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Biphasic bone substitute and fibrin sealant for treatment of benign bone tumours and tumour-like lesions

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Abstract

Purpose Bone defects resulting from tumour resection or curettage are most commonly reconstructed with autologous bone graft which is associated with limited availability and donor site morbidity. Recent research has focussed on synthetic biomaterials as bone graft substitutes. The aim of this study was to assess the safety and efficiency of a bone substitute as an alternative for autologous bone in the treatment of benign bone tumours and tumour-like lesions.
Methods In the present study, a biphasic ceramic (60% HA and 40% β-TCP) combined with a fibrin sealant was used to reconstruct defects in 51 patients after curettage of benign bone tumours or tumour-like lesions. Patient age ranged from eight to 68 years (mean 29.7), defect size from 2 cm^3 to 35 cm^3 (mean 12.1), and time of follow-up from one to 56 months (mean 22.7).
Results Radiologic analysis showed complete bony defect consolidation in 50 of 51 patients after up to 56 months. No postoperative fractures were observed. Revision surgery had to be performed in one case. Histological analysis showed new bone formation and good biocompatibility and osseointegration of the implanted material.

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Conclusion In summary, the biphasic ceramic in combination with fibrin sealant was proven an effective alternative to autologous bone grafts eliminating the risk of donor site morbidity for the patient.

Introduction

Benign bone tumours and tumour-like lesions are a heterogenic group of bone lesions. Benign bone tumours are defined as autonomic and slowly growing neoplastic lesions with no potential for metastasis with the exception of few potentially malignant entities such as osteoclastoma. Tumour-like lesions are self-limiting, non-neoplastic lesions originating from manifold tissues and potentially leading to a destruction of bone [1].

According to the World Health Organisation (WHO), benign bone tumours can be classified by the type and degree of matrix production and the predominantly residing cell type into bone-forming, cartilage-forming, connective-tissue and vascular lesions [2]. The incidence of most of these lesions is low [3]. The term "tumour-like lesion" summarizes various conditions of non-neoplastic nature originating from or affecting the bone that are manifested as solitary or multiple bone lesions. Different fibro-osseous and cystic lesions represent the most common entities in this group with non-ossifying fibromas, simple and aneurysmal bone cysts as the most frequent [3]. Many benign bone tumours and tumour-like lesions require no further treatment and can be identified radiologically [4].

Bony lesions that are accompanied by clinical symptoms or show growth over time or are of unclear radiological appearance need to be biopsied and examined histologically. After histological classification an adequate treatment is initiated. Once indicated, intralesional curettage and defect

reconstruction by transplantation of cancellous bone graft is the therapy of choice for most benign bone tumours and tumour-like lesions [5].

Reported complication rates after autologous bone graft harvest from the iliac crest vary between 8% and 13% [6, 7]. In addition, autologous cancellous bone is limited in availability [8]. Nevertheless, the augmentation of bony lesions with autologous cancellous bone is the most effective treatment and therefore remains the "gold standard" [7].

Searching for an alternative to cancellous bone grafts, synthetic calcium phosphate bone substitute materials have been developed. The most widely known representatives of calcium phosphates are hydroxyapatite (HA) and β-tricalciumphosphate (β-TCP). Combinations of HA and β-TCP are considered biphasic calcium phosphates (BCP). Ceramic based biomaterials are amongst the most promising candidates for bone tissue engineering as they unite good biocompatibility with osteoinductive properties and mechanical strength. Pore size and shape of these ceramics can be tailored to aid bone ingrowth and therefore osseointegration [9, 10].

Macropores promote osteoconduction by facilitating in-growth of bone by invasion, proliferation and differentiation of osteogenic progenitor cells. The proliferating cells, supported by residing macrophages, gradually resorb and replace the ceramic material with newly formed mineralized bone [11]. Combining the bioceramic with fibrin sealant provides a mouldable composite material. The combination represents a novel approach and has been shown to have a positive effect on bone in-growth and new bone formation [10]. The fibrin based sealant acts as a bioactive matrix stimulating stem cell in-growth additionally containing growth factors and haematological proteins involved in wound healing and angiogenesis [12–14].

In the presented prospective clinical study, a biphasic synthetic bone substitute was used in combination with a fibrin matrix to fill bone defects of benign bone tumours and tumour-like lesions. The aim of this study was to assess the efficiency of the biomaterial as an alternative for autologous bone in the treatment of benign bone tumours and tumour-like lesions.

