COMPARATIVE HOLDING STRENGTH BETWEEN PARTIALLY THREADED TIPPED AND NONTHREADED TIPPED PINS FOR FRACTURE FIXATION IN THE CANINE FEMUR: HISTOLOGIC RESULTS*

Zeki OĞURTAN

Department of Surgery, College of Veterinary Medicine, University of Selcuk

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Köpeklerde Ucu Yivli ve Ucu Yivsiz İntramedullar Pinlerin Aksiyel Ekstraksiyon Güçlerinin Deneysel Olarak Araştırılması: Histolojik Bulgular

Özet

Bu çalışma, kırık oluşturulan ve oluşturulmayan köpek femurlarında ucu yivli ve yivsiz pin uygulamasının spongioz kemikte etkilerini araştırmak amacıyla gerçekleştirildi.

İntramedullar pinin kemik dokusuna uygulanıp akabinde uzaklaştırılmasından sonra, kemik dokusunda oluşturduğu etkinin biyolojik faktörlerden ziyade mekaniksel olduğu tespit edildi. Ucu yivli pinlerin kırık femurlarda kırık oluşturulmayan femurlardakinden daha fazla hasar meydana getirdiği bulundu.

Dördüncü haftada kırık femurlara uygulanan ucu yivli pinlerin yivleri içerisine aşırı miktarda kemik dokusu üremesi ile birlikte kemik dokusu ölümüne rastlandı. Osteoklastik aktiviteye rağmen yoğun kemik dokusu rezorpsiyonuna rastlanmadı. Kırık oluşturulmayan femurlarda daha az kemik dokusu ve daha fazla kemik iliği oluşumuna rastlandı. Kırık ve kırık oluşturulmayan femurlara uygulanan ucu yivsiz pinlerin ise sınırlı bir osteoklastik aktivite ve fibröz doku oluşumuna sebep olduğu tespit edildi.

Sekizinci haftada kırık ve kırık oluşturulmayan femurlara uygulanan ucu yivli pinlerin oluşturduğu kemik dokusunun remodeling aktivitesi ile birlikte uzaklaştırılarak yerini fibröz dokusuna bıraktığı tespit edildi. Kırık kemiklerde aynı zamanda aşırı miktarda doku yivi rezorpsiyonu (kemik dokusu yivlerinin yüksekliğinin azalması) ve kemik dokusu ölümüne rastlandı.

Anahtar kelimeler: IM pin, femur, köpek.

Summary

This study was carried out to investigate the effects of partially threaded and nonthreaded tipped intramedullary (IM) pins in the cancellous bone of fractured and intact femurs in dogs.

At the time of IM pin insertion, mechanical other than biological factors affect the bone exposed to the IM pins. Fractured femurs had more damage from the partially threaded tipped pins compared to the intact femurs.

At 4 weeks, tremendous amount of new bone formation took place, growing into the threads of the pin in the fractured femurs. In spite of osteoclastic activity, there was not evidence of extensive bone resorption. Less amount of new bone formation and greater amount of bone marrow were observed with the tissue threads of intact femur. In the nonthreaded group, fractured and intact femurs had limited osteoclastic activity with fibrous tissue formation.

At 8 weeks, with partially threaded tipped pins of fractured and intact femurs, bone was removed and/or remodeled and replaced with fibrous tissue: There was also tremendous amount of tissue thread resorption (reduction in the height of tissue threads) and bone death in the fractured femur. The tissue threads of partially threaded tipped pins of intact femurs at 8 weeks appeared to have the same patterns on the tissue threads of intact femurs at 4 weeks. In the nonthreaded pin group, osteoclastic bone resorption along with replacement with fibrous tissue and bone necrosis were the characteristic pictures at 8 weeks.

Key words: IM pin, femur, dog.

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Introduction

Numerous experimental studies have been conducted regarding comparative studies of holding power and tissue reactions to bone with regard to screw fixation (1-4,10,11).

Screw failure due to fibrous tissue and cartilaginous tissue formation around the screw threads is greatly affected by the microenvironment (4,7,8) of the bone-screw interface resulting from cracks during screw insertion into bone (5,7,11). This leads to fibrous and cartilage formation with screw failure (4,7,8,10).

