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Fracture healing after reamed and unreamed intramedullary nailing in sheep tibia

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ABSTRACT

Intramedullary nailing is a well-established method for stabilisation of long-bone shaft fractures. It is still a controversy as to whether the procedure should be done by an unreamed or reamed technique.

In the present animal study, 24 sheep were treated with intramedullary nailing. Midshaft fractures (Arbeitsgemeinschaft für Osteosynthese (AO) type 42-A2/3) were created. Eight sheep were treated with an unreamed nailing technique (UN), a further eight sheep underwent tibia nailing by the reamed technique using the conventional AO reaming system (RC) and in a further eight sheep, reamed nailing was performed using an experimental reaming system (RE). Intra-operatively, the intramedullary pressure was measured and, during a healing time of 10 weeks, the growth of callus formation was labelled with fluorescence markers after 4 and 6 weeks. After 10 weeks, the animals were euthanised and the quality of fracture healing was determined by recording stiffness in torsion, antero-posterior and mediolateral bending and the load at yield. In addition, the callus formation at the fracture zone was evaluated by fluorescence microscopy and macroradiographs.

The results showed a decrease of intramedullary pressure when reamed nailing was performed with the RE (72.5 mmHg) system compared with the conventional AO reaming system (227 mmHg). Mechanical testing did not reveal any significant differences either for torsional or bending stiffness or for load at yield for any of the three procedures. Histological evaluation showed a similar callus formation for the UN group and the RE group. Callus formation in the UN (65 mm^2) and RE (63 mm^2) groups showed a higher increase during the first 6 weeks than those treated with the conventional AO reaming system (27 mm^2). This means that, especially during the first weeks of fracture healing, damage to the bone by the reaming process can be reduced by reaming with a reaming device with lowered cutting flutes and smaller drive-shaft diameter.

Intramedullary pressure can be significantly reduced by using reaming systems with reduced drive-shaft diameters and deepened cutting flutes. In the early phase of fracture healing, callus formation can be influenced positively when using the RE system.

Introduction

Intramedullary nailing has been well established as a standard treatment procedure for diaphyseal fractures of the long bones for many years even though the negative effects of intramedullary nailing, such as aseptic endosteal necrosis and systemic fat embolism have been known for years and have been the subject of much controversy.[14,34,35]

In the tibia, damage to the blood supply is the greatest problem, whereas systemic embolism is more relevant to the treatment of femoral fractures. Trauma caused by the reaming procedure has been made responsible for the negative effects of intramedullary nailing. For this reason, unreamed nailing, a method used even by Kuentscher, was further developed in the 1980s and enjoyed widespread clinical application not only in the treatment of closed, but also in the treatment of open fractures.[11,19,20,15]

Depending on the surgical school of thought and the geographical location, the two procedures, that is, unreamed versus reamed nailing, were the subject of lively debate.

It has been consistently demonstrated that the reaming procedure damages the endosteal blood supply, which consequently leads to avascular endosteal necrosis. If healing is uneventful, these necrotic zones will be remodelled in the normal course of healing.[3–5,13,33,24,28,29] If reaming is not

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performed, primary endosteal necrosis can be reduced from 70% to 31%.[12] This accelerates healing by approximately 2 weeks for simple fractures in sheep.[28,29] Reichert was able to demonstrate a positive effect of reaming, namely, that the blood supply to the periosteum was increased sixfold after reaming.[26] What consequences the increased blood supply has for fracture healing and how long the effect lasts is unknown because the measurement is only momentary. A clinical study of the Canadian Orthopaedic Trauma Society, published in 2003, stated the other side of the coin. This multicentre study showed a significant higher rate of nonunions in femoral fractures.[2] Another positive effect on reaming the medullary canal is the internal bone grafting. Högel et al.[10] were able to show that osteoblasts are still vital in the bone debris after correctly performed reaming. A study by Froelke et al.[7] showed the positive effect of reaming debris on the healing of bone after being placed in a defect in the sheep tibia. They also showed that there is no significant difference between reaming debris or iliac crest.

This study should clarify the influence of intramedullary pressure on callus development and quality of callus formation when intramedullary nailing is performed by an unreamed or reamed nailing technique. We hypothesised that lower intramedullary pressure will increase the speed of callus formation and the quality of the fracture callus during the healing process of tibia-shaft fractures.

Materials and methods

For this study, 27 adult Swiss mountain sheep were used (Animal trial adoption: GR 2/1997, 7/12/13/1998). They were all female with an average age of 5 years, and a weight ranging from 65 to 70 kg.

First, the diameter of the medullary cavity of the left tibia was measured by X-rays in the lateral view. Whilst reaming was performed up to 9.0 mm, sheep with a cavity diameter ranging from 8.0 to 9.0 mm were selected to be treated with the unreamed technique and sheep with a diameter of 7.0–8.0 mm were chosen to be treated with reamed intramedullary nailing. The magnification was 1.15.

