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Re-implantation of autoclaved bone segments in musculoskeletal tumor surgery

Clinical experience in 9 patients followed for 1.1–8.4 years and review of the literature

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Abstract Nine patients who had malignant bone tumors of the lower extremity were managed with wide en bloc resection and re-implantation of the extracorporally autoclaved specimens. The segments were fixed by plate osteosynthesis, knee arthrodesis rod, or intramedullary nails. In one patient the complete femur was re-implanted. After a mean follow-up of 66 months (range 13–101 months), 8 out of 9 patients were still free of disease. One patient with Ewing's sarcoma and re-implantation of the complete femur died of systemic recurrence. No local recurrence was seen. One patient with Ewing's sarcoma of the tibia who had undergone postoperative irradiation developed a local infection 18 months postoperatively which finally had to be treated by knee disarticulation. After an average duration of 13 months, all graft-host junctions had healed. The functional result of the patient with the knee disarticulation was poor. In all other patients, the functional outcome was good or excellent. The evaluation of 115 patients (106 from the literature, 9 from our study) with a mean follow-up of 63 months showed 8 local recurrences. There were 4 secondary infections and only 1 primary infection. In tumors of the extremities and the pelvis, the functional outcome was excellent or good in about 80%. Limb salvage using re-implantation of autoclaved tumor-bearing bone segments for reconstruction has a low complication rate and good functional results in appropriately selected patients compared with other options of management.

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Introduction

During the last three decades, the proportion of limb salvage operations in the treatment of primary malignant bone tumors has increased considerably and today is about 70%–80%, even with high-grade sarcomas [23]. This is mainly a consequence of the development of excellent imaging methods like computed tomography (CT) and magnetic resonance imaging (MRI), which can define local tumor extension very precisely [9, 54]. Preoperative chemotherapy is also an essential factor influencing the ratio of ablative to limb salvage procedures [4]. Long-term results after implantation of tumor prostheses in the mostly young patients were disappointing because of the accumulating rate of complications like aseptic loosening, implant failure or infection, which are considered as almost inevitable sequelae associated with prosthetic replacement [29]. That is why many orthopedic surgeons have striven for long-lasting results by means of biological reconstruction methods.

Re-implantation of extracorporally devitalized tumor-bearing bone segments by means of autoclaving is an interesting alternative reconstruction method. In 1918, Gallie first reported encouraging results when using boiled bony transplants [21]. Orell was the first to employ the orthotopic replantation of autogenous autoclaved bone in oncological surgery when he treated a periosteal osteosarcoma [42]. While in the reconstruction of the mandible Harding found that the autoclaved bone acted as a tolerated foreign body which was gradually resorbed and replaced by fibrous tissue [24, 25], other authors could prove that the retransplants revitalized [18, 26, 36].

Patients and methods

Between June 1989 and September 1995 at the Department of Orthopedic Surgery of the University Hospital in Tübingen, 7 patients with primary malignant bone tumors were operated on using the autoclaved tumor-bearing bone segment for reconstruction (patients 1–7, Table 1). In 1993, another 2 patients were operated on at the Department of Orthopedic Surgery of the hospital in Schw-

Table 1 Characteristics, complications and follow-up of patients managed with autoclaved re-implants (*f* femur, *t* tibia, *p* proximal, *s* shaft, *d* distal, *c* chondrosarcoma, *co* chondroblastic osteosarcoma, *e* Ewing's sarcoma, *mfh* malignant fibrous histiocytoma, *o* osteosarcoma, *po* parosteal osteosarcoma, *i* intercalary, *k* knee arthrodesis, *r* re-implantation of total femur with knee and hip prosthesis, *ct* chemotherapy, *cfd* continuously free of disease, *dod* dead of disease)