At the time of screw insertion, only part of the thread surface has intimate contact facing the head of the screw; the remaining surface is separated by interposed soft tissue (8). The invasion of the spaces by migrating cells occur during the first 2 weeks. Connective tissue and compact bone fill these gaps after two and four weeks respectively, followed by osteon (haversian) remodeling during the subsequent weeks in stable conditions (8). After four weeks, absorption due to osteoclastic activity increases the distance between screws and bone interface (8). The objective of this study was to determine the histologic appearance of cancellous bone in the distal femurs subjected to intramedullary (IM) pinning.

Materials and Methods

Fourteen adult mixed bred dogs, weighing 20-25 kg were divided into 3 experimental groups: Group 1, 2 and 3 at 0, 4 and 8 weeks, respectively. In each dog of each group, the left femur (fractured) and right femur (intact or control) were implanted with the same type of either partially threaded tipped or nonthreaded tipped IM pins. Three sixteenths inch both partially threaded tipped and nonthreaded tipped IM pins were used in this experiment. A standard lateral approach to the femoral middiaphysis was used. Only left femurs in all dogs were subjected to fracture and IM pinning, whereas the contralateral femurs were subjected to IM pinning only. At the required time of 0, 4 and 8 weeks, each individual was subjected to euthanasia. After euthanasia, femurs were dissected, freed of soft tissues. Following fixation in 10% neutral buffered formalin and decalcification, the partially threaded pins were carefully removed with a pliers using contra-clock wise motion and the decalcified bones were cut in half with a razor blade longitudinally, embedded in paraffin and sectioned 8 microns thick parallel to the long axis of the specimens, and stained with H&E, and Masson's trichrome stains.

Results

Group 1–0 Week

Fractured and Intact Femurs–Partially Threaded Tipped and Nonthreaded Tipped IM Pins

At 0 week group, there was a great amount of trabecular bone damage with micro fractures (Fig. 1) of the partially threaded tipped pin. Intact femurs in the 0 week group seemed to have less damage from the partially threaded tipped pins.

Group 2–4 Weeks

Fractured and Intact Femurs–Partially Threaded Tipped IM Pins

In the 4 week group, with partially threaded tipped pins of fractured and intact femurs, osteoclastic activity had already started along with development of fibrous tissue (Fig. 2).

A tremendous amount of new bone formation took place following pinning, growing into the threads of the pin, along with the occurrence of dead bone around the margins of the tissue threads by which the threads of IM pins were separated from the underlying newly formed woven bone along with lesser amounts of lamellar bone (Fig. 3) at 4 weeks. There was less amount of new bone formation (Fig. 4) and greater amount of bone marrow within the tissue threads of intact femur at 4 weeks. However, bone ingrowth was apparently remarkable in engaging the threads of the IM pin. Despite the fact that osteoclastic activity was occurring with fractured and intact femurs, there was not any evidence of extensive bone resorption.

Group 2–4 Weeks

Fractured and Intact Femurs–Nonthreaded Tipped IM Pins

What has been observed with partially threaded tipped pins of dogs at 4 weeks was also evident with nonthreaded tipped pins of fractured and intact femurs at 4 weeks. It consisted of limited osteoclastic activity along with fibrous tissue formation. Osteoclastic activity was evident along the pin track with removal of the bone and replacement to a certain extent with fibrous tissue (Fig. 5). Intact femurs developed less fibrous tissue than fractured femurs in the nonthreaded tipped pins of 4 weeks postoperative. Dead bone was present in the nonthreaded tipped pins of fractured femurs.

Group 3–8 Weeks
Fractured and Intact Femurs–Partially Threaded Tipped IM Pins

In the 8 week group, with partially threaded tipped pins of fractured and intact femurs, bone was being removed and/or remodeled by numerous osteoclasts and replaced with fibrous tissue (Fig. 6). It was more pronounced when compared to the 4 week group of partially threaded tipped pins of fractured and intact femurs. Along with this, there was a tremendous amount of tissue thread resorption (reduction in the height of tissue threads) which was obvious in histologic all sections (Fig. 6) which consisted of removal of bone within the tissue threads consequently resulting in replacement with fibrous tissue (Fig. 6). The tissue threads of partially threaded tipped pins of intact femurs, where the resorption was less pronounced at 8 weeks (Fig. 7), appeared to have the same pattern as the tissue threads of partially threaded tipped pins of intact femurs at 4 weeks (Fig. 4). In some instances, there was a small amount of fibrous tissue formation with marked osteoclastic bone resorption (Fig. 7).

