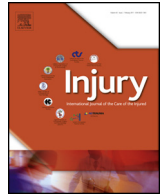




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## Long-term radiographic appearance of calcium-phosphate synthetic bone grafts after surgical treatment of tibial plateau fractures

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### ARTICLE INFO

#### Article history:

Accepted 18 October 2017

#### Keywords:

Tibial plateau fracture  
Synthetic bone graft  
Calcium phosphate  
Hydroxylapatite  
Brushite  
β-TCP  
Resorption  
Norian SRS  
ChronOS inject  
Tegner activity scale  
Lysholm score  
HSS knee score  
X-ray  
Knee joint  
Joint function  
Long-term follow-up  
Rehabilitation

### ABSTRACT

**Objectives:** Synthetic bone grafts (SBGs) are widely used to fill bone defects after fracture reduction. This study assessed the long-term resorption of two different calcium phosphate products (A = ChronOS™ inject and B = Norian® SRS®; both DePuy Synthes, Oberdorf, Switzerland) used in the surgical treatment of tibial plateau fractures.

**Design:** Long-term clinical and radiologic follow-up of 52 patients after surgical treatment of intraarticular tibial plateau fractures augmented with SBGs.

**Setting:** The study was performed at a level 3 trauma center.

**Patients:** Between January 2000 and December 2006 a total of 52 patients with intraarticular tibial plateau fractures were operatively treated and augmented with SBGs consisting of a Brushite matrix with β-TCP granules (SBG A) or hydroxylapatite with 4–6% carbonate content (SBG B). 46 patients could be contacted and 38 were included in the study. Half of the patients received SBG A and the other half SBG B. **Main outcome measurements:** Loss of reduction and SBG resorption was investigated by comparison of follow-up X-ray images to pre- and postoperative X-ray images. Furthermore, pain, activity level and knee function were evaluated by means of questionnaires and clinical examination.

**Results:** The mean age of patients was  $59.7 \pm 12.5$  years. The follow-up was  $8.6 \pm 0.9$  years for SBG A and  $11.6 \pm 1.4$  years for SBG B ( $p < 0.001$ ). In most cases SBG A was completely resorbed in a homogenous pattern, while SBG B was still visible on the X-ray images revealing a peripheral resorption pattern. A loss of reduction ( $>2$  mm) could be observed in two patients with SBG A and two patients with SBG B, although only one of them had an impaired knee function.

**Conclusions:** The composite SBG A reveals a comprehensive long-term resorption in comparison to SBG B. Nevertheless, both provided suitable mechanical support as part of the surgical treatment of tibial plateau fractures.

**Level of evidence:** Case series, Level IV.

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### Introduction

Fractures of the tibial plateau usually involve articular and meta-epiphyseal segments of the proximal tibia [1,2]. Their management can be challenging because of severe depression of the subchondral cancellous bone and concomitant cartilage injury.

Special surgical techniques and implants have been developed to create and maintain anatomical reduction for improved long-term clinical outcome [3].

Various autologous, allogenic or synthetic materials have been proposed to fill osseous defects secondary to compacted cancellous bone and facilitate its augmentation. Currently, synthetic bone grafts (SBGs) are very frequently used [4,5], due to high donor site morbidity after autologous iliac crest bone graft harvesting [6]. A total of 59 different SBGs were commercially available on the market in 2013. Most of them primarily consist of calcium

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phosphates (CaPs) [7] that offer osteoconductivity and structural support. However, they do not have osteoinductive or osteogenic properties [8]. CaPs can be manufactured in many different types of compounds, depending on their phases and application forms. As granules, porous blocks, cements and putties CaPs have different biological and mechanical properties [9]. Combinations of different CaPs are called biphasic CaPs [10,11]. In general, after hardening CaPs have a better biomechanical stability than autologous iliac crest bone grafts. They maintain their initial volume in the early phase of fracture remodeling [12], and therefore may facilitate earlier weight bearing [13]. Compared to autologous iliac crest bone grafts for treatment of depression fractures of the tibial plateau, the synthetic CaPs reveal similar functional results [5,14], however, with a decreased incidence of loss of reduction [15–17].

After implantation, CaPs can either be resorbed or remain stable at the implantation site according to their general solubility, porosity and particle size [18]. These physical and chemical properties influence biodegradation, which takes place actively by cellular mechanisms (macrophages, giant cells, osteoclasts) or passively by dissolution [19]. For example, Brushite ( $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$ ) is resorbed faster than  $\beta$ -tricalcium phosphate ( $\beta$ -TCP,  $\beta$ - $\text{Ca}_3(\text{PO}_4)_2$ ), while apatite ( $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ ) remains principally unchanged and does not dissolve [19,20].