Material and methods

Over a period of three years 51 patients (age eight–69 years, mean 29.7 ± 17.0 years) presented with benign bone tumours or tumour-like lesions, located at different anatomic sites (Tables 1, 2), and were treated with a biphasic synthetic bone substitute (TricOs®, manufactured by Biomatlante, Vigneux de Bretagne, France) in combination with a diluted fibrin matrix (TissuCol®, Baxter BioScience, Vienna, Austria). The study was approved by the local ethics committee.

TricOs® is a biphasic calcium phosphate ceramic (60% HA and 40% ß-TCP). The material consists of granules of 1–2 mm in diameter. The granules have a surface structure with macropores within a range of 300–600 μm and micropores (<10 μm) accounting for an interconnective overall porosity of 70–80% [15]. Each application-syringe contains 3.5 cm^3 of granules. Prior to use the ceramic is moistened with 1 ml of distilled water.

TissuCol® Duo S 1 ml Immuno (Baxter BioScience, Vienna, Austria) is a biological two-component fibrin sealant consisting of two frozen ready-to-use syringes. Each unit contains 70–110 mg of fibrinogen and 500 units of human thrombin. Prior to application the thrombin was defrosted and diluted with a 20 mM calcium-chloride solution (St. Vincenz Krankenhaus, Limburg) to obtain a

Table 1 Entities, localisation and average size of benign bone tumours and tumour-like lesions

Entity	Tibia	Fibula	Femur	Humerus	Scapula	Calcaneus	Others	Total	Size (cm^3)
Osteoclastoma	1	0	0	0	0	0	0	1	10.5±0.0
Chondroblastoma	1	0	0	1	0	0	0	2	17.5±3.5
Enchondroma	3	0	3	4	0	0	0	10	13.1±5.2
Chondromyxoidfibroma	0	0	0	0	0	1	0	1	10.5±0.0
Solitary cyst	2	0	2	2	1	0	1	8	9.0±5.5
Calcaneal cyst	0	0	0	0	0	9	0	9	12.1±2.9
Fibrous dysplasia	0	0	2	1	0	0	0	3	18.7±12.9
Fibr. met. defect	1	0	0	1	0	0	0	2	2.0±0.0
N. o. fibroma	3	1	2	0	0	0	0	7	9.0±2.5
Aneurysmatic cyst	0	1	1	0	0	0	1	3	14.0±9.9
Others	3	0	1	0	1	0	0	5	11.7±6.3
Total	14	2	11	9	2	10	2	51	12.1±6.8

