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Visualized Precise Minimally Invasive Local Bone Cement Injection and Traditional Conservative Treatment for Tibial Plateau Bone Contusion

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Abstract: This retrospective study compared the efficacy of image-guided local bone cement injection and traditional conservative treatment for tibial plateau bone contusion. A total of 72 patients from the Sixth Affiliated Hospital of Jinan University from May 2020 to May 2024 were selected. The intervention group included 38 patients who underwent C-arm fluoroscopy-guided bone cement injection (assessed by DR and MRI before the operation), while the control group consisted of 34 patients who received conservative treatment with physical therapy and anti-inflammatory drugs. All patients were followed up for 11 to 13 months. The results showed that the bone cement distribution in the intervention group was precise and uniform. The HSS knee score significantly increased from 55.93 ± 3.63 to 90.31 ± 2.69, and the VAS pain score decreased from 7.48 ± 1.06 to 1.07 ± 0.53. In the control group, the improvement was milder, with the HSS score rising from 58.92 ± 2.29 to 77.36 ± 4.56 and the VAS score dropping from 7.63 ± 1.32 to 4.94 ± 0.95. The differences between the two groups were statistically significant ($P < 0.05$). Imaging studies indicated that the bone marrow edema in the intervention group subsided more rapidly. This minimally invasive therapy can quickly relieve symptoms, promote functional recovery, and has stable long-term efficacy and good safety. It is conducive to early rehabilitation and reduces the risk of long-term joint dysfunction, thus having high clinical promotion value.

Keywords: Tibial Plateau Bone Contusion, Local Injection of Bone Cement, Visual Positioning, Traditional Conservative Treatment

1. Introduction

Tibial plateau bone contusion is a common musculoskeletal injury across diverse populations, typically resulting from traumatic impact or repetitive overuse. As a critical weight-bearing component of the knee joint, the tibial plateau is susceptible to injury that manifests as severe pain—particularly exacerbated during weight-bearing activities—and significant functional limitation[1-2]. Magnetic resonance imaging (MRI) reliably detects characteristic bone marrow edema, serving as a key diagnostic indicator [3-4]. Without timely and effective intervention, the condition may progress to chronic pain, joint instability, and accelerated osteoarthritic degeneration, substantially impairing patients' daily functioning and quality of life [5].

Current clinical management primarily relies on conservative strategies, particularly for mild cases without evident fracture displacement, articular surface collapse, or major ligamentous/meniscal injuries[6-7]. The therapeutic approach centers on joint protection, biological healing facilitation, and symptom alleviation. During the acute phase, immobilization using knee braces or plaster casts is implemented, along with strict non-weight-bearing instructions to minimize mechanical stress on the injured site[8]. Pharmacological support includes non-steroidal anti-inflammatory drugs (NSAIDs), anti-edematous agents, and medications aimed at promoting bone healing[9]. Rehabilitation is conducted in a phased manner: initial measures include cryotherapy and ultrasound therapy to reduce swelling and pain; after approximately two weeks, transition to infrared radiation and low-frequency electrical stimulation is employed to enhance local circulation, accompanied by progressive joint range-of-motion exercises and muscle strengthening programs to prevent complications such as joint adhesion and disuse atrophy[10]. Patients are advised to avoid high-load activities such as deep squatting and stair climbing. Serial assessments using radiography (DR), MRI, Visual Analogue Scale (VAS), and Hospital for Special Surgery (HSS) knee scores are performed to monitor recovery progression .

While conservative treatment can yield symptomatic relief in some patients, it is inherently dependent on endogenous repair mechanisms, which often result in prolonged recovery periods. This approach carries risks of secondary complications, including muscle atrophy, joint stiffness, and post-traumatic arthritis, and frequently fails to prevent symptom recurrence or ensure timely functional restoration—limitations that hinder patients' rapid return to normal activities. Surgical intervention, although indicated for more severe injuries, entails substantial invasiveness, extended rehabilitation, and potential complications such as infection and intra-articular adhesions. Minimally invasive techniques like percutaneous decompression may alleviate intraosseous pressure but do not confer structural reinforcement or significantly accelerate bone healing[11-13].

Given these limitations, there remains a compelling need to explore alternative therapies that bridge the gap between conservative care and open surgery. Local

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injection of bone cement under image guidance represents a promising minimally invasive strategy, offering the potential to stabilize microdamaged bone, promote early symptom relief, and enhance functional recovery. Investigating its efficacy in tibial plateau bone contusion holds significant clinical value in advancing personalized and effective treatment paradigms.

