Percutaneous Radiofrequency Epiphysiodesis in a Rabbit Model

A Pilot Study

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Abstract

Background Techniques for epiphysiodesis have evolved from open surgical techniques requiring direct observation of the physis to percutaneous techniques performed with fluoroscopy.

Questions/purposes Our purposes were to (1) describe a new minimally invasive surgical technique used to achieve epiphysiodesis using radiofrequency ablation, (2) document the effect of radiofrequency ablation on tibia length at 2, 6, and 12 weeks after ablation in a skeletally immature rabbit model, and (3) assess the effects of radiofrequency ablation on the histologic appearance of the proximal tibia physis and proximal tibia articular cartilage.

Materials and Methods We performed epiphysiodesis of the rabbit proximal tibia on 15 skeletally immature male New Zealand White rabbits using a 22-gauge

radiofrequency probe. The probe was positioned percutaneously and heated to 90°C for 4 minutes on the medial and lateral ½ of the physis. The opposite tibia was used as a control. Five animals were sacrificed at 2, 6, or 12 weeks postoperatively. Tibia length was compared using Faxitron® radiographs and electronic calipers. Histology of the growth plate was assessed with light microscopy.

Results We observed differences in tibia length between 4.16 mm and 11.59 mm (average 7.86 mm) at 12 weeks. The proximal tibia physis closed radiographically and histologically in all animals by 12 weeks. Histologic analysis showed no evidence of articular cartilage injury.

Conclusions This technique was reproducible and resulted in bone fusion of the rabbit proximal tibial growth plate. The use of radiofrequency ablation as described in this report may be used as an alternative to other surgical epiphysiodesis techniques.

Clinical Relevance This technique may be useful for epiphysiodesis of small tubular bones of the hands and feet in humans.

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Each author certifies that his or her institution approved the animal protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research. This work was performed at the Hospital for Special Surgery.

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Introduction

Epiphysiodesis is among the most widely used methods for limb-length equalization in growing children with projected limb-length discrepancies at maturity as much as 5 or 6 cm [7, 9, 11, 20]. Phemister [14] introduced the concept of open surgical epiphysiodesis in 1933. This technique required exposure of the growth plate and excision and replacement of a bone block from either side of the physis resulting in physeal bar formation on both sides of the physis. Blount and Clarke [2] popularized the use of epiphyseal stapling as a method to achieve formal epiphysiodesis and controlled angular growth for correction of angulation deformities.

Subsequent advancements in surgical techniques have included the development of percutaneous methods for achieving epiphysiodesis [3, 4, 9, 12]. Bowen and Johnson [3] described ablation of the growth plate using a curette under fluoroscopic guidance, and Canale et al. [4] described a technique using a cannulated reamer and a burr to obliterate the physis. Radiographic obliteration of the physis and subsequent limb-length equalization have been used with these percutaneous ablative surgical techniques [1, 5–7, 13, 15, 20]. Surgical complications have included failure of growth arrest [4, 20], incomplete growth arrest with angular deformity [7, 9, 20], and postoperative knee effusion [5, 6, 15]. In most patients undergoing percutaneous ablative epiphysiodesis, surgeons recommend protected weight-bearing between 1 and 6 weeks postoperatively and restriction from return to athletics for variable lengths of time. Concerns have been raised regarding fracture risk and risk of intraarticular drill penetration with this technique [5, 9]. Percutaneous epiphysiodesis using transphyseal screws has several advantages over percutaneous drill epiphysiodesis: immediate full weightbearing postoperatively, less risk of joint penetration, and immediate effect on cessation of longitudinal growth [9, 11]. However, many of these patients will have a second surgical procedure for removal of implants at the end of skeletal growth. Several other alternative techniques for achieving controlled physeal arrest have been proposed, including the use of laser destruction of the growth plate in a rabbit model [10] and thermal destruction of the growth plate in rabbit and dog models using standard electrocautery [16].

Radiofrequency ablation has been used successfully for ablation of osteoid osteomas in bone [17, 18]. This technique has been performed percutaneously under CT guidance. The technique results in minimal bone loss as a bone biopsy needle is placed percutaneously, and patients may return to full activities almost immediately. There have been few surgical complications with this technique aside from recurrent lesions [18].