Fibr. met. fibrous metaphyseal, *N.o.* non-ossifying

Table 2 Patient population and characteristics

Patient number	Age (y)	Gender	Bone	Localisation	Diagnosis	Size (cm^3)	Autologous bone graft	Complications	Follow-up (mo)	Stage
1	23	Female	Tibia	Met/Epi	Osteoclastoma	10.5	Yes	None	56	2
2	14	Male	Calcaneus		Calcaneal cyst	14.0	No	None	54	2
3	52	Female	Femur	Met	Enchondroma	10.5	Yes	Pain at donor site pelvis	36	3A
4	16	Female	Humerus	Met/Epi	Chondroblastoma	14.0	No	None	47	2
5	38	Female	Tibia	Met	Solitary cyst	7.0	No	Intraosseous ganglion, revision	48	2
6	20	Male	Tibia	Met	Abscess, Salmonella spec.	10.5	No	None	48	2
7	16	Male	Tibia	Met	N.o. Fibroma	10.5	No	Pain	36	3A
8	43	Female	Humerus	Met	Enchondroma	17.5	No	CRPS I	6	1
9	46	Female	Scapula		Solitary cyst	10.5	No	None	48	3A
10	19	Male	Femur	Dia	Fibrous dysplasia	35.0	No	None	10	2
11	26	Male	Calcaneus		Calcaneal cyst	14.0	No	None	48	1
12	68	Female	Femur	Met	Enchondroma	10.5	No	None	17	1
13	12	Male	Calcaneus		Calcaneal cyst	10.5	No	None	17	2
14	39	Female	Femur	Met	Solitary cyst	7.0	No	None	16	1
15	9	Male	Calcaneus		Calcaneal cyst	10.5	No	None	1	1
16	50	Male	Tibia	Met	Solitary cyst	7.0	No	None	26	2
17	43	Female	Calcaneus		Calcaneal cyst	14.0	Yes	None	25	1
18	30	Male	Calcaneus		Calcaneal cyst	10.5	No	None	23	1
19	30	Male	Calcaneus		Calcaneal cyst	10.5	No	None	22	2
20	11	Female	Calcaneus		Chondromyxoidfibroma	10.5	No	None	24	1
21	13	Female	Tibia	Met	N.o. fibroma	7.0	No	None	22	3A
22	16	Male	Tibia	Met	Fibrous cortical defect	2.0	No	None	12	3A
23	35	Female	Calcaneus		Calcaneal cyst	7.0	No	None	2	2
24	57	Male	Femur	Met	Fibrous dysplasia	17.5	No	None	25	2
25	57	Male	Scapula		Solitary cyst	2.0	No	None	1	1
26	41	Female	Humerus	Met	Enchondroma	21.0	No	None	37	2
27	14	Female	Fibula	Met	Aneurysmatic bone cyst	7.0	No	Temp. paralysis peroneal nerve	12	2
28	16	Male	Tibia	Met	Enchondroma	7.0	No	None	13	2
29	35	Male	Tibia	Met	Intraosseous ganglion	17.5	No	Wound healing	17	2
30	58	Male	Femur	Met	Solitary cyst	17.5	No	None	35	1
31	26	Female	Humerus	Dia	Fibrous dysplasia	3.5	No	None	30	2
32	15	Male	Tibia	Met	N.o. fibroma	10.5	No	None	29	3A
33	47	Female	Humerus	Met	Enostoma	10.5	No	None	25	1
34	9	Female	Calcaneus		Calcaneal cyst	17.5	No	None	25	1
35	26	Female	Tibia	Dia	Enchondroma	14.0	No	None	2	2
36	55	Female	Tarsus	Os cunei.	Solitary cyst	3.5	No	None	4	2
37	14	Female	Femur	Met	N.o. fibroma	10.5	No	None	15	2

Table 2 (continued)

Patient number	Age (y)	Gender	Bone	Localisation	Diagnosis	Size (cm^3)	Autologous bone graft	Complications	Follow-up (mo)	Stage
38	18	Female	Pelvis	Os pubis	Aneurysmatic bone cyst	28.0	No	None	28	2
39	13	Male	Fibula	Met	N.o. fibroma	10.5	No	None	13	2
40	11	Male	Femur	Dia	Aneurysmatic bone cyst	7.0	No	None	13	2
41	8	Female	Femur	Met	N.o. fibroma	3.5	No	None	12	2
42	56	Female	Tibia	Met	Osteonecrosis	7.0	Yes	None	24	1
43	48	Female	Femur	Met	Enchondroma	5.0	No	None	12	2
44	15	Female	Humerus	Met	Fibrous cortical defect	2.0	No	None	6	2
45	54	Male	Humerus	Met	Solitary cyst	17.5	No	None	12	1
46	44	Male	Humerus	Met	Enchondroma	21.0	No	None	13	2
47	21	Female	Tibia	Dia	Enchondroma	10.5	No	None	7	2
48	48	Female	Femur	Met	Enchondroma	14.0	No	None	27	2
49	16	Male	Tibia	Met/Epi	Chondroblastoma	21.0	Yes	None	24	1
50	13	Female	Femur	Met	Lipoma	24.0	No	None	26	1
51	11	Male	Tibia	Met	N.o. fibroma	10.5	No	None	26	2

Met metaphysis, *Epi* epiphysis, *Dia* diaphysis, *Stage* radiographic stage at final follow-up, *N.o.* non-ossifying

thrombin solution of 5 units/ml. The fibrin sealant was deposited onto the ceramic granules. After approximately 2 min the fibrin was cross-linked and the composite was ready for use (Fig. 1).

The lesions treated were a heterogeneous group of entities (Table 2). In all cases the cortical bone was fenestrated and intralesional curettage was performed. Samples for histological assessment were obtained. Afterwards, the defects were completely filled with the composite material (see Figs. 2, 3, 4). Autologous cancellous bone graft was applied in five cases. The decision to use autologous bone graft was made when the lesion was in close contact with the joint.

Radiological evaluation was performed six weeks, and at three, six, 12 and 24 months postoperatively. Decisions on the necessity of and indication for further follow-up visits beyond 24 months were made on an individual basis.