For this experiment, three groups were made. In the first group, intramedullary reaming was performed with an experimental reaming system (RE) and in the second group, the conventional Arbeitsgemeinschaft für Osteosynthese (AO) reaming system (RC) was used. Sheep with a cavity diameter of 7.0–8.0 mm were randomised. Eight animals were treated with the unreamed nailing technique (UN) (Table 1).

The operative procedure was performed under anaesthesia with isoflurane. After correct positioning of the sheep, the left leg was shaved and disinfected. To produce standardised fractures, a custom-made fracture device was used (ADI, Davos, Switzerland) as described in the venia legendi of Prof. Christof Müller. This fracture device worked on the principles of four-point bending. After incision of the skin, an osteotomy of the cortex of one third was performed and a bending plate was positioned, and by Schanz screws, which were placed bi-cortically, guided through the bending plate, prestress was applied. A2/A3 fractures were produced by the impulse of a guided weight in the midshaft of the tibia, which was constantly 11 cm proximal from the medial malleolus. After performing the fracture, the soft tissues were closed and the fracture was reduced.

Table 1
Groups due to the diameter of the medullary cavity.

Method	*n*	Medullary cavity diameter
Experimental reaming system (RE)	8	7–8 mm
Conventional AO reaming system (RC)	8	7–8 mm
Unreamed nailing (UN)	8	8–9 mm

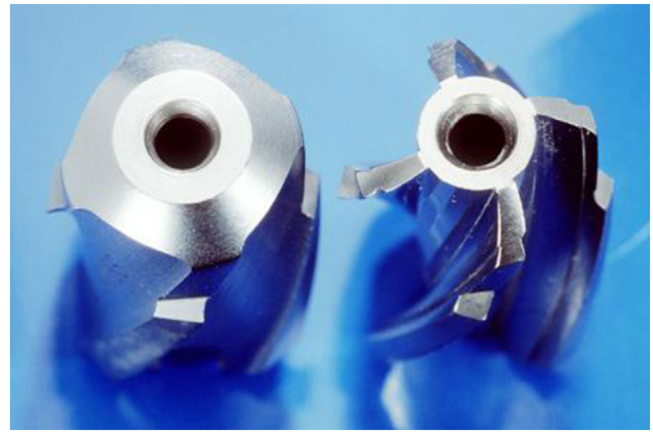

Fig. 1. Reaming systems with different reamer heads. The experimental reaming system contains a reamer head with deepened cutting flutes and a reduced drive shaft.

For fracture stabilisation, a solid nail (UHN, Synthes, Paoli, USA) with a length of 190 mm and a diameter of 7.5 mm was used. Interlocking was performed with two proximal and two distal 3.9-mm screws. The entry point for intramedullary nailing of the sheep tibia was placed anterior to the anterior cruciate ligament, which is different from the entry point in humans.

As reaming systems, we used the RC system (Synthes®) containing four front-cutting reaming edges with relatively small chip flutes, which were adapted on flexible two- to three-layered spring band steel drive shafts. The experimental reaming system was based on the geometry of the AO reaming system, but the chip flutes were deepened. All reamer heads were fixed on 3.3-mm steel shafts (Custom-made product, Mathys®, Medical AG, Bettlach, Switzerland). All reamer heads were brand-new and of 7.0-, 8.0-, 8.5- and 9.0-mm diameter (Fig. 1).

For measuring pressure 3 cm from the distal epiphysis of the tibia, the pressure tube, filled with sterile Ringer solution, was fixed in the anterior cortex. The piezoresistant pressure sensor (Type: PR-11-2; Keller Druckmesstechnik AG, Winterthur, FS: ±0.5%) was connected with the computer system. After opening of the medullary canal, the reaming procedure was done, starting with the 7.0-mm reamer heads, followed by the 8.0-mm, 8.5-mm up to 9.0-mm. In the unreamed group, the nail was inserted directly after opening the medullary canal. Intra-operatively, the intramedullary pressure was measured during the reaming process and the nail insertion (Fig. 2). For the examination, the highest pressure values during the reaming and nailing procedures were used.

The animals were euthanised after 10 weeks and the tibiae explanted. The quality of fracture healing was determined after implant removal using a uniaxial testing device (MTS, Bionix; resolution of ±1%, accuracy 0.1 mm). After embedding the proximal and distal ends of the bone in acrylate (Beracryl™), torsional testing was performed via a universal joint set for inner rotation at a speed of $1^\circ\ \mathrm{min}^{-1}$. Loading was carried out within the elastic range, whereby measuring was discontinued at an applied force of approximately 1000 Nm.

Next, bending stiffness in the antero-posterior plane within the range of elasticity was determined in four-point bending, whereby the anterior cortex was placed under tension.