Our purposes were to (1) describe a new minimally invasive surgical technique used to achieve epiphysiodesis with radiofrequency ablation, (2) document the effect of radiofrequency ablation on tibia length at 2, 6, and 12 weeks after ablation in a skeletally immature rabbit model, and (3) assess the effects of radiofrequency ablation on the histologic appearance of the proximal tibia physis and proximal tibia articular cartilage.

Materials and Methods

We used 15 12-week-old male New Zealand White rabbits weighing between 1.8 and 2.1 kg. The rabbit tibia achieves 86% of its adult length by 12 weeks and 98% of its adult

length by 20 weeks [8]. The tibia was chosen because of the mostly uniplanar proximal tibia physis in rabbits, which facilitates surgical and fluoroscopic identification and manipulation. Five animals then were sacrificed at three intervals after the radiofrequency ablation procedure: 2 weeks, 6 weeks, and 12 weeks. The contralateral tibia served as the control for each animal. This study received approval from the hospital and university IACUC review board.

All animals were anesthetized intravenously with ketamine and acetylpromazine and then intubated. The animals were monitored closely during surgery by a veterinary nurse anesthetist. The back of the animals was shaved for placement of the radiofrequency grounding pad. Both hind limbs of the rabbits were shaved, prepared, and draped in a sterile manner. The location of the proximal tibial physis was identified fluoroscopically and a 5-mm longitudinal incision was made over the medial aspect of the physis. A 0.045-inch Kirschner wire then was inserted under power transversely across the proximal tibial physis from the medial cortex through the lateral cortex (Fig. 1). The Kirschner wire entry site was located in the midportion of the physis from anterior to posterior.

The Kirschner wire was removed and the Radionics (Burlington, MA) SMK-10 22-gauge radiofrequency probe was inserted in the track left by the Kirschner wire. The active 5-mm tip of the probe was centered fluoroscopically in the lateral ½ of the physis, and the radiofrequency generator (RF-5; Radionics) was set at 90°C and activated for 4 minutes. The probe then was partially withdrawn and centered in the medial ½ of the physis and again

Fig. 1 Fluoroscopic insertion of a 0.045-inch Kirschner wire into the proximal tibia physis of a 12-week-old male New Zealand White rabbit is shown.

activated at 90°C for an additional 4 minutes. On the control side, the identical procedure was performed with placement of the 0.045-inch Kirschner wire across the proximal tibia physis and placement of the SMK-10 radiofrequency probe without activation of the radiofrequency generator. The wounds were closed on both sides with Monocryl® suture (Ethicon, Inc, Somerville, NJ). There were no complications related to anesthesia or surgery.

Immediately after surgery and while the animals were still under anesthesia, radiographs were obtained of the hind limbs of all the animals. The animals were permitted unrestricted weightbearing postoperatively with adequate pain control and standard wound care. The animals were euthanized by intravenous administration of sodium pentobarbital/isopropyl alcohol solution.

At the time of sacrifice, each tibia was anatomically dissected free of soft tissue attachments. Tibia length from the tibial plateau to tibial plafond was measured by two individuals (TA and XY) using electronic calipers, and the average of the two measurements was used to describe the tibial length. High-resolution Faxitron® (Faxitron X-Ray LLC, Lincolnshire, IL) single-plane AP radiographs of the dissected tibia were obtained after sacrifice for an additional length measurement (Fig. 2).

Fig. 2 Faxitron® radiographs show the control (right) and experimental (left) tibia of an 18-week-old male New Zealand White rabbit 6 weeks after a proximal tibia radiofrequency epiphysiodesis procedure. The proximal tibia physis remains open on the control side.

The proximal portion of each tibia including the metaphysis, physis, and entire epiphysis then was submitted for histologic examination. The proximal tibia specimens were fixed in 10% formalin and decalcified in EDTA. Five 6- μ m sagittal sections then were obtained at the midpoint of the medial and lateral segments of the proximal tibial physis. Representative slides were prepared with hematoxylin and eosin, alcian blue (for proteoglycan molecules in the hyaline cartilage of the physis), and collagen (for Type I collagen signifying bone production). Two independent observers (TA and XY) performed histologic evaluation including assessment for articular cartilage damage and for the presence or absence of bony bar across the physis.