Case no.	Age at operation (years)	Gender	Location of tumor	Histological diagnosis	Surgical staging[a]	Type of reconstruction	Length of resected specimens (cm)	Adjuvant therapy	Bony union (months)	Full weight-bearing	Oncological result	Functional result[b]	Follow-up (months)	Occupation	Comments
1	12	M	t/s	e	IIB	i	15.5	ct (CESS 86), irradiation (44 Gy)	10	10	cfd	50%/ poor	101	Full-time bank employee	18 months post op. local infection, insufficient callus formation after segment shifting, knee disarticulation (29 months post op.)
2	17	F	t/p	co	IIB	k	20	ct (COSS 86)	21	4	cfd	70%/ good	95	Retrained from hairdresser to full-time office worker	∅
3	34	M	f/d	mfh	IIB	k	20	ct (COSS 86)	13	4	cfd	77%/ good	94	Full-time waiter	∅
4	27	F	f/s	c	IA	i	18	∅	11	10	cfd	100%/ excellent	74	Full-time packer	∅
5	18	M	f/p	po	IB	i	11	∅	11	8	cfd	100%/ excellent	60	Retrained from informatics electrician to full-time balcony builder	∅
6	30	M	t/p	po	IB	k	12	∅	16	5	cfd	83%/ good	45	Farmer in North Africa	∅
7	23	M	f/s	e	IIB	r	48	ct (EICESS-92), irradiation (56 Gy)	Not to apply	1.5	dod	Good	13		Systemic recurrence; no local recurrence
8	49	M	t/s	c	IA	i	17	∅	12	12	cfd	83%/ good	55	Temporary pension	Primary stabilization: external fixation; 4 months postoperatively Küntscher nail; aseptic fistula developed 1 year postoperatively; healed after revision
9	33	M	f/p	c	IA	i	13	∅	12	12	cfd	97%/ excellent	54	Full-time metal-worker	Primary stabilization: external fixation; 6 months postoperatively Gamma nail

[a] After Enneking (1983)
[b] After Enneking/Amino

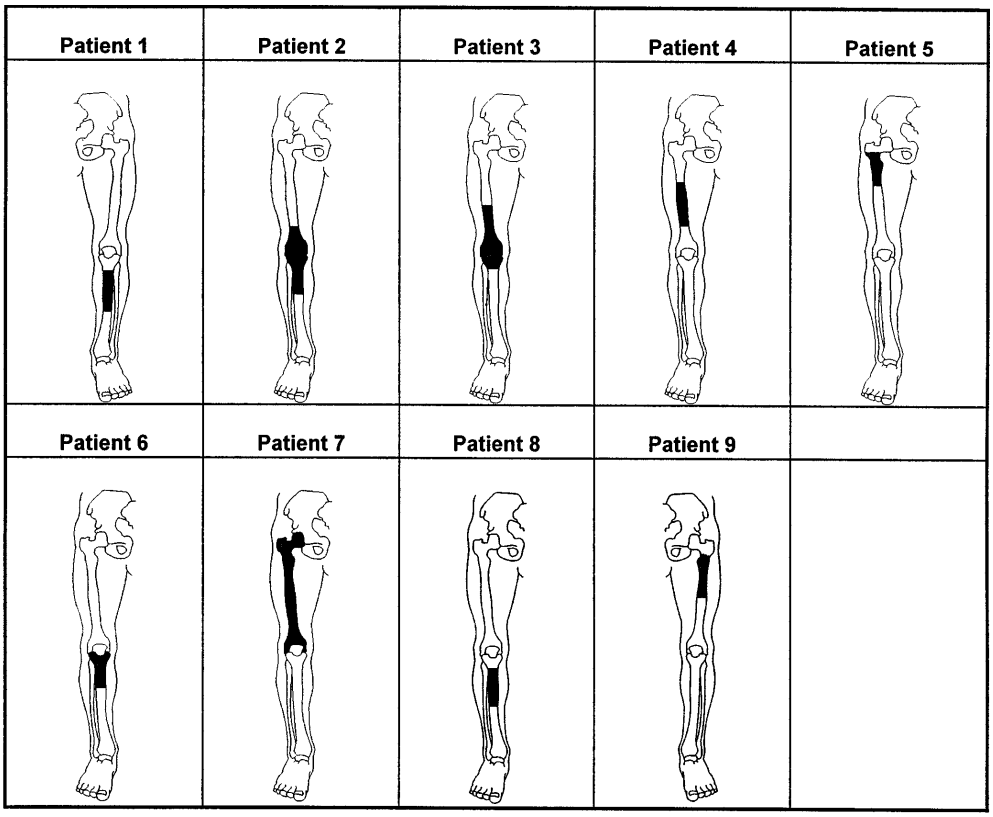

Fig. 1 Schematic drawing of the extent of the resected specimens

erin (patients 8 and 9, Table 1). In all 9 cases a wide surgical margin [15] was achieved when resecting the tumor. In 5 patients (nos. 1, 4, 5, 8, and 9), an intercalary segment was resected. In one patient (no. 6), an intra-articular resection and in 2 patients (nos. 2 and 3), an extra-articular resection was performed. In one patient (no. 7), the complete femur was resected (Fig. 1).