CT or MRI scans were performed 12 months postoperative to rule out recurrence of benign bone tumours. Radiographic findings were described according to the classification system proposed by Matsumine et al. (stage 1 clear margin, stage 2 hazy margin, stage 3 absorbed margin: stage 3A absorption<50% and stage 3B absorption>50%) [16]. Radiographs were evaluated regarding to defect consolidation, osseointegration and resorption of the transplanted material.

Histological examination was performed after fixation in 4% paraformaldehyde, and the sample was embedded in Glycol-PMMA. Samples of 30-μm thickness were prepared using a circular diamond saw (Leitz, Wetzlar, Germany) and sectioned using a hard tissue microtome (Reichert-Jung 2050, Supercut, Cambridge Instruments, Austria). One section was polished and sputter-coated prior to visualization with a 20 kV scanning electron microscope (Jeol JSM 6300, Japan). Histological sections of 10 μm were also stained with Movat's pentachrome and viewed using a light or polarized light microscope.

For statistical analysis univariate analysis was performed using the Mann-Whitney U-test for nonparametric data. A p-value of less than 0.05 was considered significant.

Results

The size of the lesions treated ranged from 2–35 cm^3 (mean 11.8±6.6 cm^3) measured as the amount of synthetic bone substitute applied. The average time of follow-up was 22.7± 14.3 months (range one–56 months). Histological analysis revealed one osteoclastoma, two chondroblastomas, ten enchondromas and one chondromyxoidfibroma. The group of tumour-like lesions consisted of eight solitary cysts, nine calcaneal cysts, three fibrous dysplasias, two fibrous metaphyseal defects, seven non-ossifying fibromas, three aneur-

Fig. 1 a Macroscopic appearance of biphasic calcium phosphate granules. b SEM images of bone substitutes macrostructure and microstructure (c). d The material is moistened with 1 ml aqua dest./3.5 cm³ and the diluted fibrin sealant is added to form a mouldable mass (e, f) that can easily be applied to a lesion
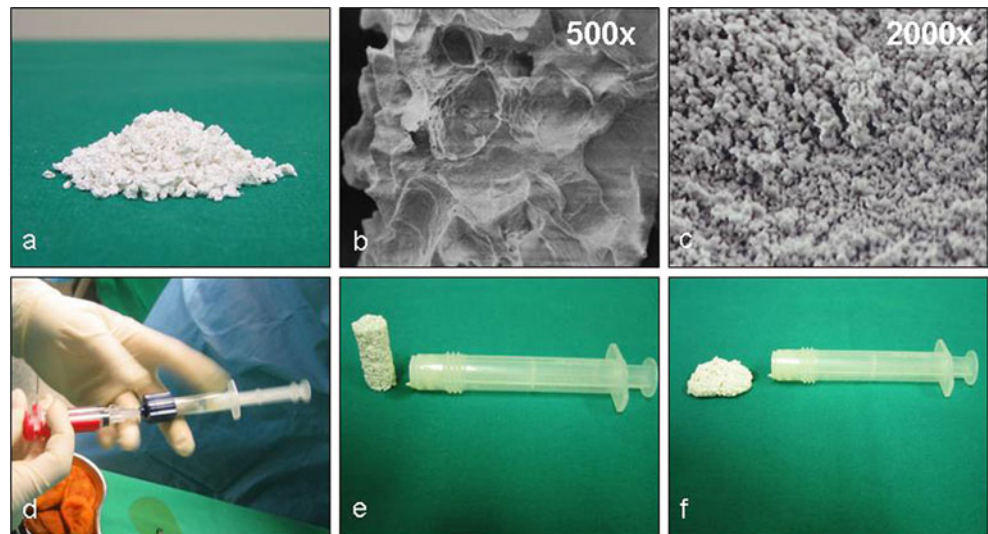
ysmatic cysts and five entities that were classified as others (one lipoma, one osteonecrosis, one bone abscess, one intraosseous ganglion, one enostoma).