Tibia length was compared between the experimental and control tibias at each interval (2, 6, and 12 weeks) using electronic calipers for measurement. Differences in tibial length as measured with electronic calipers were determined using the paired-samples Student's *t* test.

Results

The experimental tibias were consistently shorter than the control tibias at all intervals (Fig. 2). At 2 weeks ($p = 0.003$), 6 weeks ($p = 0.0003$), and 12 weeks ($p = 0.004$), all of the experimental tibias were shorter than the control tibias (Table 1). Although we did not formally measure angulation, one of the five experimental tibias in the 6-week group had apparent mild angulation of the proximal tibia physis in addition to relative shortening (Fig. 3).

On the experimental side 2 weeks after radiofrequency ablation, the proximal tibial physis showed evidence of thermal injury with fissuring, destruction of normal cells, and the presence of cellular debris (Fig. 4). The columnar arrangement of the chondrocytes was truncated, and there was a sharp transition from normal cells to a sudden demarcation without chondrocytes. Reparative processes on the outer edge of the thermal zone were evident, with a display of fibrotic tissue response and the appearance of fibroblasts interspersed among chondrocytes. The histologic specimens of the proximal tibia physis at 6 and 12 weeks on the experimental radiofrequency side showed

Table 1. Electronic caliper measurement of tibia length

Time	Tibia length (mm)		p Value
	Control side	Radiofrequency ablation side	
2 weeks	95.20	93.79	0.003
6 weeks	103.29	97.54	0.0003
12 weeks	106.75	98.89	0.004

Fig. 3 A Faxitron® radiograph shows normal alignment and length on the control (right) tibia compared with angulation and shortening on the experimental (left) tibia of an 18-week-old male New Zealand White rabbit 6 weeks after proximal tibia radiofrequency epiphysiodesis procedure.

progressive replacement of the physis with normal-appearing bone (Figs. 5, 6). The histologic appearance of the control side proximal tibia physes was normal at 2, 6, and 12 weeks after Kirschner wire insertion with the exception of one control specimen from the 2-week group. This specimen had a small cartilage island where the probe had been inserted just distal to the normal-appearing physis. In all of the control specimens, the articular cartilage anatomy was well preserved, and there was no evidence of physeal bar formation (Figs. 4, 5A, 6A). There was no evidence of articular cartilage injury on the experimental radiofrequency ablation side at any time.

Discussion

Epiphysiodesis is among the most widely used methods for limb-length equalization in growing children with projected limb-length discrepancies at maturity of as much as 5 or 6 cm [7, 9, 11, 20]. Advancements in surgical techniques have included the development of percutaneous methods for achieving epiphysiodesis [3, 4, 9, 12, 19]. The purposes of our study were to (1) describe a new minimally

Fig. 4A–B (A) An histologic specimen of the proximal tibia physis on the control side in the 2-week group, which underwent drilling without a radiofrequency ablation procedure, is shown (Stain, alcian blue; original magnification, $\times 45$). The articular cartilage is seen at the top of the image, the bony epiphysis in the middle, and the physis at the bottom. (B) The proximal tibia physis on the experimental side 2 weeks after radiofrequency ablation shows truncation of the normal columnar arrangement of the chondrocytes and sharp demarcation in the area of the prior radiofrequency procedure (Stain, alcian blue; original magnification, $\times 45$).

invasive surgical technique used to achieve epiphysiodesis using radiofrequency ablation, (2) document the effect of radiofrequency ablation on tibia length at 2, 6, and 12 weeks after ablation in a skeletally immature rabbit model, and (3) assess the effects of radiofrequency ablation on the histologic appearance of the proximal tibia physis and proximal tibia articular cartilage.