In order to confirm that the surgical margin was adequate, frozen sections of multiple relevant and representative biopsies were performed. In our experience, it was very helpful when the pathologist was present in the operating room while performing the biopsies. In cases with preoperative chemotherapy, the percentage of tumor necrosis was evaluated according to Salzer-Kuntschik et al. [47]. Therefore, large intraosseous biopsies must be taken from the resected specimens before autoclaving. If there is an extraosseous tumor, the entire extraosseous part can be used for pathological examination. After autoclaving at 120° C for 20 min, the specimens were re-implanted. Three out of 5 intercalary specimens were stabilized by means of plate osteosynthesis. In the 2 patients with intercalary specimens operated on in Schwerin, a primary stabilization by means of an external fixator was performed. In patient 8, the external fixator was removed 4 months postoperatively, and an internal osteosynthesis of the tibia was done by means of a Küntscher nail. In patient 9, the external fixator was removed 6 months postoperatively and a gamma nail was implanted. An arthrodesis of the knee joint was performed in 3 patients by means of an arthrodesis rod. In patient 7, the complete femur was re-implanted including a cemented bicentric femoral head prosthesis and a cemented hinged knee endoprosthesis.

All 4 patients with high-grade sarcoma received neoadjuvant chemotherapy, and the 2 patients with Ewing's sarcoma additionally received radiation therapy (Table 1). Patient 3 refused to continue postoperative chemotherapy after the first postoperative course.

The functional outcome of the 9 patients (Table 1) was documented according to the modified Enneking scoring system [16], and additionally the Amino scoring system [3], which is also applicable to the cases reviewed from the literature.

Results

At the time of writing, 8 out of 9 patients are still alive, while 1 patient had died of systemic metastases. There was neither fracture of the re-implants nor local recurrence. Only one patient (no. 1) developed a serious local complication: 18 months postoperatively he was walking without support, but used a Sarmiento brace for his leg. During his holidays in the summer, when the patient had forgotten to use a cotton sock, a little pustule developed on the skin under the brace. A few days later, the infection spread to the re-implant under the thin irradiated skin, and the tibia segment had to be removed. Segment-shifting was not successful because formation of callus in the irradiated area was insufficient, and finally a knee disarticulation was performed. Patient 8 developed an aseptic fistula originating from the biopsy window 1 year after re-implantation. The fistula was revised, and a biopsy from the autoclaved bone was taken. The biopsy showed no viable osteons, but revascularization was clearly visible.

The degree of morphological regression after preoperative chemotherapy was 1 (= no viable tumor) according to Salzer-Kuntschik et al. [47] in 2 patients (nos. 1 and 3) and 6 (= no effect of chemotherapy) in one patient (no. 2), respectively. After a mean follow-up of 66 months (range 13–101 months), 8 out of 9 patients were continuously free of disease. In patient 7, there was a large intraosseous and extraosseous extension of the tumor before treatment. Intraoperative biopsies (27 biopsies were performed) after preoperative chemotherapy and preoperative irradiation