All but one patient showed complete bone defect filling in radiological controls at the time of final follow-up. In 17 cases sclerosis of the outer margin was observed (stage 1), and in 28 cases a hazy margin was observed (stage 2) (Figs. 2, 3). In six cases a partial resorption of less than 50% was seen classified as a stadium 3A according to Matsumine et al. (Fig. 4) [16]. In all cases an overall decrease in radiolucency over time was found. Only incomplete resorption of the transplanted material was observed as determined
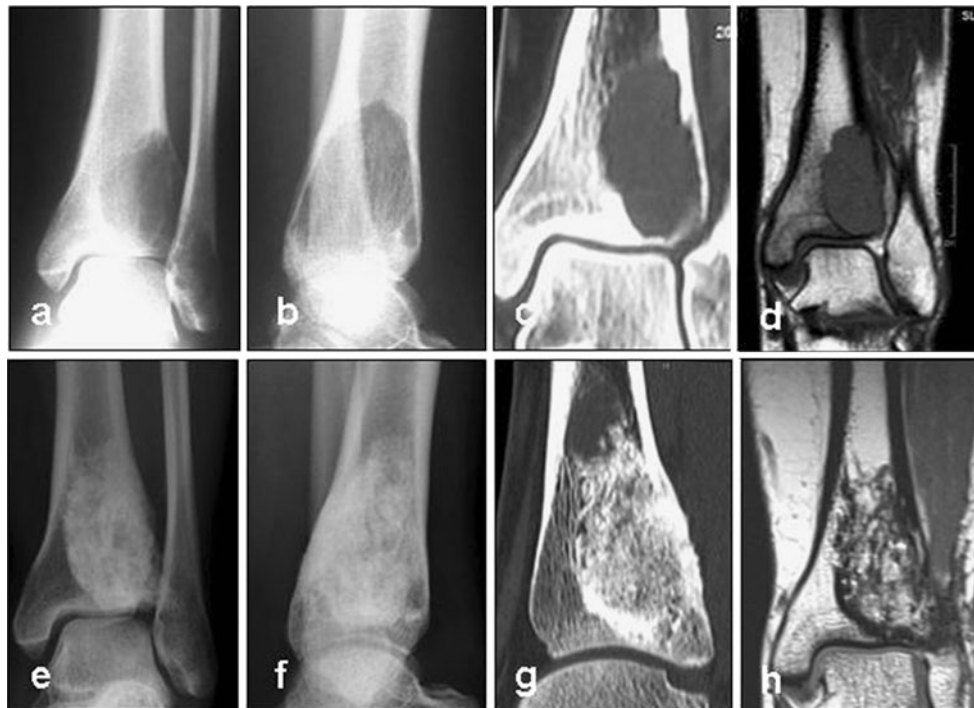
Fig. 2 X-ray (a, b) and CT (c, d) images of a 24-year-old female patient diagnosed with an osteoclastoma of the distal tibia. The patient experienced pain when weight-bearing. TricOs bone substitute material was applied in combination with autologous cancellous bone from the iliac crest at a rate of 1:5. The defect had a volume of 10.5 cm³. At 18 months post surgery, CT scans were performed. The lesion was completely filled with newly formed tissue reminiscent of healthy cancellous bone. A sclerotic margin was observed. After 56 months the bone substitute material was radiographically still detectable. Resorption was determined as a stage 2 (e–g). Also, MRI was performed after 56 months to rule out recurrence of the osteoclastoma. A hypointensive zone was seen in the CT images corresponding to the sclerotic margin (h)
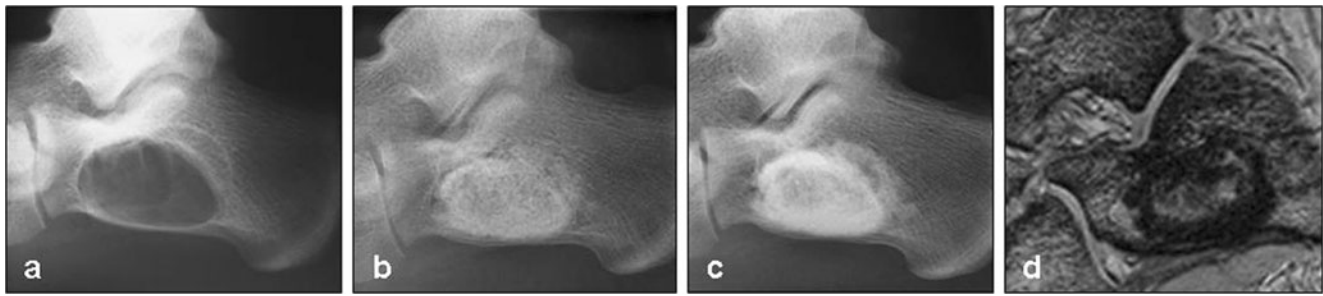
Fig. 3 X-ray and MRI images of a 16-year-old male suffering from a large calcaneal cyst (**a**). Intralesional curettage was performed and the lesion filled with 14 cm^3 TricOs®. Radiographs showed complete defect filling postoperatively (**b**), and after 54 months postoperatively (**c**). Over time radiolucency decreased especially in the marginal area of the lesion. No signs of osteolysis were evident. The resorption was classified as a stage 2. High dissolution MRI was performed after 12 months postoperatively to assess defect filling. In T1-weighted images (**d**) the margin of the filled lesion showed no signal intensity. The patient had fully recovered six weeks after surgery and was free of pain