Although we showed percutaneous radiofrequency epiphysiodesis is an effective and reproducible method for destruction of the proximal tibia growth plate in a rabbit model, our study does have some limitations. First, was the small size of the rabbit tibia, which makes transition to a larger animal model necessary. Growth plate ablation in larger animals and human long bones may require application of radiofrequency energy at several locations to

Fig. 5A–B (A) The proximal tibia physis in the 6-week control group is shown (Stain, alcian blue; original magnification, $\times 45$). (B) The proximal tibia physis on the experimental side 6 weeks after radiofrequency ablation shows bony bar formation interrupting the architecture of the proximal tibia physis (Stain, alcian blue; original magnification, $\times 45$).

Fig. 6A–B (A) The proximal tibia physis in the 12-week control group is shown (Stain, alcian blue; original magnification, $\times 45$). (B) The proximal tibia physis on the experimental side 12 weeks after radiofrequency ablation shows complete replacement of the proximal tibia physeal cartilage with bone (Stain, alcian blue; original magnification, $\times 45$).

effectively ablate the entire growth plate and prevent angular deformities. Second, the localization of the radiofrequency probe was limited by the resolution of the fluoroscopic techniques used and the undulating character of the rabbit proximal growth plate. Third, the lack of orthogonal imaging of the tibia prevented accurate assessment for angular deformities of the tibia. Fourth, this is a small study with 15 animals, and a larger study is needed to confirm the findings of this pilot study.

We describe a new minimally invasive surgical technique using radiofrequency to achieve epiphysiodesis of the proximal tibia in a rabbit model. We verified the epiphysiodesis by the differences in tibia length between the control and experimental tibias at 2, 6, and 12 weeks after radiofrequency ablation. The epiphysiodesis effect also was verified histologically. The use of radiofrequency ablation is a logical evolution following other percutaneous

surgical techniques including drill epiphysiodesis [3, 4] and percutaneous transphyseal screw epiphysiodesis [9, 11]. The advantages of the percutaneous surgical techniques are obvious, including smaller incisions and shorter recovery. The disadvantages of percutaneous drill epiphysiodesis include the need for postoperative immobilization and delayed return to full activity, occasional postoperative joint effusion [5, 6, 15], and the potential for temporal delay in achieving the true epiphysiodesis effect [4, 7, 19, 20]. The disadvantage of the percutaneous transphyseal screw technique is the need for implant removal at the completion of skeletal growth [9, 11].

The epiphysiodesis effect of radiofrequency ablation on tibial length at 2, 6, and 12 weeks after ablation was confirmed by direct measurement of tibial length with an electronic caliper. The experimental side was shorter than the control side at every interval and in every animal

studied. Surgical complications of traditional drill epiphysiodesis techniques have included failure of growth arrest [4, 20], and incomplete growth arrest with subsequent angular deformity [7, 9, 20]. Although we did not have any instances of complete failure of growth arrest, we did note the occurrence of angular deformity in addition to shortening in one animal (Fig. 3).

The radiofrequency ablation epiphysiodesis technique described in this study resulted in complete closure of the proximal tibia physis by 12 weeks after ablation without any observed evidence of damage to the proximal tibia articular cartilage. The radiofrequency ablation method resulted in predictable limited physeal injury with a limited surrounding zone of injury. The limited zone of bone necrosis from the use of radiofrequency probes has been studied extensively in conjunction with the controlled ablation of benign bone tumors, specifically osteoid osteoma [17, 18]. Investigators have described the creation of a controlled area of marrow and cortical necrosis from 0.9 to 1.3 cm in diameter with this radiofrequency technique in the femur of dogs “regardless of the probe size or duration of heating” [21]. The use of radiofrequency ablation techniques for osteoid osteoma ablation in humans has been preferred by its proponents because it generally does not require hospitalization, and it is associated with rapid convalescence [17, 18].

The percutaneous radiofrequency epiphysiodesis technique we describe resulted in bone fusion of a rabbit tibial proximal growth plate by 12 weeks after radiofrequency ablation without any evidence of damage to the articular cartilage. Although this approach may be useful as described to achieve epiphysiodesis of small tubular bones of the hands and feet in humans, additional studies are necessary to assess the efficacy of radiofrequency epiphysiodesis in larger growth plates. The use of radiofrequency ablation techniques as described in this report may offer an alternative to other surgical epiphysiodesis techniques.

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