The mean score (296 microns) of the height of the tissue threads on the anterior and posterior aspects of the femur of fractured femur at 8 weeks was found to be only 44% of the mean value of (666 microns) the height of the tissue threads on the anterior and posterior aspects of the femur of fractured femur at 4 weeks, which was statistically significant ($P<0.001$). There was a 30% (statistically significant, $P<0.001$) decrease in the mean value (327 microns) of the tissue thread height on the anterior and posterior aspects of the femur from the base to the tip of intact femur at 8 weeks compared to the mean value (469 microns) of intact femur at 4 weeks. However, intact femur showed only 6% decrease in the mean value (443 microns) of the tissue thread height at 8 week group compared to the mean value (469 microns) of the tissue thread height of intact femur at 4 weeks. This was not statistically significant ($P>0.2$). At 8 weeks, tissue thread heights were greater with intact femurs than those of the tissue threads of the fractured femur and vice versa for the 4 week group. The mean height (296 microns) of the tissue threads with the fractured femur was 9.5% less ($P>0.2$) than the mean height (327 microns) of the tissue threads of intact femur at 8 weeks. The mean height (469 microns) of the threads of intact femur was 70.4% of the mean height (666 microns) of fractured femur at 4 weeks with the statistical significance of $P<0.001$.

Few tissue threads showed evidence of bone death at 8 weeks (Fig. 8). Extensive bone death was present with the tissue threads of fractured femurs compared to that of intact femur.

Group 3–8 Weeks
Fractured and Intact Femurs–Nonhreaded Tipped IM Pins

Marked osteoclastic bone resorption along with replacement with fibrous tissue (Fig. 9) and bone necrosis were the characteristic picture of histologic sections of nonthreaded tipped pins of fractured and intact femurs of dogs at 8 weeks. However in the nonthreaded tipped pin of fractured femur, more fibrous tissue was noted. Intact femurs of the dogs developed lesser amount of fibrous tissue compared to the contralateral part of the fractured femurs at 8 weeks. The nonthreaded tipped IM pins of dogs (fractured and intact femurs) developed a greater amount of fibrous tissue than the 4 week group of dogs.

Fig. 1. Pin track of partially threaded tipped pin (fractured femur) at 0 week. Immature woven bone (arrow) and old, mature bone (arrow head). Masson's trichrome X10.

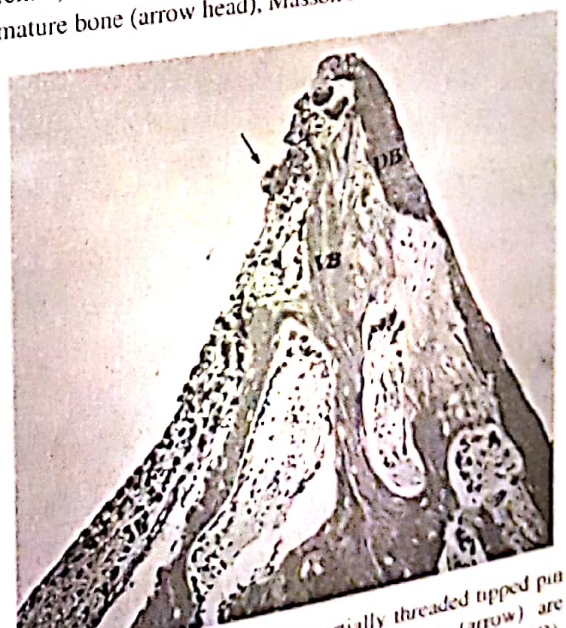

Fig. 2. Single tissue thread of partially threaded tipped pin (fractured femur) at 4 weeks. Osteoclasts (arrow) are resorbing the viable bone (VB) and dead bone (DB). Fibrous tissue development (FT) has already started at 4 weeks, H&E X40