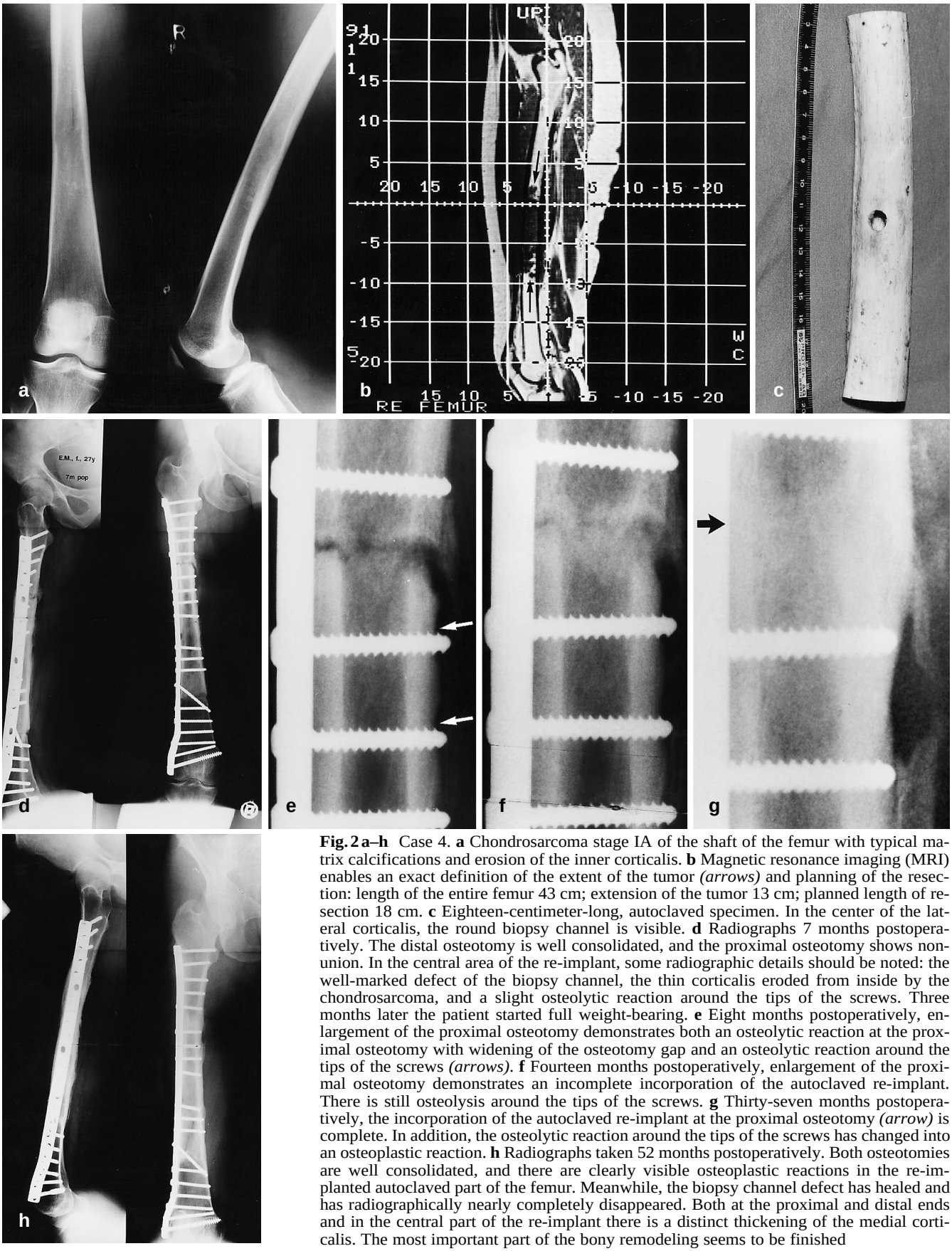

Fig. 2 a–h Case 4. **a** Chondrosarcoma stage IA of the shaft of the femur with typical matrix calcifications and erosion of the inner corticalis. **b** Magnetic resonance imaging (MRI) enables an exact definition of the extent of the tumor *(arrows)* and planning of the resection: length of the entire femur 43 cm; extension of the tumor 13 cm; planned length of resection 18 cm. **c** Eighteen-centimeter-long, autoclaved specimen. In the center of the lateral corticalis, the round biopsy channel is visible. **d** Radiographs 7 months postoperatively. The distal osteotomy is well consolidated, and the proximal osteotomy shows nonunion. In the central area of the re-implant, some radiographic details should be noted: the well-marked defect of the biopsy channel, the thin corticalis eroded from inside by the chondrosarcoma, and a slight osteolytic reaction around the tips of the screws. Three months later the patient started full weight-bearing. **e** Eight months postoperatively, enlargement of the proximal osteotomy demonstrates both an osteolytic reaction at the proximal osteotomy with widening of the osteotomy gap and an osteolytic reaction around the tips of the screws *(arrows)*. **f** Fourteen months postoperatively, enlargement of the proximal osteotomy demonstrates an incomplete incorporation of the autoclaved re-implant. There is still osteolysis around the tips of the screws. **g** Thirty-seven months postoperatively, the incorporation of the autoclaved re-implant at the proximal osteotomy *(arrow)* is complete. In addition, the osteolytic reaction around the tips of the screws has changed into an osteoplastic reaction. **h** Radiographs taken 52 months postoperatively. Both osteotomies are well consolidated, and there are clearly visible osteoplastic reactions in the re-implanted autoclaved part of the femur. Meanwhile, the biopsy channel defect has healed and has radiographically nearly completely disappeared. Both at the proximal and distal ends and in the central part of the re-implant there is a distinct thickening of the medial corticalis. The most important part of the bony remodeling seems to be finished

of the extended Ewing's sarcoma showed histologically an extensive myelofibrosis with signs of old hemorrhaging. Tumor cells could not be found either intraosseously or in the surrounding soft tissue (degree of regression 1 according to Salzer-Kuntschik). In spite of the high risk for developing metastases, the patient refused a postoperative continuation of the chemotherapy. In March 1996, during follow-up examination, imaging diagnostics revealed no indication of local recurrence or systemic metastases. The punch biopsies of the iliac crest with proof of RNA, however, yielded a positive beta-actin amplification and a gene fusion-transcription with a translocation 11,22. After the initial chemotherapy, no tumor RNA had been found. Thus, chemotherapy was started again because of the reappearance of tumor RNA, which may be a molecular biologic indication for a systemic recurrence. In spite of the chemotherapy, systemic recurrence (bone marrow) occurred, and the patient died 13 months postoperatively. There was no local recurrence.

