Reimplantation of a Large Extruded Segment of Bone in an Open Fracture

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Replacing an extruded segment of bone in an open fracture imposes a challenging decision concerning the best and safest patient management. There are numerous advantages to restoring the patient's own extruded bone segment to its original location, particularly when the bone segment is of structural importance. However, reimplantation of contaminated and avascular extruded bone segments can potentially result in serious infection or nonunion. There is no conclusive evidence regarding the best decontamination protocol for the safest use of the recovered bone segment as an autologous graft. Among the different chemical sterilization solutions 10% povidone-iodine and chlorhexidine gluconate solutions are the author's most preferred solutions. Regarding cellular toxicity, 10% povidone-iodine has been found to be the most favorable among the readily available solutions. *(J Hand Surg Am. 2017;42(2):128–134. Copyright © 2017 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Extruded bone, open fracture, reimplantation, povidine-iodine, chlorhexidine gluconate.

Open fractures may be complicated by bone loss. Fractures with minimal bone defects may heal with stabilization alone. Small circumferential and segmental bone loss may be treated with autologous or allogenic bone grafts. Large segmental bone defects may require massive bone graft, vascularized bone graft, bone transport, or allograft for reconstruction.[1–4] If the structurally important segment of bone is retained but is heavily contaminated or extruded, or not attached by periosteum, one has to decide if one can replace that segment in its natural position.

Retrieving a large extruded bone segment from the field of an accident imposes a challenging question of whether to use the bone in its original place or discard it. The segment may be heavily contaminated in road traffic accidents, farm accidents, war-related injuries, or industrial accidents. There are some published reports regarding successful reimplantation of a large segment of extruded bone in open fractures of the femur, tibia, humerus, forearm bones, and talus.[1–23] However, there are concerns regarding the introduction of a contaminated devitalized bone fragment back into the wound, which increases the risk of infection, subsequent osteomyelitis, and nonunion. This article reviews the evidence to pose the question: what to do with a large extruded segment of bone in an open fracture regarding its safe use to preserve best function?

Table 1 demonstrates a summary of successful reports regarding the reimplantation of extruded large bone segments from open fractures. A majority of patients had been involved in road traffic accidents. Hand surgeons who treat upper limb open fractures may encounter a large extruded fragment of the upper limb skeleton. Among the 24 reports in Table 1, 6 involve the upper limbs.

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Advantages of reuse of the patient's own extruded bone fragment

There are numerous advantages to reusing the patient's own extruded bone fragment in its original

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place, particularly when the bone fragment is structurally important. The fragment preserves the shape and length of the bone and soft tissue during reconstruction. It is immunologically compatible and acts as a scaffold for osteoblastic, osteoinductive, and osteoconductive bone repair. It circumvents morbidity of autogenous bone harvest. It provides a near-perfect reconstruction of the skeleton, especially if such a fragment is a major portion of an adjacent joint. It obviates the need for allograft or bone transport and may allow earlier and more physiological rehabilitation.[1–23]

Preparation of the recipient soft tissue

It is important to provide a clean and healthy vascularized bed and periosteum to enhance revascularization and incorporation of the extruded bone. The soft tissue injuries may occur from a contaminated agricultural wound, road traffic accidents, or war-related wounds. Essential to successful reimplantation is meticulous debridement and irrigation of the wound and disinfection of the extruded bone.[1–23]

Disinfection of a corticocancellous extruded bone strut

Table 1 presents several successful reports of reimplantation of corticocancellous extruded bone fragment.[2,4,5,6,8,10–14,17,18–22]

In vivo *experiments:* Harper[11] scrubbed a segment of the femur with povidine-iodine and soaked it in a 0.5% neomycin solution. Then he stored the structurally important extruded fragments of the left femur open fracture in a subcutaneous pouch of the right thigh for a later use as autologous bone grafts. After 65 days, he used the stored fragments to reconstruct the bone defect. Histopathological study at the time of reimplantation demonstrated that osseous cells in the fragments were viable and had preserved their osteoblastic activities.