Fig. 3. Dead bone (thin arrows) separate the threads from the newly formed woven bone (thick arrows) of partially threaded tipped pin (fractured femur) at 4 weeks, Masson's trichrome X10

Fig. 4. Diminished amount of new bone formation along with invasion of the tissue threads mostly with bone marrow. Fibrous tissue formation has also started at 4 weeks around the margins and base of the threads, (partially threaded tipped pin, intact femur), H&E X16

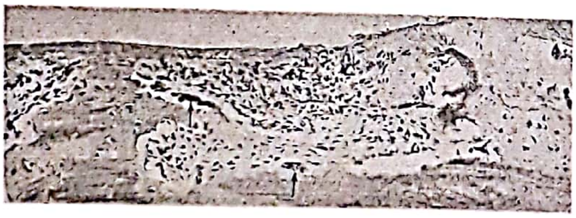

Fig. 5. Pin track of nonthreaded tipped pin (fractured femur) at 4 weeks. Note the removal of bone by osteoclasts (arrows) and replacement by fibrous tissue (FT), H&E X40

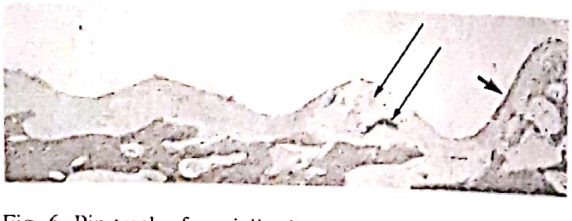

Fig. 6. Pin track of partially threaded tipped pin (fractured femur) at 8 weeks. There is tremendous amount of resoption of the threads. Bone has been removed and replaced with fibrous tissue. Dead bone (long arrows) incorparated into the fibrous tissue. The last tissue thread of the pin (first from the right) is being removed and replacement with fibrous tissue (short arrows) is taking place, H&E X10

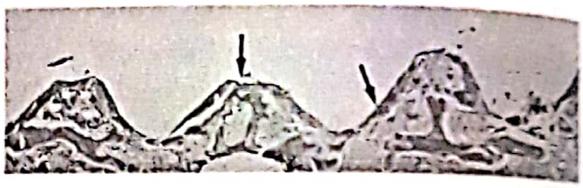

Fig. 7. Pin track of partially threaded tipped pin (intact femur) at 8 weeks. There is evidence of fibrous tissue formation (arrows) along with the resorption of pin threads, H&E X10

Fig. 8. Tissue threads of partially threaded tipped pin (fractured femur) at 8 weeks. Extensive bone death took place (short arrows). Routine removal of IM pin resulted in fracture and displacement of the middle thread (thin arrow) leaving an empty spot between the two threads (arrow head), Mason's trichrome X10

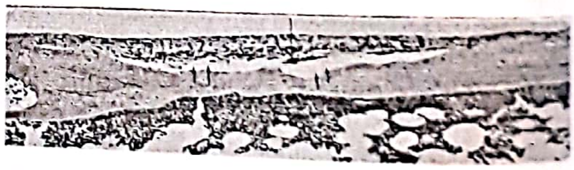

Fig. 9. Pin track of nonthreaded tipped pin of fractured femur at 8 weeks. Osteoclastic bone removal (long arrows) within the resorption cavity (double arrows), H&E X40

Discusion

Biomechanical results correlated well with the histological results at 4 weeks. An abundant amount of new bone formation took place growing into the threads of the pin. The presence of dead bone around the margins of the tissue thread, which lacked blood supply resulted from the insertion of intramedullary pins at 0 week. The difference in the holding strength of partially threaded tipped pins between the fractured and intact femurs is mainly due to the configuration of the tissue thread patterns with less bone per tissue thread with the intact femur, compared to the formation of the bone within the tissue threads of fractured femur at 4 weeks (Fig. 6). The mean height of the tissue threads (from the base to the tip) of femur was 666 and 469 microns for fractured and intact femurs, respectively which obviously was a contributing factor for the increased holding strength with regard to the fractured femur. The fibrous tissue development was more pronounced in the fractured femur compared to that in the intact femur at 4 weeks. In addition to this, the presence of dead bone might have been a contributing factor, to underestimate the actual holding strength of the partially threaded tipped pins in the fractured femurs at 4 weeks.