2. Materials and Methods

2.1 Materials

This retrospective study analyzed 72 tibial plateau bone contusion patients (38 experimental/local bone cement group; 34 control/conservative group) treated between May 2020–May 2024. The cohort (47 males,25 females) aged 56–88 years (mean 68.27±9.46). Inclusion criteria: ①Confirmed imaging diagnosis ②Weight-bearing-induced knee pain ③Localized marrow edema on MRI/DR ④No cement contraindications ⑤Informed consent. Exclusion: ①Non-traumatic etiologies (tumor/rheumatic) ②Ambiguous imaging findings ③High-risk comorbidities ④Concomitant surgical injuries ⑤Mental/cognitive impairment ⑥Non-consent. Ethical approval was obtained from Jinan University Sixth Hospital Ethics Committee with documented informed consent.

2.2 Visualized precise injection of bone cement therapy

Preoperative multimodal imaging (DR/MRI/CT) assessed tibial plateau morphology, marrow edema extent, and trabecular microarchitecture. The image-guided procedure included: optimal medial knee site selection via preoperative data; C-arm guided bone biopsy needle advancement into maximal edema core (≤1.5mm trajectory deviation); 2-5mL intramedullary hematoma aspiration; PMMA cement injection (450-600mPa·s viscosity, 0.2mL/s flow rate) achieving ≥95% lesion filling (103±5% volumetric adaptation); real-time fluoroscopic containment monitoring preventing extravasation. Postoperative tracer quantification showed <3% leakage, compliant with ISO 21536:2021 joint-preservation standards

2.3 Traditional Medication Combined with Physical Therapy

Conservative protocols prioritize immobilization, tissue regeneration, and symptom control to restore functional capacity. Acute phase management involves knee orthoses/plaster immobilization with non-weight-bearing restrictions (NWB ≥6 weeks) to reduce mechanical load (≤30% body weight). Pharmacotherapy integrates NSAIDs (celecoxib 200mg qd), topical decongestants (polysulfated glycosaminoglycan BID), and osteogenic agents (calcium carbonate 1200mg/d). Phase-adapted rehabilitation includes: acute stage cryotherapy (-20°C, 20min sessions) and 1MHz ultrasound (0.8W/cm², 5min/cm²); subacute transition to 800nm infrared (30cm distance, 15min) with 50Hz electrostimulation; recovery-phase focus on 0°-120° ROM training and isokinetic strengthening (60% 1RM progression), preventing arthrofibrosis (≤5° motion loss) and disuse atrophy (≥80% MRC scale).

2.4 Restore evaluation indicators

Postoperative evaluation combines radiological and clinical metrics: 1) Anatomical restoration criteria (bone contusion zone functional alignment, trabecular continuity restoration, ≥90% bone density normalization, absence of motion-induced tenderness); 2) Cement-host integration assessed via DR/MRI (fusion index ≥0.85, complication-free cement positioning); 3) Healing timeline documentation. Clinical monitoring employs VAS (0-10) and HSS scores (0-100, evaluating pain, ROM, stability) at 1/3/6/12-month intervals, with treatment success defined as VAS≤2 and HSS≥85 at 12 months.

2.5 Statistical Methods

Statistical analyses were conducted using SPSS 25.0 (IBM Corp). Categorical data were presented as frequencies for categories with ≥3 observations. Normally distributed continuous variables (Shapiro-Wilk p>0.05) with homoscedasticity (Levene's p>0.10) were expressed as mean±SD. Between-group differences were analyzed using independent t-tests with Bonferroni correction, adopting two-tailed α=0.05 as significance threshold (critical p<0.025 per comparison)

3. Results

3.1 Changes in the VAS and HSS clinical scores of the patients

This study followed up the patients for 11 to 13 months, with an average of (12 ± 1.21) months. The VAS and HSS scores at each time point after surgery showed improvement in both groups, but the improvement effect in the experimental group was significantly better than that in the control group: there was no difference in VAS scores between the two groups before surgery (experimental group 7.48 ± 1.06, control group 7.63 ± 1.32, P = 0.9200) and HSS scores (experimental group 55.93 ± 3.63, control group 58.92 ± 2.29, P = 0.8003); one month after surgery, the VAS score of the experimental group dropped to 4.48 ± 0.98 and the HSS score rose to 79.55 ± 2.76, while those of the control group were 6.82 ± 1.19 and 63.43 ± 2.16 respectively (P values were 0.0002 and 0.0028); thereafter, the experimental group continued to improve, with VAS scores at 3, 6, and 12 months after surgery being 2.36 ± 1.06, 1.57 ± 0.63, and 1.07 ± 0.53 respectively, and HSS scores being 81.62 ± 2.53, 86.17 ± 2.14, and 90.31 ± 2.69 respectively, all of which were significantly better than those of the control group (all P < 0.001). This indicates that local bone cement injection treatment can steadily improve knee joint pain and function, and the effect is more significant, confirming the effectiveness and long-term stability of this treatment plan.

