* investigated the use of MIIG (*Wright Medical Technology*, Arlington, TN), which is a biodegradable calcium sulfate cement. This bone graft substitute was used in 85 patients with periarticular fractures, including 36 TPF. All fractures went on to fracture union with no reports of infection. Joint function was deemed excellent or good based on the corresponding functional score system. Two patients with TPF demonstrated articular subsidence of 2mm at 1-year follow-up. It was concluded that biodegradable calcium sulfate cement shows high compressive strength and provides stability for periarticular fracture reduction [20].

One clinical study examined TPF stability and functional outcome between autografts, allografts, and synthetic bone grafts during ORIF. 14 patients received hydroxyapatite calcium carbonate synthetic bone graft and 10 patients received allograft or autograft. No significant statistical differences were found in articular reduction, long-term subsidence, and WOMAC scores. Knee flexion was better in the allograft/autograft group, which was attributed to reduced inflammatory response of the allograft/autograft compared to the synthetic bone composites [21].

Hanke *et al.* conducted a long-term study of 52 patients undergoing ORIF using one of two calcium phosphate synthetic bone graft products: ChronOS and NorianSRS (both *Depuy Synthes*, Oberdorf, Switzerland). Radiographic assessment demonstrated that ChronOS completely resorbed in a homogenous pattern at 8.6±0.9 years post-op, while Norian-SRS was still visible on imaging in a peripheral resorption pattern at 11.6±1.4 years post-op. Complications included 2 patients from each group with loss of reduction (>2mm). The authors concluded that ChronOS showed comprehensive long-term resorption compared to that of Norian-SRS, but both products provided adequate support in the surgical treatment of TPF [22]. Another study examined calcium phosphate cement (CPC) in the treatment of 28 patients with depression-type TPF. Union was achieved in all patients at an average follow-up of 22.2 months. Radiographs showed resorption of the graft in 25 of 28 knees. Rassmussen radiologic score was excellent in 17 patients, good in 9, and fair in 2. Rassmussen clinical score was excellent in 9 patients, good in 18, and fair in 1. The Lysholm knee score, which evaluates knee functionality, showed excellent results in 16 patients, good in 8, and fair in 4 [23]. In another clinical trial of calcium phosphate cement (CPC), 42 patients with TPF were treated with ORIF and CPC. 34 of the 42 patients underwent a subsequent ORIF to collect bone samples from their first surgery (ORIF+CPC) for histology comparison to their second surgery. Bone cell counts were significantly higher in samples obtained from the second surgery and bone healing scores significantly increased with time after surgery. The histology samples from the second surgery revealed well-arranged trabeculae, along with new bone and blood vessel formation [24].

A prospective randomized 11-year follow-up study by Pernaa *et al.* compared bioactive glass S53P4 (BAG) as a bone graft substitute to autologous bone grafts in the treatment of TPF. 5 patients in the BAG group and 10 patients in the autologous graft group followed up 11 years after their surgery. The articular depression at follow up was the same (1.4mm) for each group. No significant differences were found in the tibial-femoral angle and no deviation of mechanical axes were found between the groups [25]. Another prospective *bioactive glass* substitute for the treatment of lateral TPF was conducted by Heikkila *et al*. 14 patients received the bioactive glass, and 11 patients received the autogenous bone graft. Postoperative subsidence for both groups was equivocal (1mm at 3 months and unchanged at 12 months), and no differences were identified in the subjective, functional, and clinical evaluations at the 1-year follow-up [26].

A randomized clinical trial compared porous titanium granules as a graft substrate and autograft bone in 20 patients with depressed fractures of the lateral tibial plateau (Schatzker II or III). The two main outcome measures were risk of recurrent depression of the joint and duration of surgery. The risk for depression was lower and operation time was less in those treated with the titanium granules, both of these were statistically significant findings [27].

Xenografts

Xenograft is a type of bone/skin graft that takes material from a donor of another species. The disadvantage of xenografts is that there is a delay in osteo-integration and requires careful chemical processing and sterilization to reduce their antigenicity. The chemical processes include: delipidation, hyperosmotic saline bath, oxidative treatment, acetone wash, and low gamma irradiation. These processes reduce the osteoinductive potentials [5]. A retrospective study by Bansal *et al.* evaluated the efficacy of xenograft substitutes in improving the outcomes of geriatric patients (age above 65) with proximal TPF that had poor predicted outcomes. 19 patients (9 females and 10 males) aged 63-86 underwent operative management of tibial plateau fracture with bovine cancellous xenograft [28]. Each patient was assessed for their pain scale, walking distance, and range of knee motion and stability to evaluate the success of the graft incorporation. Postoperative encounters were performed at 1.5-, 3-, 6-, and 12-months from the date of surgery. There was excellent incorporation (about 95%) of the xenograft at an average of 5 months. No reports of infection were reported and all patients had favorable clinical and radiological outcomes. Researchers discovered that these xenogenous tissues provide osteoconductive potential and act as a scaffold for the subchondral bone of the tibial articular surface [5]. In addition, it was reported that the use of xenograft correlated with reduced operative time and reduced vascular complications associated with elderly populations aged 65 and older.