In an animal study, 20 samples of femur of rats were contaminated by *Staphylococcus aureus* broth. They were divided into 4 groups and underwent 4 different decontamination protocols: normal saline, autoclave, boiling, and 10% povidone-iodine. The samples were replaced and fixed by Kirchner wires. Radiological examination demonstrated that the 10% povidone-iodine group had lower infection rate and higher radiological union rate than the boiled, autoclaved, and normal saline groups.[24]

In vitro *experiments:* van Winkel and Neustein[22] compared 6 different treatments for sterilization of contaminated bovine metatarsals. They compared normal saline, povidone-iodine scrub/normal saline, povidone-iodine scrub/autoclave, povidone-iodine scrub/thimerosal immersion, povidone-iodine scrub/povidone-iodine immersion, and chlorhexidine gluconate scrub/antibiotic solution immersion. They found that povidone-iodine scrub/autoclave and chlorhexidine gluconate scrub/antibiotic solution immersion were 100% effective for sterilization of the contaminated bovine metatarsals.

Bauer et al[25] compared 5 treatment protocols of autoclaving and mechanical agitation by 2% chlorhexidine gluconate, dry povidone-iodine, wet povidone-iodine, and normal saline for contaminated bone samples with regard to sterility and cell viability. The samples were contaminated by a broth prepared from the operating room floor bacterial culture. Among the 5 treatment protocols, autoclaving, chlorhexidine gluconate, and dry povidone-iodine sterilized all samples; however, autoclaving and chlorhexidine gluconate left no viable cells. They observed that dry povidone-iodine provided the best result for sterilization and maintenance of tissue viability.

Disinfection of an extruded osteochondral fragment

The extruded skeleton may contain some chondral structures that add to the complexity of the sterilization technique to preserve the function of the chondral tissue. Table 1 presents several successful reports of reimplantation of osteochondral fragment.[3,7,9,15,16]

In vitro *experiments:* Bruce et al[26] compared chemical decontamination of the osteoarticular fragments that were dropped on the operating room floor with 10% povidone-iodine, 4% chlorhexidine gluconate, and 70% isopropyl alcohol/2% chlorhexidine gluconate followed by decontamination by mechanical agitation with normal saline. They reported that 5 minutes of cleansing with a 10% povidone-iodine solution followed by a normal saline solution rinse provided the best balance between effective decontamination and cellular toxicity.

In an effort to evaluate scientific protocols for sterilizing and salvaging of contaminated osteochondral allograft fragments that do not adversely affect cartilage viability, Campbell et al[27] studied the effects of various concentrations of chlorhexidine on human articular chondrocyte viability. They reported that pulse lavage with 0.002% chlorhexidine gluconate did not cause significant cell death within 7 days after exposure and that chlorhexidine gluconate at concentrations more than 0.002% significantly decreased chondrocyte viability.

Disinfection of an extruded bone fragment with an attached ligament

In vitro *experiments:* Goebel et al[28] compared the effectiveness of 3 different disinfection solutions:

TABLE 1. Successful Reimplantation of Large Segments of Extruded Bones in Open Fractures

Authors	Age/ Gender	Site/Length	Type of Injury	Sterilization Technique	Time of Reimplantation	Storage of the Fragment
Abell, 1966[5]	26/M	Femur/19 cm	Motorcycle-vehicle accident	Soaked in benzalkonium chloride (Zephiran Chloride) and autoclaved	After 3 d	In a sterile container
Aizah et al, 2014[6]	14/M	Femur/8 cm	Motorcycle-vehicle accident	Washed with normal saline and gamma irradiated	After 2 wk	Refrigerated at 4°C
Burston et al, 2011[7]	28/F	Talus (osteoarticular)	Bicycle-vehicle accident	Washed, soaked in 10% iodine-saline solution and frozen	After 8 d	Frozen at −80°C
Canovas et al, 1999[8]	16/?	Tibia/12 cm	Cycling accident	Boiled in saline for 20 min	Immediately	-
Farrelly et al, 2012[9]	14/F	Distal tibia (osteoarticular)/ 15 cm	Pedestrian-vehicle accident	Scrubbed with chlorhexidine, rinsed with 1% povidine-iodine diluted with normal saline	Immediately	-
Hansson et al, 1977[10]	16/M	Tibia/15 cm	Motorcycle-vehicle accident	Not specified	Immediately	-
Harper, 1982[11]	31/M	Femur/9 cm	Motorcycle accident	Scrubbed with povidine-iodine and soaked in a 0.5% neomycin solution	After 65 d	Subcutaneous pouch of the opposite thigh
Kao and Comstock, 1995[12]	22/M	Radius/5 cm	Motorcycle accident	Scrubbed with povidine-iodine	After 3 d	Refrigerated at 4°C in a sterile container with bacteriostatic saline
Kirkup, 1965[13]	20/M	Femur/25 cm	Motorcycle-vehicle accident	Boiled and autoclaved before reimplantation	After 12 d	-
Kumar et al, 2006[1]	10/M	Radius/10 cm	Fell from a tree	Washed with povidine-iodine, rinsed with saline, autoclaved, and soaked in gentamicin solution	Immediately	-
Kumar et al, 2013[14]	12/F	Radius/12 cm	Fell from a tree	Brushed with Savlon, hydrogen peroxide, normal saline, and povidine-iodine and autoclaved	Immediately	-
Mnif et al, 2010[16]	34/M	Talus (osteoarticular)	Fell from a height	Cleansed for 30 minutes with 4% chlorhexidine	Immediately	-
Mazurek et al, 2003[2]	15/M	Femur/13 cm	Motorcycle-vehicle accident	Soaked in 4% chlorhexidine gluconate for a total of 270 min	After 17 d	Refrigerated in a sterile container
Meininger et al, 2010[15]	33/M	Distal tibia (osteoarticular)/ 20 cm	Motorcycle-vehicle accident	Irrigated by pulse lavage of normal saline	Immediately	-