The present study was conducted to assess the long-term resorption of two different CaP synthetic bone graft products used for operative treatment of tibial plateau fractures by comparing their radiographic visibility in a long-term follow-up. Special attention was paid to the extent and pattern of resorption, as well as to the clinical function of the affected knee joints. We hypothesized that the synthetic bone grafts would be fully resorbed and degraded over time.

## Methods

### Ethics statement

The study was approved by the institutional review board. Written informed consent was obtained from every patient in accordance with the declaration of Helsinki.

### Patients

Between January 2000 and December 2006, a total of 172 alpine skiers with intra-articular tibial plateau fractures AO/OTA 41 B1 to B3 and C1 to C3 were operatively treated at a level 3 trauma center (Spital Davos, Davos, Switzerland). All patients were older than 18 years, and the tibial plateau fracture was their most severe injury. A total of 116 patients received synthetic bone grafts (SBGs). Patients residing in Switzerland, Germany or Austria ( $n = 52$ ) were followed (minimum 7 years), while those residing in other countries ( $n = 64$ ) were not included in the study. Six patients were lost to follow-up, leaving 46 patients for inclusion in the present study. Of those included, six patients declined to participate, one patient was treated with two different types of bone grafts, and one – with a total knee arthroplasty in the meantime. Of the remaining 38 patients 19 received SBG type A (ChronOS<sup>TM</sup> Inject, DePuy Synthes, Oberdorf, Switzerland), and 19 received SBG type B (Norian<sup>®</sup> SRS<sup>®</sup>, DePuy Synthes, Oberdorf, Switzerland) (Fig. 1).

### Data acquisition

All eligible patients were seen for a follow-up in the outpatient clinic, where a standardized clinical examination of the affected knee joint was performed. The Tegner Activity Scale [21] was used to determine activity levels, the modified Lysholm Score [22], the

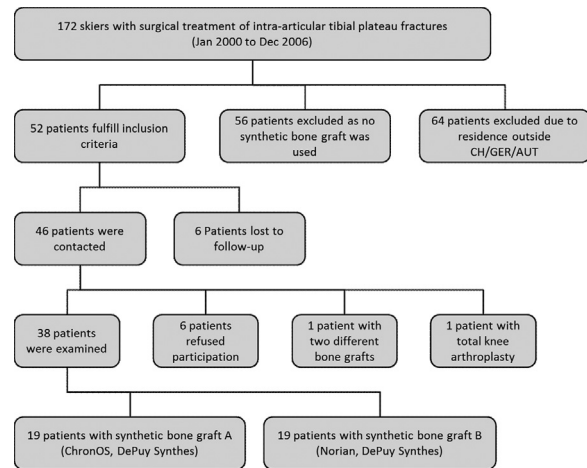


Fig. 1. Patient flow diagram. CH: Switzerland, GER: Germany, AUT: Austria.

HSS Knee Score [23], and the Visual Analog Scale (VAS for pain (0 representing no pain" and 10 representing maximal imaginable pain") were used to determine functional outcome. Plain radiographs of the affected knee joint were taken in two planes (anteroposterior and lateromedial). For comparison, pre- and post-operative x-ray images of the affected knee joint were obtained from the local database.

### Synthetic bone grafts

As part of the operative treatment, the post-reduction bone void was filled with SBG A or SBG B. Both SBGs are based on calcium phosphate and require 3–6 min to settle during an isothermic reaction and show their maximum compressive strength after 24 h, according to the manufacturer's specifications. They have different structures after hardening: SBG A utilizes a brushite matrix (dicalcium phosphate dihydrate) with  $\beta$ -tricalcium phosphate ( $\beta$ -TCP) granules, whereas SBG B consists of hydroxylapatite (HA) with 4–6% carbonate content. The selection of the used SBG was made by surgeons' preference in each individual case.

### Resorption of synthetic bone grafts

The follow-up x-ray images of the affected knee joints were compared with the initial post-operative images with special regard to resorption of used SBGs. The extent of resorption of the graft material, as well as the pattern of resorption were assessed blinded by three trauma surgeons according to the protocol described by Kotnis et al. [24] (Table 1). The extent of resorption was graded with "no resorption" (1), "partial resorption (less than 50%)" (2), "partial resorption (more than 50%)" (3), or "complete resorption" (4) of the graft material (Fig. 2). The resorption pattern was described as "peripheral" (a), "central" (b), or "homogenous" (c) (Fig. 3).

### Loss of reduction

All x-ray images were calibrated and available for measurement. The maximum depression of the joint line was determined on all anteroposterior x-ray images. Applying the measurement tools of Surgimap software (Version 2.0.8., Nemaris Inc., Sydney, Australia), a horizontal reference line was drawn through an intact part of the tibial plateau joint line, and the distance to the depressed joint line was measured in millimeters on the post-operative and follow-up x-ray images of each patient. The loss of

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