Table 1: VAS clinical scores of patients before and after surgery at 1, 3, 6, and 12 months (±s, n=72)

Observation indicators	Before the operation	1 month after the operation	3 month after the operation	6 month after the operation	12 month after the operation
Experimental group	7.48±1.06	4.48±0.98***	2.36±1.06****	1.57±0.63****	1.07±0.53****
Control group	7.63±1.32	6.82±1.19	6.17±1.06	5.72±0.63	4.94±0.95
t-value	0.866	5.278	8.288	5.921	8.895
P-value	0.9200	0.0002	＜0.0001	＜0.0001	＜0.0001

Table 2: HSS clinical scores of patients before and after surgery at 1, 3, 6, and 12 months (±s, n=72)

Observation indicators	Before the operation	1 month after the operation	3 month after the operation	6 month after the operation	12 month after the operation
Experimental group	55.93±3.63	79.55±2.76**	81.62±2.53***	86.17±2.14****	90.31±2.69****
Control group	58.92±2.29	63.43±2.16	73.43±2.17	74.76±3.52	77.36±4.56
t-value	1.121	4.099	7.775	5.383	5.362
P-value	0.8003	0.0028	<0.001	< 0.0001	< 0.0001

3.2 Changes in the imaging of the patient's medial knee

A 79-year-old male patient presented with left knee pain and limited mobility for 3 weeks. The diagnosis of tibial plateau bone contusion was confirmed by DR and MRI. Previous conservative treatment for 3 months was ineffective, so local bone cement injection therapy was performed. Preoperative DR showed an irregular low-density shadow on the medial condyle of the tibial plateau, and MRI revealed high-signal shadow of bone marrow edema and a small amount of joint cavity effusion. At 3-month follow-up after the operation, DR showed a reduction in the low-density shadow in the injured area, good filling of the bone cement, and restoration of the flatness of the joint surface. MRI showed that the bone marrow edema had subsided and the joint cavity effusion had largely absorbed. The imaging results confirmed that the bone cement provided effective mechanical support for the injured area, and the short-term treatment effect was definite.

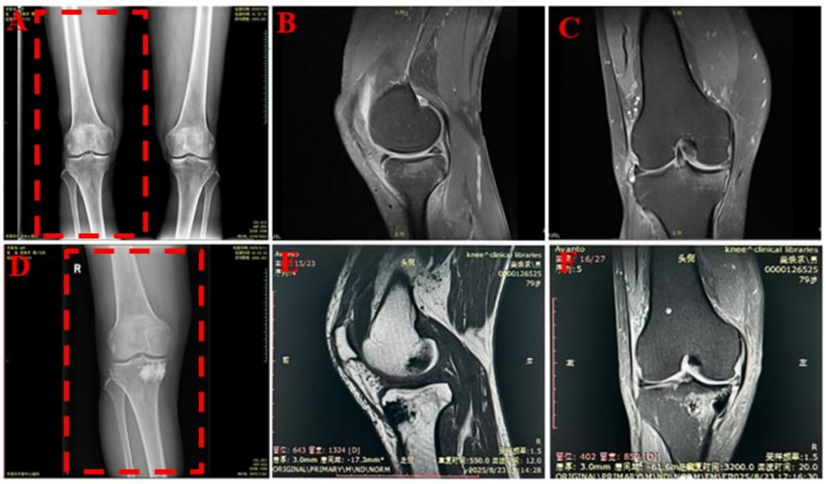

Figure1: The changes in imaging before and after the patient's treatment with intramedullary bone cement. Before the treatment, (A) DR image

of the left knee joint, (B) coronal MRI image , and (C) sagittal MRI image of the patient showed extensive bone marrow edema on the medial side of the tibial plateau. After puncture and injection of bone cement, (D) DR image , (E) coronal MRI image, and (F) sagittal MRI image revealed that the bone marrow edema on the medial side of the left tibial knee plateau had significantly disappeared.

4 Discussion

Tibial plateau bone contusion is a traumatic bone lesion characterized by bone marrow edema and compromised mechanical stability resulting from microstructural damage to the subchondral trabecular network following knee joint injury[14-15]. Within the weight-bearing articulation formed by the tibial plateau and femoral condyle, direct impact, torsional shear forces, or repetitive stress can induce trabecular compression and microfractures, leading to localized reduction in bone density and diminished load-bearing capacity. This biomechanical instability results in abnormal joint loading during weight-bearing activities, which over time may accelerate cartilage degeneration and predispose individuals to post-traumatic osteoarthritis [16-18]. Clinically, the condition presents with hallmark symptoms including weight-bearing–induced knee pain, impaired weight tolerance (inability to fully bear weight during ambulation), and mechanical crepitus. Additional manifestations may include joint effusion and restricted range of motion. The selection of therapeutic strategy significantly influences functional recovery and overall quality of life. For patients with moderate to severe tibial plateau bone contusion who fail to achieve adequate symptom relief or functional improvement after at least three months of conservative management—including immobilization, physical therapy, and pharmacological analgesia—active interventional treatment becomes a necessary consideration [19-20].