A study by Li *et al.* evaluated a novel surgical technique involving titanium cage packing with xenograft DBM bovine augmentation in the treatment of subchondral bone defects associated with TPF. 18 patients were followed for an average of 18.1 months. Radiographic evidence of bony union was achieved at an average of 12.8 weeks and full weight-bearing was at a mean of 12.4 weeks. All 18 cases had satisfactory reduction and no secondary loss of reduction occurred. Superficial infection was noted in one case, but no implant failures occurred [29].

In a cohort retrospective study, Ferracini *et al.* recorded clinical and radiological outcomes of TPF in patients treated with a composited xenohybrid bone graft. 34 patients were evaluated with VAS and physical exam at each follow-up, and Tegner Lyshold Scoring Scale (TLSS), SF-36, and IKDC at the 1-year follow-up. VAS scores significantly decreased (6.33 ± 1.40 to 1 ± 0.79). TLSS was 89 ± 4.10, IKDC was 78.67 ± 3.31. Secondary complications such as infection or neurovascular issues related to the implants were not seen. Radiographs showed a "good" grade of integration of the implant. This study demonstrates that xenograft has the qualities of a safe and efficacious biomaterial with good osteointegration and remodeling in the setting of TPF [30].

DISCUSSION

Many alternative grafting agents are available for augmenting tibial plateau fracture fixation. A majority of these have clinical data to support their use, but autologous bone graft still remains the gold-standard treatment option. In their 2013 meta-analysis of various graft treatments utilized in TPFs, Goff *et al.* concluded that there is arguably sufficient evidence supporting the use of bone graft substitutes [17]. They also stated that a trend towards using synthetic graft compounds was evident during their review. Supporting their findings, this review demonstrates more recent clinical research regarding bone graft substitutes that have demonstrated success in the treatment of TPF. Two challenges that remain for surgeons: choosing the best type of graft substitute and the best brand-specific product within that substitute category. Future studies should aim to generate Level 1 evidence comparing different graft substrates in the treatment of TPF to further establish treatment guidelines based on product

Table 1: Summary of Bone Graft Options Utilized in the Treatment of Tibial Plateau Fractures and their Clinical Evidence

Study	Graft Type	N	Study Type	Author's Findings
Sferopoulos *et al.* [3]	Autograft	35	Retrospective	-Ipsilateral femoral condyle autograft exhibits shorter time to union -Significantly shorter operative time by average of 5 minutes -Cheaper option than allograft
Mohammed *et al.* [4]	Autograft	34	Prospective	-Contralateral proximal tibia autografts showed complete union -Similar functional knee score compared to iliac crest autograft
Bagherifard *et al.* [8]	Freeze-dried Allograft	81	Prospective Randomized	-Freeze-Dried allograft (n=58) showed excellent results in clinical and radiologic scores -Minimal complications -Comparable results to autograft (n=23)
Feng *et al.* [9]	Frozen Allograft	22	Prospective	-Excellent or Good Rasmussen Score in 88.9% of pts -20/22 patients incorporated & healed -2/22 patients exhibited resorption
Veitch *et al.* [10]	Fresh-Frozen Allograft	6	Prospective	-Plateau heights were maintained in 5 of 6 pts at follow up. -Complications: 1 case of knee stiffness at 3 months; valgus deformity requiring osteotomy at 15 months post-op
Gracitelli *et al.* [11]	Osteochondral Allograft	29	Prospective	-6/29 patients failed union -23/29 had statistically significant improvement of IKDC function/total score, and KSF score
Berkes *et al.* [12]	Plexur P & Fibular Allograft	77	Retrospective	-No patients experienced depression > 2mm = Statistically sig. when compared against published rates of autogenous grafts -No significant differences between Plexur P & Fibular allograft
Newman *et al.* [15]	DBM	41	Prospective	-All fractures achieved union -Subsidence in 4 patients -1 patient developed osteomyelitis
Nota *et al.* [16]	DBM	1	Case Study	-DBM potential cause of heterotopic ossification
Iundusi *et al.* [18]	CERAMENT (Hydroxyapatite + Calcium Sulfate)	24	Prospective	-Satisfactory joint alignment in all patients -14 patients excellent & 10 good results based on Rasmussen score.
Hofmann *et al.* [19]	CERAMENT (Hydroxyapatite + Calcium Sulfate)	135	Prospective Randomized	-Healing rates, functional scores, remodeling, and subsidence all comparable to autograft group -CERAMENT showed significant reduction of blood loss & pain levels post-op day 1
Zhou *et al.* [20]	MIIG x3 (Biodegradable Calcium Sulfate Cement)	36	Prospective	-Uneventful healing in all patients -Excellent/good joint function in all patients -2 patients with subsidence, but no joint dysfunction