by X-ray analysis, and CT or MRI scans, even after up to 56 months. No postoperative fractures occurred. Clinical and radiological follow-up indicate no signs of inflammatory tissue reactions or osteolysis.

In MRI scans the biomaterial showed no signal intensity in T1- and T2-weighted images. No case of tumour recurrence was observed during the period of follow-up. One patient, initially with a solitary cyst of the distal tibia developed an intraosseous ganglion and led to a failure. In this case revision surgery was performed 37 months postoperatively and autologous cancellous bone graft from the iliac crest was applied to the defect. A biopsy was obtained which showed that the bone substitute material was still present, being well integrated with the native bone. The histological examination of this case showed unmineralized osteoid, mineralized plexiform bone and remodelling with the formation of haversian systems. No signs of inflammation or adverse reactions to the transplanted material were observed while the material itself was not completely resorbed (Fig. 5).

Minor complications were observed in five cases (9.8%). None of the complications were attributed to the applied biomaterial. Longitudinal bone growth was not disturbed.

Statistical analysis showed a significantly higher stage of resorption in smaller defects (≤ 10.5 cm^3; $p=0.045$). The data do not indicate a significant difference in the resorption stage between gender, age, type of bone, localisation or time of follow-up. The application of autologous bone did not show a significant difference in the stage of resorption (Table 3).

Discussion

The ideal bone substitute material should be osteoinductive, osteoconductive and should be subject to complete resorption during the process of new bone formation. A well-balanced equilibrium between biomaterial degradation and new bone formation is desirable. The described scaffold requirements may vary depending on type, size and anatomic location of defects.

Synthetic bone substitutes such as calcium phosphate ceramics reveal good results in various clinical applications [16–18]. Only few reports are available regarding the clinical application of such ceramics in the treatment of bone defects resulting from benign tumours or tumour-like lesions and long-term outcomes [16, 18, 19].