The most interesting aspect of the evaluation is the radiological analysis of the incorporation of the re-implanted devitalized bone segments (Fig. 2). The 5 intercalary re-implants were incorporated between 10 and 12 months postoperatively, and full weight-bearing was possible between 8 and 12 months postoperatively. Four of the 5 patients enjoy full function with no restrictions (Table 1). Patient 1 uses a knee disarticulation prosthesis. Three patients have a stable arthrodesis of the knee joint, and they are all working in a full-time job. After knee arthrodeses full weight-bearing was possible between 4 and 5 months postoperatively. Patient 7 has been walking without support since the 6th postoperative week. However, there was a distinctly reduced (about 50%) flexion of the hip and knee joint as a consequence of the preoperative high-dose irradiation. Using the modified Enneking functional scoring system, in the 8 surviving patients, the mean score was 83% (pain 98%, function 73%, emotional acceptance 83%, supports 95%, walking ability 80%, and gait 68%).

Discussion

Since limb salvage surgery is no longer the therapy of choice only for benign bone tumors and tumor-like lesions, but has changed from exception to standard in the therapy of primary malignant bone tumors, the development of reconstruction techniques has become a most interesting field of orthopedic research. Nowadays, the surgeon can select from among a great variety of methods to bridge the defects created by the local resection. In long bones, generally we have to distinguish between biologic and nonbiologic reconstruction methods. Since modular tumor prostheses are available, customized total joint replacements are no longer attractive, because modifications of the length of resection are easily done only with the former. The operative technique is relatively simple. Nevertheless, the implantation of a tumor prosthesis is probably not a good long-term reconstruction method. The 7- to 10-year follow-up reports of these prostheses showed failure rates between 33% [37, 49] and 60% [46] and up to nearly 100% [32] because of late complications like infections, breakage, and aseptic loosening. Diaphyseal endoprostheses offer a good clinical and functional outcome, with a mean Enneking score of about 84%. Infection seems not to be a problem with this reconstruction technique, but aseptic loosening is in about one-third of patients after a mean follow-up of 66 months [1]. Therefore, especially in very young patients with a good prognosis quoad vitam, biologic reconstructions are preferred. In tumors of small bones and in small tumors of the spine, pelvis, or long bones, transplantation of fresh autografts probably may achieve the best results despite prolongation of the operating time and complications at the donor site. In large defects, fresh autogenous bone, the most valuable biologic material, is not available in sufficient amounts.

Massive allografts provide a good alternative, but bone banking requires a lot of time, energy, and money [10]. In this reconstruction method, a high rate of early infection (up to 30%) is reported, especially in patients with high-grade tumors and adjuvant chemotherapy [22]. The risk of transmission of known or not yet identifiable viruses or other agents can be diminished, but not completely eliminated in spite of a highly developed bone banking system [10, 50]. The nonunion rate in allografts is reported at between 12% [5, 39] and 23% [22]. The rate of fractures of the allografts is about 16% [5] to 67% [40]. Most authors report a 50% fracture rate [2, 56]. Intercalary allografts offer excellent functional results, but about 50% of patients require up to 4 additional procedures to achieve adequate reconstruction [43]. Immunologic problems may play a major role in infection, fracture, and nonunion as the most serious complications [43].

Since Orell, 106 cases of re-implantation of bone tumors after extracorporeal autoclaving could be found in 16 original publications [14, 15, 18, 19, 24, 26, 27, 31, 34, 36, 41, 42, 51, 55, 57, 58] and in 4 follow-up papers [17, 25, 48, 52]. Thus, in total 115 patients including our own 9 patients, with a follow-up of between 6 and 300 months (mean 63 months, median 48 months) form the base of this analysis. The diagnoses of the 115 (56 female and 59 male) patients are listed in Table 2, and the sites are illustrated in Fig. 3. The youngest patient at the time of operation was 12 years old, and the oldest 76 (mean 40 years; median 41 years). In 8 patients the age was not documented. In 55 cases, the exact length of the resected (long) bone was indicated. The mean length was 16.7 cm (range 10–48 cm). The longest resected bone in the literature may be the entire femur of our patient 7. The length of a second re-implanted autoclaved entire long bone, a humerus, is not documented [19]. In 19 patients, there was no information about adjuvant therapy available. In 85 patients, there was no adjuvant therapy, while 11 patients underwent an adjuvant therapy: radiation 1, chemotherapy 7, chemotherapy plus radiation 3.