(Continued)

TABLE 1. **Successful Reimplantation of Large Segments of Extruded Bones in Open Fractures (Continued)**

Authors	Age/ Gender	Site/Length	Type of Injury	Sterilization Technique	Time of Reimplantation	Storage of the Fragment
Moosazadeh, 2002[17]	24/M	Femur/13.5 cm	Motorcycle-vehicle accident	Brushed, washed with heated saline, soaked in gentamicin solution for 20 min	Immediately	-
Panisello et al, 2003[3]	17/M	Distal humerus (osteoarticular)/?	Motorcycle accident	Cleansed for 20 min in 4% chlorhexidine and autoclaved	Immediately	-
Rao and Patil, 2004[18]	17/M	Radius/10 cm	Motorcycle-vehicle accident	Scrubbed with cetrimide and soap (20 min), immersed in hydrogen peroxide (10 min), washed with normal saline, and autoclaved	Immediately	-
Rouvillain et al, 2006[19]	17/M	Femur/11 cm	Motorcycle accident	Autoclave	After 20 d	-
Shanmuganathan et al, 2015[20]	30/M	Femur/10 cm	Motorcycle-vehicle accident	Washed with saline and povidine-iodine for 20 min, soaked in vancomycin for 30 min	Immediately	-
	62/M	Tibia/4.5 cm	Motorcycle-vehicle accident	Washed with saline and povidine-iodine for 20 min, soaked in vancomycin for 30 min	Immediately	-
	18/M	Femur/10 cm	Motorcycle accident	Washed with saline and povidine-iodine for 20 min and autoclaved	Immediately	-
Tuli, 1967[21]	8/M	Radius and ulna	Vehicle accident	Scrubbed with Cetavlon lotion, boiled for 12 min, and soaked in crystalline penicillin and streptomycin	Immediately	-
Van Winkle and Neustein, 1987[22]	24/M	Femur/10 cm	Motorcycle-vehicle accident	Scrubbed with chlorhexidine and soaked in bacitracin and polymyxin B solution for 4 h	Immediately	-
Wu and Shih, 1996[4]	16/M	Femur/14 cm	Motorcycle accident	Autoclaved	Immediately	-

10% povidone-iodine, a triple-antibiotic solution (gentamicin, clindamycin, polymyxin), and 4% chlorhexidine gluconate in the setting of contaminated bone—patellar tendon—bone grafts harvested from rabbits. They observed that using a triple-antibiotic solution after chlorhexidine gluconate was the most effective method for disinfection of the contaminated bone—patellar tendon—bone grafts.

Cooper et al[29] evaluated the efficacy of saline solution containing bacitracin and polymyxin B for 15 minutes for disinfection of patellar tendon grafts contaminated by dropping on the operating room floor. The authors reported positive cultures in 30% of their samples.

Burt et al[30] compared the effect of benzalkonium chloride, castile soap, castile soap followed by benzalkonium chloride, triple antibiotic, chlorhexidine gluconate, and chlorhexidine gluconate/triple antibiotic on the contaminated bone-tendon allografts. They reported that only the 4% chlorhexidine power irrigation solution and 4% chlorhexidine/triple antibiotic bath completely disinfected all tissues. They also found that a 2% chlorhexidine irrigation solution was as effective as a 4% solution.

Disinfection of extruded calvarial bone

Although the literature on extruded calvarial bone deals mostly with a piece being accidentally dropped on the operating room floor, extruded calvarial bone may occur from injuries. Calvarial bone may be expected to behave differently from nonmembranous bone.