Fig. 4 X-rays and CT image of a 47-year-old female patient with a juvenile cyst of the glenoid (**a**). The lesion was filled with 7 cm^3 of TricOs® (**b**). Radiologic controls and CT scans showed complete defect filling after 48 months (**c, d**), the resorption process of the ceramic was staged 3A. Radiologically, the implanted material was still detectable
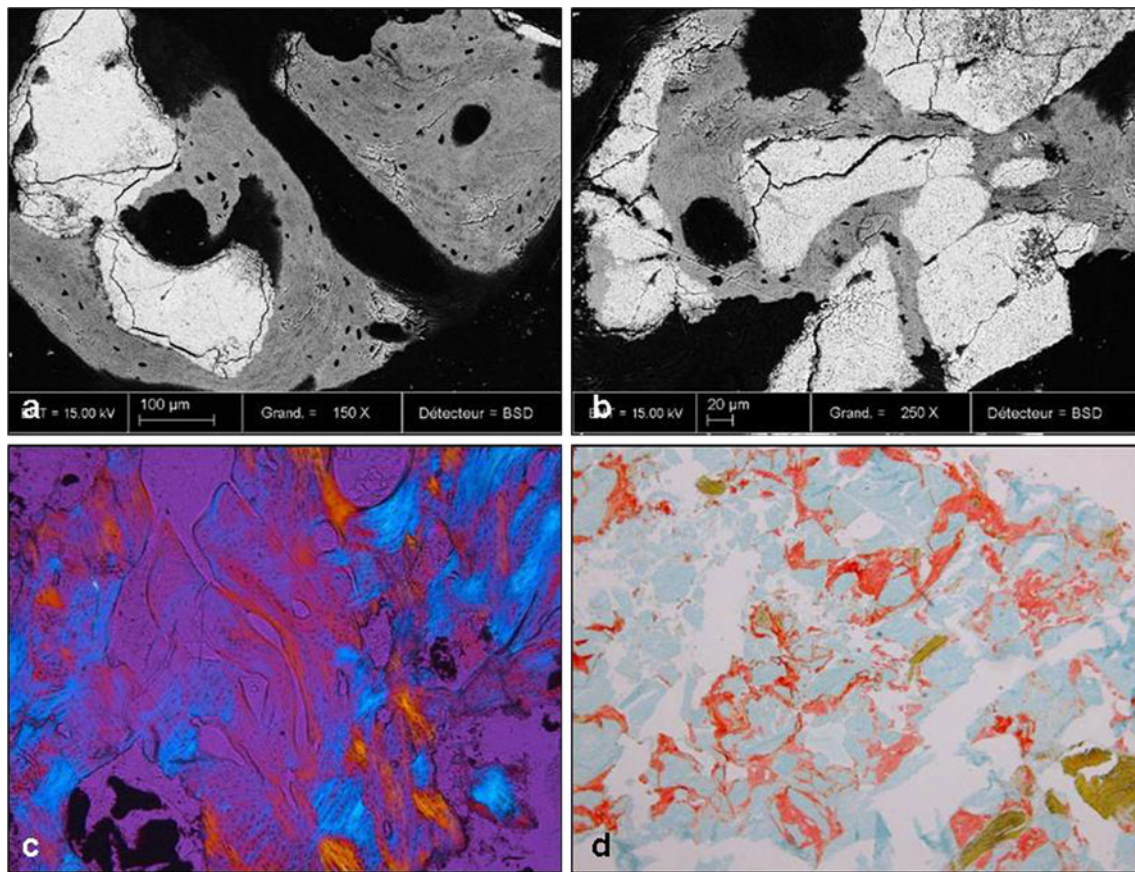
Fig. 5 **a**, **b** Backscattered scanning electron microscopy (BSEM) demonstrating remnants of the transplanted bone substitute (*white*) material and new bone formation in *grey* and *black*. New bone formation is in close apposition to the biomaterial indicating good osseointegration. **c** Polarized light microscopy (10x) showed both residual granules and newly formed bone with haversian system. **d** In PMMA sections stained for Movat's pentachrome (10x) new mineralized bone (*green*) and some unmineralized osteoid (*red*) as well as residual granules (*light blue*) were seen gradually being resorbed by osteoclastic cells

Bioceramics that are often presented in the form of granules may be difficult to handle. The combination of a biphasic ceramic with a fibrin matrix as a composite represents a new approach to improve the properties and the handling of ceramic-based bone substitute materials. Furthermore, this specific combination was shown to have positive effects on the material's osseointegration and bone formation in general [8, 14, 20, 21]. The addition of a fibrin matrix increases the malleability of the composite [13]. Moreover, fibrin acts as a bioactive matrix facilitating stem cell in-growth as the sealant contains growth factors and haematological proteins involved in wound healing and angiogenesis [12–14]. This positive effect is dependent on the density of the fibrin network that can be influenced by varying the thrombin concentration [14, 21].

Calcium phosphate ceramics provide a surface chemistry that facilitates protein absorption, e.g. the absorption of circulating bone morphogenetic proteins, and have been shown to have osteoinductive properties [22]. The osteoinductive properties of such calcium phosphate based ceramics, however, are by no means comparable to the osteoinductive properties of potent bone growth stimulating agents such as BMP-2 or BMP-7 and other growth factors. As a result, the osteoinductive effect of these ceramics greatly depends on the local microenvironment provided by the host and therefore the delivery of osteoinductive mediators such as bone morphogenetic proteins, transforming growth factors and platelet-derived growth factor secreted by residing hematopoetic cells and stem cells/progenitor cells of the surrounding bone [19].