When surgically treating bone tumors with curative intent, definite removal of all tumor tissue is the most im-

Table 2 Histologic diagnosis in 115 patients with autogenous autoclaved re-implants

Diagnosis	Number	Percent
Condrosarcoma	43	37
Osteosarcoma	15	13
Parosteal osteosarcoma	7	6
Teleangiektatic osteosarcoma	1	1
GCT sarcoma	3	3
Adamantinoma	3	3
Ewing's sarcoma	3	3
MFH (malignant fibrous histiocytoma)	2	2
Squamous-cell carcinoma	2	2
Angiosarcoma	1	1
Liposarcoma	1	1
Fibrosarcoma	1	1
Hemangioendothelioma	1	1
Epidermoid carcinoma	1	1
Solitary myeloma	1	1
Solitary metastasis	4	3
Meningioma	14	12
GCT (giant cell tumor)	6	5
Osteoid osteoma	1	1
Fibrous dysplasia	4	3
Cylindroma	1	1
	115	

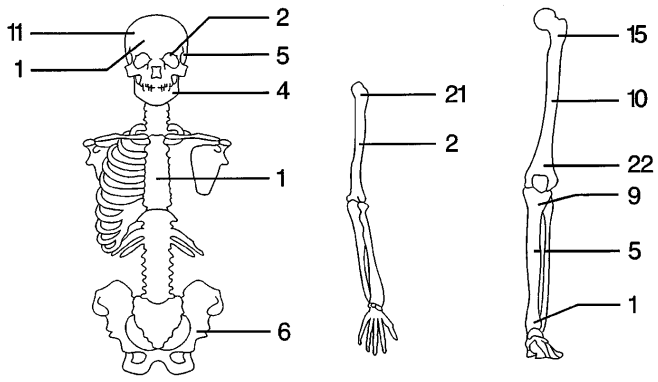

Fig. 3 Location of autoclaved re-implants in 115 published cases

portant factor. In this context, we have to emphasize the crucial importance of conscientiously performed biopsies to confirm that the surgical margin is adequate. This point is essential in using autoclaved re-implants because the resected specimen is not available in its entirety. However, the low local recurrence rate of 0% in our 9 cases and 7% in all 115 published cases – all of them in high-grade sarcomas – may suggest that this problem can be solved without disadvantage for the patient. Four of the 8 local recurrences occurred in one series of 12 patients [14], and the other 4 in the remaining 103 patients. Considering these facts, 'sacrificing' the pathologic specimen may be justified because – after excision of relevant and representative biopsies – the specimen might be more beneficial as an excellent biological reconstruction to the patient than as a pathological preparation to the pathologist. Systemic recurrences are documented in 17 patients after a mean follow-up of 27 months (range 8–54 months). However, the information about systemic recurrences is only of limited importance, because of the different histological diagnoses (Table 2), sites (Fig. 3), and adjuvant treatment methods.

When using the tumor-bearing bone segment after extracorporeal devitalization as an autoclaved autograft for reconstruction, it is necessary to guarantee not only a safe margin but also the definite killing of all tumor cells by means of the extracorporeal treatment. Thus, definite killing of all tumor cells is 'conditio sine qua non' for this method. It is evident that an effective heating time as long as possible at a high temperature is desirable. On the other hand, however, inductive capacity and the biomechanics of the bone will be considerably reduced by a higher temperature and longer heating time [30, 35]. Thus, the treatment objective is a thermal dose which guarantees devitalization of tumor tissue and which does not impair the biological quality of the re-implant more than necessary. In the 1920s Friedgood found that Walker rat sarcoma cells were killed after heat treatment at 44° C for 30 min [20]. Up to now, many studies have been published which show that the thermal death doses of different tumor cell lines were of the same scale [11, 30, 44, 45]. Because of the exponential effect of increasing temperatures above 43° C on the killing of cells, several investigations showed that the time required for an isoeffect must be decreased by a factor of 2 when the temperature is elevated 1° C [13, 53]. Taking into account a certain security factor for definite devitalization of tumor tissue, we have to insist on an exposure time of about 2 min at 60° C or 0.5 min at 65° C as an absolute minimum [8]. In an experimental study, we could show that penetration of heat in large cancellous bone areas like the femoral condyles requires a reasonably long time. In accordance with these data, we recommend a minimum effective autoclaving time of 15 minutes at 134° C or 20 minutes at 120° C when for large long bones with the intention to devitalize tumor cells [8].

