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Stabilization of multiple rib fractures in a canine model

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ABSTRACT

Background: Operative stabilization is frequently used in the clinical treatment of multiple rib fractures (MRF); however, no ideal material exists for use in this fixation. This study investigates a newly developed biodegradable plate system for the stabilization of MRF.
Methods: Silk fiber-reinforced polycaprolactone (SF/PCL) plates were developed for rib fracture stabilization and studied using a canine flail chest model. Adult mongrel dogs were divided into three groups: one group received the SF/PCL plates, one group received standard clinical steel plates, and the final group did not undergo operative fracture stabilization ($n = 6$ for each group). Radiographic, mechanical, and histologic examination was performed to evaluate the effectiveness of the biodegradable material for the stabilization of the rib fractures.
Results: No nonunion and no infections were found when using SF-PCL plates. The fracture sites collapsed in the untreated control group, leading to obvious chest wall deformity not encountered in the two groups that underwent operative stabilization.
Conclusions: Our experimental study shows that the SF/PCL plate has the biocompatibility and mechanical strength suitable for fixation of MRF and is potentially ideal for the treatment of these injuries.

1. Introduction

The fracture of multiple ribs (MRF) is a major cause of morbidity and mortality in severely injured patients, especially in the presence of a flail chest, defined as three or more consecutive ribs fractured at more than two sites [1,2]. Patients with a flail chest require aggressive pain control, pulmonary toilet, and often intubation and mechanical ventilation to establish internal pneumatic stabilization of the flail segment. This may result in a prolonged intensive

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care unit (ICU) stay and pulmonary complications including pneumonia, septicemia, and barotrauma [3]. The ideal treatment of MRF has remained controversial. In the 1950s, surgical fixation was a first-line therapy, but by the 1970s, the advent of mechanical ventilation dramatically altered the focus of chest wall fracture management to treatment of the lung rather than the bone injury [4–7]. In recent years, some researchers have advocated for operative stabilization of the fractured ribs, claiming that surgical fixation of select patients with MRF markedly minimizes ventilator support time, the length of ICU and overall hospital stay, and long-term disabilities [8].

Wiring, plates, intramedullary devices, and vertical bridging are different types of fixation devices that have been introduced and used for surgical fixation of rib fractures. Traditionally, metal has been the most popular material for fracture fixation. Despite excellent results, metal implants can cause problems, including stress shielding where osteopenia can occur from a lack of stress on the bone, accumulation of metals in tissues although modern metal composites may reduce this effect, hypersensitivity, growth restriction, pain, corrosion, implant migration, and imaging and radiotherapy interference. Furthermore, an operation to remove the implant is often required once the healing process is complete or due to any complications [9,10].

Currently, there is a trend away from the use of metal materials for fracture fixation toward a preference for biodegradable implants. This can be attributed to the increasing sophistication of biodegradable materials, which allows them to overcome the limitations of metal implants. The main advantage of a biodegradable device is that it provides the correct amount of support when needed, but it harmlessly degrades over time. This means that there is no need for an additional removal operation, reducing the total treatment and rehabilitation time of the patient and providing economical advantages by avoiding an expensive removal operation [11].

Biodegradable materials have application as pins for the fixation of chondral or osteochondral small defects of articular surfaces, and as thin plates and areas used for fracture treatment in the maxillofacial area, including the orbit and skull, especially in children [11,12]. The use of biodegradable compounds in chest wall fracture with favorable results has occasionally been reported [13–15].

One biodegradable material is a biocomposite based on poly (e-caprolactone) (PCL) and reinforced by natural fibers [16]. An example of these natural fibers, silk fiber spun from silkworm cocoons (*Bombyx mori*), has excellent mechanical properties such as high tensile strength and modulus, high elongation, good elasticity, and excellent resilience [17]. *B mori* silk fiber consists primarily of two protein-based components, the inner fibroin filaments, and the outer sericin, which account for approximately 75 and 25% by weight, respectively. Because of the higher mechanical properties of silk fibroin (SF) fiber compared with sericin, before silk fiber is used; degumming is usually performed to obtain pure fibroin filaments with the removal of the sericin component [18].

Biocomposites consisting of PCL and SF fibers have promising potential in biomedical fields owing to their favorable mechanical characteristics and biocompatibility, especially in bone substitute and bone tissue engineering applications. In this study, we investigated by using a canine model, whether there are obvious benefits in undertaking surgical stabilization of MRF and if the use of SF/PCL plates for stabilization can be used successfully and offer an alternative to the use of metal.

2. Materials and methods

2.1. *Preparation of the SF/PCL plates*

The silk fiber was degummed by boiling in 0.5 wt% Na_2CO_3 water solution for 40 min and rinsing in deionized water to remove the sericin component. SF/PCL composites with 45% fiber content by weight were prepared by melt-mixing PCL and SF fiber at 140°C in a Haake Rheocord 900 Rheometer (Haake Mess-Technic GmbH, Berlin, Germany) for 15 min and hot pressing the composite in a mold at 140°C for 10 min. The SF/PCL plates were 4.8 cm long and 3.6 cm wide with lateral hooks on each side (Fig. 1). The plates were visualized with scanning electron microscopy (SEM), and biomechanical properties were evaluated with the three point bending test. The plates were sterilized using ethylene oxide gas before implantation.

2.2. *Animal experiments*

Eighteen adult mongrel dogs aged 2–3 y, weighing 15.9–20.6 kg, were used in this study. Dogs were divided into three groups: one group received SF/PCL plates, one group received standard clinical steel plates, and the final group did not undergo operative fracture stabilization ($n = 6$ for each group). The study protocol was approved by the Animal Care and Use Committee of the Second Military Medical University, Shanghai, and carried out in accordance with the latest version of the United States National Institutes of Health's Guide for the Care and Use of Laboratory Animals.

The same operative procedure was used for all animals. The dogs underwent general anesthesia with sodium pentobarbital (30 mg/kg intravenously) throughout the procedure. Lying supine, the skin was shaved and treated with an iodine based skin preparation. On the right side of the chest wall, the sixth, seventh, and eighth ribs were exposed through a 10 cm transverse incision. The latissimus dorsi and the serratus anterior muscles were divided. To create conditions simulating a flail chest in each dog, the three ribs were cut respectively at two points approximately 30-mm apart using a rongeur. After creation of the rib fractures, the SF/PCL plates were immersed in hot water (>70°C, 30s) until they became pliable enough to mold. When the two fracture ends were adequately reduced, each plate was bent in a convex curvature to approximate the surface of the rib overlying the fracture line; plates were anchored with lateral hooks. In the other operative fixation group, steel plates (Ti-Ni SMA encircling plate, 4HL I ∼ III, Seemine, China) were used to fix the fractures in the standard fashion. The size of plate was 4.8 cm in length and 3.6 cm in width. Subcutaneous tissue and skin was closed layer-by-layer, with a subcutaneous negative pressure drain left in place.

Prophylactic antibiotics (1,600,000 U of procaine penicillin and 80,000 U of gentamicin sulfate a day) were given postoperatively and maintained for 6 d.

During the operation, care was taken to ensure that (a) all the procedures were performed as closely as possible to the