In vivo experiment: Jho et al[31] found that sterilization with ethylene oxide gas was effective for later usage of skull bones as autologous bone grafts for cranioplasties. The bone grafts were stored at room temperature. Cranioplasties were performed after an average of 4 months after decompressive craniectomy.

In vitro experiment: Schültke et al[32] compared 3 different disinfection methods: 3% H_2O_2, boiling in normal saline for 15 and 30 minutes, and a special process of steam disinfection at a temperature of 75°C for 20 minutes for disinfection of explanted skull bones. Skull bone fragments were artificially contaminated with strains of *Serratia marcescens*, *Enterococcus faecium*, and *S. aureus*. Among the 3 different disinfection methods, only the steam disinfection completely eliminated the bacterial strains tested.

Disinfection related to collagen structure and cellular viability

In vitro experiments: Molina et al[33] investigated the sterilization efficacy of a solution of neomycin and polymyxin B, 4% chlorhexidine gluconate, and 10% povidone-iodine on contaminated anterior cruciate ligament grafts dropped on the operating room floor. Among the 3 sterilization agents, chlorhexidine solution was the most effective. However, Alomar et al[34] studied the effects of various concentrations of chlorhexidine on decontamination of the tendon graft collagen and cell viability. They reported that 4% chlorhexidine gluconate caused collagen fibrils to dissolve *in vitro* and tendon graft disinfection with 2% chlorhexidine gluconate was cytotoxic to the cells. They suggested that 4% chlorhexidine gluconate should not be used as a disinfectant because of its chemical and cytotoxic effects on tendon collagen and fibroblasts. They also noted that 2% chlorhexidine gluconate can be used to disinfect contaminated anterior cruciate ligament grafts; however, such treatment will drastically reduce the metabolic activity of the cells within the graft, making it similar to an acellular allograft tendon.

Summary

Reusing a large retrieved bone segment from the scene of an accident is an important decision. Parallel clinical scenarios include a fragment of critical bone graft that is accidentally dropped on the operating room floor, the surgeon contemplates reconstructing the skeleton of a mutilated limb using the bones from a contaminated unsalvageable or amputated limb, or bone fragments recovered from the scene of an accident need to be decontaminated and disinfected before being either used immediately or preserved for later usage.

There is no conclusive evidence regarding the best decontamination protocol for the safe use of the recovered bone fragment.[35,36] Washing, soaking, and mechanical agitation by brushing and scrubbing of the recovered bone fragment with copious amount of normal saline and different chemical solutions have been used to remove the contaminants and disinfect the extruded bone fragment. Some authors used boiling or autoclaving for final sterilization of the extruded bone. However, boiling and autoclaving damages the collagen fibers and kills the cells as well as eliminates the induction properties of regenerating bone; these methods convert the living bone into a scaffold of mineral matrix.[3,11] The autoclaved bone is brittle and mechanically weak and requires an extended period for revascularization and incorporation of the graft.[18]

Gamma irradiation has also been used for disinfection of the extruded bones.[6] It has been extensively used for preparation of allograft. However, it is not readily available and adversely affects cell viability and mechanical properties of collagen structure and bone tissue.[37–39]

Regarding satisfactory bacteriocidal capabilities, among the different chemical sterilization solutions, 10% povidone-iodine and 2% and 4% chlorhexidine gluconate solutions were the most preferred solutions.[9,22,25,28,30,33,34] However, chlorhexidine gluconate may induce adverse effects on collagen structure and cellular viability.[27,34] Regarding cellular toxicity, 10% povidone-iodine has been found to be the most favorable among the readily available solutions.[23–26]

EDITOR'S NOTE

The topic of inadvertent contamination of an important bone segment seems to be one that almost every orthopedic surgeon (and many plastic surgeons and neurosurgeons) seems to have witnessed at some point in their experience. Despite this, Dr Afshar's analysis of the literature found few reported cases relating to the hand or upper extremity. What this finding most likely reflects is the effect of publication bias – the absence from the literature of important and useful information simply because of the perceived implication of failure associated with negative research findings or an unusual occurrence that might be considered as reflecting incompetence. However, it is clear that the loss of these important insights actually impedes our progress. As a result, an upper extremity surgeon who must deal with this situation – contamination of a structurally critical fragment of bone – is forced to extrapolate from the experiences of surgeons who have had to address this in the lower extremity. In this regard, Dr Afshar's contribution provides an excellent overview of the results of both clinical experiences and *in vitro* experiments to help guide us in managing this rare and unexpected occurrence.

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