The most interesting question in addition to local recurrence rate is whether or not the re-implanted autoclaved bone segments are incorporated. Additional grafting with fresh autogenous cancellous bone was performed in 37 patients and in 1 patient, supplementation with allogeneic bone matrix [34]. Unfortunately, the data about consolidation of the re-implant-host junction are quite incomplete. Consolidation took place in 80 cases, and in 3 further cases the re-implants consolidated after secondary grafting. In 25 cases, the time until consolidation was documented at a mean of 9.7 months (range 2–21 months). In 8 cases, no consolidation took place during the follow-up. In 2 cases of re-implantation of an entire long bone, consolidation was not possible. In 22 cases no data about consolidation were documented. In the first 4 patients operated on in Tübingen and in the 2 patients in Schwerin, we also used autogenous cancellous bone grafting. However, we could not see any advantage with respect to incorporation and thus, we do not generally recommend bone grafting.

We distinguish between different reconstruction techniques: Intercalary bone segments, pelvic bones, or skull bones were re-implanted and stabilized with various osteosynthesis techniques. In tumors of the proximal humerus, shoulder arthrodesis was performed in one case and in the other 20 the re-implant was combined with a long-stem shoulder prosthesis. A hip arthrodesis was done for one tumor of the proximal femur, and in the other 14 cases with this location, the re-implant was stabilized by means of a long-stem hip prosthesis. The re-implanted distal femoral segments were stabilized in 3 cases by means of a knee arthrodesis and in 19 cases by means of a long-stem total knee arthroplasty. In our analysis of 115 cases of autoclaved re-implants, 11 revisions (10%) were necessary because of aseptic loosening or breakage of implants or fractures of the re-implants after a mean time of 41 months (range 4–132 months) postoperatively. In our 9 patients, we still have not seen any nonunions or fractures. In our patients, both intramedullary nailing and plate osteosynthesis led to incorporation of the autoclaved re-implant. According to our experience with an external fixation device, we do not see any advantage in this form of osteosynthesis. On the contrary, there may be a higher risk of infection via the fixation pins. The time until consolidation will take place may even be prolonged when using an external fixator. As there will be a reduced mechanical stability of the re-implant for some years, we think that the bone should be strengthened by means of an internal fixation device for many years, or even permanently. That is why an external fixator will not be the definitive osteosynthesis in most cases. Changing the osteosynthesis device, however, also increases the risk for infection. Therefore, we recommend a primary internal osteosynthesis. After intra-articular or extra-articular resections of the knee joint, we prefer arthrodesis to the use of an autoclaved autogenous graft in association with joint arthroplasty because we think that for the patient a definitive procedure with a stiff knee joint and a low rate of late complications is preferable to a movable joint with a high risk of late complications. We have not seen any problems when using a custom-made arthrodesis rod of high mechanical stability that allows full weight-bearing prior to bony incorporation. On the whole, we have to emphasize that good results can only be obtained when a biomechanically correct osteosynthesis is performed. Faults of the osteosynthesis technique have a much more negative effect under the biologically more unfavorable conditions of a devitalized transplant than under ‘normal conditions’. According to our experimental investigations, bone healing between viable and dead bone is possible, when the biologically unfavorable situation is improved by means of a mechanically optimized osteosynthesis [7]. Both the data in the literature and our cases demonstrate that under these conditions, bony union can be achieved and will be followed by slow revitalization. However, the time until solid consolidation can be expected must be multiplied by a factor of 3 compared with osteotomies of nondevitalized bones (Table 1). Nevertheless, the development of a pseudarthrosis remains – similar to massive allografts and other reconstruction methods using dead bone – the main problem in this reconstruction technique. Experimental and clinical data of the use of electromagnetic fields [6] and low-intensity pulsed ultrasound [28] for accelerating bone healing are very encouraging. Further investigations are necessary for evaluating the role of these methods in the incorporation of massive allografts or devitalized autografts.