Ong *et al*. [21]	Hydroxyapatite calcium carbonate	24	Prospective	-No significant differences when compared with allograft/autograft (n=10) for reduction, subsidence, and WOMAC scores -Knee flexion better in allograft/autograft group
Hanke *et al*. [22]	ChronOS & NorianSRS (calcium phosphate)	38	Prospective Randomized	-2 patients for each product had >2mm loss of reduction -ChronOS showed comprehensive long-term resorption compared to NorianSRS -Both products provide adequate structural support for PTF treatment
Ozturkmen *et al*. [23]	Calcium Phosphate	28	Prospective	-Routine time to union achieved in all patients -25/28 showed resorption -Rassmussen clinical/radiological score: excellent in 9, good in 18, fair in 1 / excellent in 17, good in 9, fair in 2
Yin *et al*. [24]	Calcium phosphate	42	Prospective	-Histology showed higher bone cell counts and healing scores at second surgery with new bone and blood vessel formation
Pernaa *et al*. [25]	Bioactive Glass S53P4	15	Prospective	-Articular depression was the same at follow-up when compared to autograft group (n=10)
Heikkilä *et al*. [26]	Bioactive Glass	25	Prospective	-Similar results for bioactive glass (n=14) compared to autograft (n=11) for subjective, functional, and clinical assessments at 1-year follow-up
Jonsson *et al*. [27]	Titanium Granules	20	Prospective Randomized	-Titanium granules showed statistically significantly lower risk of depression and shorter operation time
Bansal *et al*. [28]	Xenograft	19	Retrospective	-Xenografts showed excellent incorporation, reduced operative time & vascular complications while improving TPF that had poor outcomes
Li *et al*. [29]	Xenograft DBM	18	Prospective	-All 18 patients achieved union and satisfactory reduction
Ferracini *et al*. [30]	Xenograft	34	Retrospective	-Radiographs showed good integration -Good scores in TLSS, SF-36, and IKDC, with reduction in VAS from pre-op to post-op

Table 2: Summary of Assessment Tools Mentioned in this Review Article by the Various Clinical Studies Involving Tibial Plateau Fractures and Graft Substrates

Assessment Tool	Purpose	Interpretation
International Knee Documentation Committee (IKDC) Total Score [31]	Symptoms, daily activities, function	Score from 0-100 100 = no symptoms, full function, no limitations with activities of daily living
Knee Society Score [32,33]	Knee Score: Pain, Flexion Contracture, Extension lag, Total Range of Flexion, Alignment, Stability Function Score: Walking, stairs, walking aids	Score from 0-100 <60 = Poor 60-69 = Fair 70-79 = Good 80-100 = Excellent
Tegner Lysholm Knee Scoring Scale [31]	Limp, support, locking, instability, pain, swelling, stairs, squatting; knee ligament surgery	Score from 0-100 <65 = Poor 65-83 = Fair 84-90 = Good >90 = Excellent

Modified Merle d'Aubigne & Postel [34]	Pre and post-op evaluation of Total Hip Arthroplasty (prefixes A: one hip, B: two hips, C: systemic disease, pain, gait, mobility)	Score from 3-18 3 = Worst state of patient 18 = Best state of patient
Rasmussen Radiologic Score [35]	Depression, condylar widening, angulation	28-30 = Excellent 24-27 = Good 20-23 = Fair <20 = Poor
Rasmussen Knee Function Score [36]	Subjective Complaints (pain, walking capacity) and Clinical Signs (extension, ROM, stability)	27+ = Excellent 20-26 = Good 10-25 = Fair 6-9 = Poor
Short Form-12 [37]	Generic measure, does not target a specific age or disease group	Score from 0-100 0= lowest level of health 100 = highest level of health
Short Form-36 [38]	Physical function, role physical, bodily pain, general health, vitality, social functioning, role emotional, mental health	-Higher scores indicate higher levels of health
Visual Analog Scale [39]	Pain	Score from 0-10 0 = No pain 10 = Worst Pain Possible
Western Ontario's and McMaster (WOMAC) Universities Osteoarthritis Index [31,40]	Pain, stiffness, physical function	Pain = 0-20 Stiffness = 0-8 Physical Function = 0-68 High scores = worst state of the patient

performance. This data could serve to help establish a future graft selection protocol, tailored to the needs of patients in the setting of tibial plateau fractures. DBM is a product that has a substantial amount of clinical evidence and success in a variety of orthopedic settings, yet lacks an abundance of evidence in the treatment of tibial plateau fractures.

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