In contrast to the results described by Uchida et al. [23] in the present study, no radiolucent areas adjacent to the implanted bone substitute were observed. Similarly, Uchida et al. have used a biphasic ceramic consisting of 70% HA and 30% ß-TCP. The applied granules, however, were of larger diameter. Nevertheless, the results of this particular study showed comparable outcomes in terms of osseointegration and increasing

Table 3 Relationship of radiographic staging at final follow-up contingent on gender, age, defect size, bone type, defect localisation, application of autologous bone graft and time of follow-up

Characteristics	Number of patients	Radiographic stage at final follow-up				p-value
		1	2	3A	3B	
Total	51	17	28	6	0	
Gender						
F	28	9	16	3	0	
M	23	7	13	3	0	0.831
Age (years)						
< 20	22	5	13	4	0	
> 20	29	11	16	2	0	0.147
Size						
≤ 10.5 cm^3	33	8	19	6	0	
> 10.5 cm^3	18	8	10	0	0	0.045*
Type of bone						
Long bone	37	9	23	5	0	
None long bone	14	7	6	1	0	0.095
Autologous bone graft						
Yes	5	3	1	1	0	
No	46	13	28	5	0	0.371
Localisation						
Diaphysis	5	0	5	0	0	
Metaphysis	29	8	16	5	0	
Metaphysis/Epiphysis	3	1	2	0	0	
Calcaneus	10	6	4	0	0	
Others	4	1	2	1	0	0.803
Time of follow-up						
< 24 months	26	7	17	2	0	
> 24 months	25	9	12	4	0	0.957

*p < 0.05

radiologic density over time, an effect that was attributed to new bone formation around and within the implanted bone substitute material [23].

Schindler et al. [19] have applied a bone substitute material containing 65% HA and 35% calcium sulphate hemihydrate in combination with autologous venous blood in 13 patients with osteoclastomas or aneurysmatic bone cysts. In this study, a radiolucent zone surrounding the graft material was also observed and interpreted as a sign of graft resorption [19]. The absence of such a radiolucent zone in defects treated in the present study could be indicative of improved new bone formation mediated by the novel bone substitute material. The radiologically detectable sclerotic defect margin present in some of the examined cases as well as the decrease in radiolucency can be explained by a summation effect of new bone formation and the bone substitute material that is still in place. This is in line with our findings of MRI scans that show a hypodense margin in T2-weighted as well as in T1-weighted images at the corresponding anatomic site. Radiologically this hypodense margin has similarities with compact bone.

Hirata et al. [24] reported on 53 patients with benign bone tumours and tumour-like lesions that were treated with curettage. Defects were filled with pure ß-TCP. Complete resorption of the transplanted material was observed in 20 cases after a mean follow-up time of 12.7 months and an average defect size of 9 cm^3. Incomplete resorption was observed in 30 cases [24].

After a follow-up period of up to 56 months, the clinical and radiological results after transplantation of our biphasic calcium phosphate fibrin composite are encouraging. No adverse effects or biological complications had occurred that were attributed to the biomaterial. Minor complications were seen in five patients (9.8%). However, in one case of an osseous cyst of the distal tibia surgical revision had to be performed. Intraoperatively, a connection of the cyst to the joint was revealed that had caused an intraosseous ganglion. In the biopsy taken from within the ganglion during revision, newly formed bone was evident while residues of the transplanted biomaterial were still present. The unsuccessful treatment in this particular case can be explained by the constant flow of synovial fluid between

cyst and joint space that negatively influenced bone formation and in-growth.

Even though there are no reports on adverse effect after application of fibrin glue it has to be stated that the product contains human plasma proteins and thrombin as well as bovine aprotinin. As a result, there is a low risk of disease transmission. Substituting the fibrin matrix with autologous platelet rich plasma (PRP) could eliminate this risk and provide both autologous thrombin and growth factors. However, the amount of growth factors and the concentration of thrombin, which may be decisive factors influencing clinical outcomes, are subject to great variation in the case of PRP application. The combination of ceramic-based biomaterials with bone marrow aspirates [25, 26], growth factors or ex vivo expanded osteogenic cells is also conceivable.

The significantly higher degree of resorption in smaller lesions (< 10.5 cm^3) is in line with the hypothesis that smaller lesions contain less biomaterial leading to a smaller surface area. This facilitates osseointegration and resorption by ingrowing cells. In contrast to the study of Matsumine et al. [16] we did not find a significant difference regarding the resorption in males and females and younger patients.

Limitations of our study include a relatively short follow-up period; long-term follow-up may be required to define differences in resorption contingent on the age of the patient, type of bone, localisation within the bone and time of follow-up. Additional, more objective methods of analysis would be desirable to assess material resorption more objectively and to avoid bias.

In summary, the biomaterial represents an easy-to-handle alternative to autologous cancellous bone grafts for the treatment of benign bone tumours and tumour-like lesions. Best long-term results, determined as resorption stage 3A, were obtained in small lesions (≤ 10.5 cm^3) at metaphyseal sites.

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