Histological examinations after re-implantation of autoclaved autografts are reported in 10 cases between 8 and 72 months postoperatively [14, 19, 24, 26, 41]. In the first case of a re-implanted mandible without stable osteosynthesis, there was considerable resorption and nonunion [24]. From a histologic point of view, the autoclaved bone had persisted as a ‘tolerated foreign body with a fibrous capsule’. In the case of a re-implanted complete humerus, there were also no viable osteocytes. However, the biopsies showed partial revascularization of the re-implant or bony ingrowth of host bone in all three other cases and – in the case of a pelvic tumor – replacing most of the autoclaved segment. How can we explain these different results? In the first case of the mandible, there was no direct contact to the host bone because of lack of an adequate osteosynthesis. The humerus, too, had no contact to an host bone, because the entire bone was resected and re-implanted. However, when there is a close contact between the devitalized bone and the host bone, the chance for bony ingrowth and slow revitalization by means of creeping substitution is high. In an experimental study in dogs, microangiography and fluorescent microscopy revealed that there is first a revascularization and then slow revitalization of the dead bone [7]. The histologic examination of our patient 8 at 12 months postoperatively apparently represents a stage in which revascularization had begun, but revitalization of osteons was not yet visible. The radiological analysis of our patients also confirms the experimental data. In this context, the distinct signs of revitalization and remodeling in the central part of the diaphyseal re-implants of our patients are very interesting. Radiological analysis illustrates that revitalization of autoclaved bone is not only possible in small re-implants or in areas of bone next to the osteotomy, but also in central areas of long diaphyseal re-implants (Fig. 2).

A primary infection was only documented in one patient [15]. Three further infections, including our patient 1, occurred secondarily by scattering from a local source: 27 months after operation from the ipsilateral toe [27]; 16 months after operation from the ipsilateral foot [26]; 17 months after operation from irradiated skin covering re-implanted tibia segment (patient 1). In one patient, infection occurred 2 months postoperatively without a local source [34]. In 2 patients, the secondary infection could be successfully treated and the limb salvaged [27]; one suffers from recurrent fistulation [34]. In the other 3 cases of infection, an amputation was necessary (two hip disarticulations and one knee disarticulation). In our opinion, the infection in our patient 1 was due to the irradiation at least to the same extent as the reconstruction method. If we had used a muscle flap of the medial gastrocnemius

muscle in the primary reconstruction of the tibia, the spread of the local infection of the skin to the underlying bone might have been prevented. From this experience, like other authors [38] we came to the obvious conclusion of recommending the use of a pedicled muscle flap in all reconstructions of the tibia. All in all, the complication rate is comparable or even lower than in other reconstruction techniques. Compared with allografting, both the rate of early complications, especially infections, and the rate of late complications like nonunion and fractures might be lower. The reason for the better results may be the geometrically optimally fitting re-implants. In agreement with Harrington and co-workers [27], we have to emphasize that the surgeon must have extensive experience with internal fixation techniques to avoid the many pitfalls of inadequate fixation and interference with healing so prevalent in this field. Compared to endoprosthetic replacement, the rate of early complications is similar, but late complications can occur more often after implantation of tumor endoprostheses. Nevertheless, tumor endoprostheses, transplantation of massive allografts, and biological reconstructions using autogenous bone will remain the standard procedures in reconstructive musculoskeletal tumor surgery because they can be applied independently of the mechanical situation of the tumor-bearing bone.

As there are very different sites of tumors, from long bones to skull bones, and the documented data about the functional results are both inconsistent concerning terminology and sometimes incomplete, it is very difficult to evaluate the functional results. In tumors of the upper or lower extremities and of the pelvis (91 patients), we assessed the functional result according to the very clear method of Amino et al. [3]. When using these assessment criteria, the functional result was excellent in 36 patients (40%), good in 36 patients (40%), fair in 7 patients (8%), and poor in 10 patients (11%). In 2 patients (2%), no data about functional outcome were available. The functional result of the tumors of the mandible (4 cases) was assessed according to the authors' descriptions. In 3 patients, the functional result was good, and in 1 patient, no data about functional outcome were available. In 19 tumors localized in the craniofacial skeleton and in 1 tumor of the sternum, an assessment of function was not possible.

Considering the analysis of the published cases and our own patients, we can conclude that oncologically correct resection, autoclaving, and re-implantation of a tumor-bearing bone segment is a practicable biological reconstruction method in limb salvage surgery. From the oncological point of view, the method has about the same risk for local recurrence as the implantation of tumor prostheses, when both the tumor is resected with a safe surgical margin and autoclaving-time and temperature are adequate. An essential prerequisite for this method is the absence of large osteolytic areas which compromise the stability of the bone.

We do not want to suggest that re-implantation of autoclaved tumor-bearing bone segments is the best method for limb reconstruction after tumor resection in every case. However, we think that it is a very good alternative in a small number of appropriately selected patients. In addition, especially in developing countries, where the resources for tumor prostheses and bone banking are limited, the use of autoclaved bone segments might be interesting. As all established reconstruction methods are associated with high complication rates, we must look for the best solution in the individual case while continuing to look for new solutions.

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