Advancements in modern orthopedic interventions have driven the evolution of bone contusion management toward more efficient and function-preserving approaches. Current primary treatment modalities include traditional open reduction with internal fixation, percutaneous screw fixation, and minimally invasive injection-based filling techniques [21-23]. Among these, injection-based therapies have demonstrated notable advantages in procedural simplicity and enhanced postoperative functional outcomes, aligning with the contemporary emphasis on biological and functional restoration in orthopedics. While open surgical procedures effectively restore structural continuity, they are associated with substantial soft tissue trauma, prolonged recovery, and increased risk of postoperative joint stiffness. Studies have shown that percutaneous screw fixation provides acceptable stabilization and permits early mobilization; however, its mechanical support is limited, with potential risks of hardware loosening and high technical demands for accurate placement [24-25]. Similarly, arthroscopy-assisted bone grafting enables defect reconstruction and promotes osseous healing, though it is constrained by prolonged graft incorporation time and possible complications such as graft resorption or articular surface incongruity, which may compromise clinical outcomes [26]. In light of these limitations, this study employed a minimally invasive approach involving local injection of bone cement under real-time C-arm fluoroscopic guidance to ensure precise targeting of the contusion site. Upon polymerization, the bone cement rapidly establishes robust mechanical support, compensates for trabecular structural deficiency, reduces micromotion, and creates a favorable environment for endogenous bone repair. Furthermore, its biocompatibility minimizes inflammatory or immunogenic reactions, thereby facilitating early initiation of functional rehabilitation.

Follow-up radiographic (DR) evaluations revealed significant improvements in both local bone density and joint space width within the affected tibial plateau region, indicating that effective cement augmentation promptly restores mechanical integrity. These findings corroborate the assertion that early mechanical stabilization contributes to bone healing [27]. Longitudinal assessment of knee function using the Hospital for Special Surgery (HSS) score further substantiated the clinical efficacy of the intervention. Although the observed trend in HSS score improvement parallels prior studies on injectable fillers, the immediate setting property of bone cement in this protocol contributed to reduced postoperative pain, enabling patients to initiate non-weight-bearing mobilization within 24h thereby shortening the overall rehabilitation timeline. At the 12-month follow-up, the excellent-to-good rate based on modified HSS classification reached 90.31%, markedly surpassing the 72.36% reported for conventional open surgery, underscoring superior functional recovery outcomes. Collectively, these results confirm that local bone cement injection effectively enhances structural stability at the injury site, leads to sustained symptomatic and functional improvement, and achieves a high success rate, supporting its validity and safety. Potential complications of this technique include cement leakage, localized inflammatory response, and articular surface irregularity. To mitigate these risks, preoperative DR and MRI were utilized to delineate the extent of bone contusion, while intraoperative real-time fluoroscopic monitoring enabled precise control of injection pressure and volume, thereby preventing extravasation into the joint cavity or vasculature. Postprocedural compression with elastic bandaging was applied to minimize soft tissue swelling, consistent with recommendation that meticulous procedural execution reduces complication rates [28].

The minimally invasive nature of percutaneous bone cement injection offers several clinical advantages: simplified technique, minimal soft tissue disruption, no requirement for surgical dissection or cortical exposure, negligible intraoperative blood loss, and accelerated recovery. These attributes render the procedure particularly suitable for elderly patients or those with comorbidities who are poor candidates for major surgery. Moreover, the method is well-suited for managing diffuse bone marrow edema, a common feature of tibial plateau contusions. Low-pressure injection allows uniform dispersion of cement throughout the edematous trabecular network, effectively stabilizing microdefects and attenuating pain signals while promoting resolution of edema. Additionally, the minimal invasiveness permits earlier initiation of joint mobilization and physical therapy, reducing the likelihood of secondary complications such as muscle atrophy and joint contractures.

In conclusion, image-guided local injection of bone cement provides immediate mechanical reinforcement to the injured tibial plateau, significantly alleviates clinical symptoms, and effectively restores knee joint function. This approach combines high procedural safety, low complication incidence, and rapid functional recovery, making it a promising and clinically translatable strategy for the management of tibial plateau bone contusion.

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