At 8 weeks, the mean holding strength values of partially threaded tipped pin in fractured and intact femurs which were below the 4 week values, correlate well with a 56% and 30% decline of the mean height of the tissue threads (from the base to the tip) of the femur in the 4 week values for fractured and intact femurs, respectively.

At the 8 week period, tissue thread heights were greater with intact femurs than those of the tissue threads of fractured femurs and vice versa for the 4 week group. In spite of this, extensive bone death which occurred with the fractured femurs, compared to the intact femurs, led to decreased holding strength to a certain degree for the partially threaded tipped pin of the fractured femurs.

Similar results were reported for various types of screws tested. The mean values for holding strength of various screws increased to between 150-190% of the initial values at 6 weeks and returned to 125-160% of the initial values at 12 weeks. This was attributed to newly formed periosteal and endosteal callus and woven bone within the medullary canal and subsequent decrease due to remodeling of the bone around the screws (7). Screw threads are not totally in contact with the cortical bone. Except for the load bearing surface of the screw threads, the remaining surfaces are separated by a space up to 150 microns in thickness (8). Undifferentiated cells fill these spaces during the first 2 weeks and differentiate into osteogenic cells in the absence of movement. In contrast, movement favors the differentiation of these cells into fibroblasts, chondroblasts and osteoclasts along with formation of fibrous cellular collar leading to a decline of holding strength (8). This is consistent with the findings of Schatzker (5), who showed that the osteoclastic activity leading to loss of holding power results from micromovement between the screw threads and cortical bone. Differentiated cells as well as undifferentiated cells are subject to and influenced by local mechanical conditions; proof of this is implied as 4 week period of stability followed by a 4 week period of instability results in partial resorption of newly formed callus. However, a 4 week period of instability followed by a 4 week of stability revealed the cessation of osteoclastic activity and the appearance of new bone around the screws (11). Cancellous and cortical bones subjected to compression by screw threads do not result in resorption and retain their integrity. However, with regard to cancellous bone, compression was continuously generated by the active epiphyseal plate (6).

The histologic changes observed in this comparative study do not fit with the histologic appearance of screw-bone interface. However, new bone growing into the threads of pins are well formed at 4 weeks which is similar to that of the tissue threads of screws in the cortical bone (9). Considering the intact femurs, free of movement with regard to the partially threaded tipped pins in situ at 4 and 8 weeks, as well as fractured femurs at 8 weeks, as a result of having considerably greater amount of stability compared to that of 4 weeks, osteoclastic bone removal and fibrous tissue formation which ensued by 4 weeks, did not cease and also were present with marked increase, along with the resorption of tissue threads at 8 weeks.

The reason for the formation of more bone per tissue thread at 4 and 8 weeks with fractured femurs than with intact femurs is not known. The absence of stress (mechanical load) or surpassed stress may be the possibilities. From the clinical standpoint because there is an interval until the return to the full use of a fractured leg, one would expect that partially threaded tipped pins in intact femurs would be subjected to more stress than in fractured femurs at 4 and 8 weeks. This does not fit with the concept of stress protection of bone with less bone formation. On the other hand, although there is lapse for return to full function of the fractured femur, it is difficult to explain that the fractured femur was subjected to more stress than the intact femur, considering the fact that at least until after the full use of the fractured leg, one would reasonably expect that, stress on the fractured femur increased bone formation. In reality, why and how more stress would be placed on fractured femurs is questionable. Changes in local mechanical conditions (instability followed by stability) result in reversal of tissue differentiation around the screws with cessation of osteoclasia and appearance of osteoblastic activity. The histologic appearance of partially threaded tipped pin of fractured femurs, considering the interval of time passing for return to full use of the leg, as implied (instability followed by stability) could not be explained with the concept of reversal of tissue differentiation around the screws. The assumption whether or not various factors, (i.e, pin length above the greater trochanter and medullary canal diameter), are associated with/or explain the tissue configuration are open to question and need clarification.

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