Acta orthop. scand. *50*, 385–390, 1979

FRACTURE HEALING IN RABBITS AFTER OSTEOTOMY USING THE CO_2 LASER

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Fracture healing was studied in 28 rabbits after their femurs had been osteotomized using the carbon dioxide laser. Twenty rabbits whose femurs were osteotomized by means of a Gigli saw served as the control group. Fracture healing was initially delayed in the laser cut femurs, yet after 60 days no significant difference between the groups could be detected. The initial delay was caused by thermal damage to the laser cut bone edges. Further fragmentation of the damaged bone occurred during the immediate postoperative period.

Key words: CO_2 laser; fracture healing; osteotomy

Accepted 13.xii.78

The carbon dioxide laser is used as a surgical tool in our Orthopaedic Department. It is also employed in the treatment of haemophilia and in oncological surgery (Horoszowski et al. 1976). Our clinical experience suggests that wound and bone healing are initially delayed after laser surgery. Experimental evidence (Verschueren 1976, Moore 1972) has confirmed the validity of this observation.

The purpose of the present study was to determine the cause of delay in bone healing after laser osteotomy, to remedy it, and to further the use, where possible, of the laser beam in surgical procedures.

MATERIAL AND METHODS

Forty-eight young adult rabbits were included in this study. Thrity-two osteotomies were performed with the laser* beam and twenty with the Gigli saw. The latter served as controls.

The animals were divided into four groups. Three of the groups were sacrificed at weekly intervals. The last group was kept alive for 60 days. Laser osteotomies were performed on the healthy femurs of four animals prior to sacrifice.

The experimental material as well as the macroscopic and roentgenologic results are summarized in Tables 1 and 2.

Operative technique

Intravenous nembutal anaesthesia and a complete aseptic technique were used.

The femur was approached through an anterolateral skin incision. Skin and fascia were incised with the carbon dioxide laser, using a 15 watt output. A subperiosteal osteotomy was performed with a 40 watt output. A sequence of small holes was made circumferentially with the laser beam, and the bone broke easily on completion of the procedure. The fracture was then fixed with one or two intramedullary Steinmann rods, although there was some unavoidable rotational instability. The wound was closed in two layers. Following this the animals were X-rayed and returned to their cages, and weight-bearing was not prevented. A similar operative technique was used in the control group: skin and fascia were incised with the scalpel and the femur was osteotomized with a Gigli saw.

* Sharplan 791 CO_2 laser.

0001–6470/79/040385–06$02.50/0

Table 1. Laser osteotomy

Day of sacrifice	No. of osteotomies	Hypertrophic callus	Further fragmentation	Unstable	Sticky	Union	Pseudarthrosis
0	4	—	—	—	—	—	—
7	6	6	3	—	—	—	—
14	10	10	6	—	—	—	—
28	6	6	5	4	1	—	1
60	6	6	6	—	—	4	2
Total	32	28	20	4	1	4	3

Table 2. Controls

Day of sacrifice	No. of osteotomies	Hypertrophic callus	Further fragmentation	Unstable	Sticky	Union	Pseudarthrosis
7	4	4	—				
14	8	8	1				
28	4	4	—	1	2	1	—
60	4	4	—	—	—	2	2
Total	20	20	1	1	2	3	2

X-ray studies

The osteotomized femur was X-rayed immediately following the operation, and examinations were repeated at weekly intervals until the rabbits were sacrificed. The fourth group was not X-rayed between the 28th and the 60th day.

Histological and microangiographic studies

The rabbits received intravenous nembutal anaesthesia and a 30 per cent micropaque® suspension was injected into the abdominal aorta.

Twenty-four hours later the femur was carefully dissected and examined for callus size and stability.

The bone was then subjected to histological preparation for the standard haematoxylin-eosin stain and according to the Spaltholtz method (Crock 1967).

RESULTS

X-ray studies

The immediate postoperative X-ray showed the osteotomized bone internally fixed in a good position (Figure 1a). After 7 days a fine opacification, disclosing the contour of the hypertrophic callus, was noted (Figure 1b). Fourteen days after surgery the callus was well developed and could be seen clearly (Figure 1c). This ossification progressed for a further 14 days (Figure 1d), and solid union usually took place about 60 days after operation (Figure 1e).

These features were common to both the laser cut femurs and to the controls.

Further fragmentation at the fracture site in the laser cut femurs took place during the first and rarely during the second week after the operation (Figures 1b and 1c). This occurred in 20 out of 28 laser cut femurs (an incidence of 71 per cent). This phenomenon was observed in only one out of 20 femurs in the control group.

Histological findings

Callus formation was not impaired by the laser beam. After seven days an organizing haematoma with cartilage and new bone formation was observed.

The callus matured gradually, although

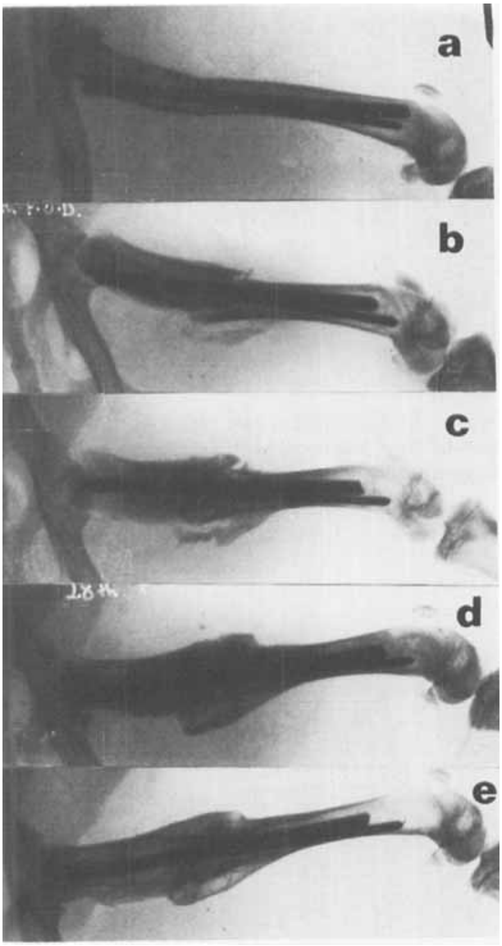

Figure 1. Healing of a laser cut femur
a. Day of operation
b. 7th day postoperatively
c. 14th day
d. 28th day
e. 60th day.

some remnants of cartilage and fibrous tissue were found in the united fractures up to 60 days after surgery. These findings were similar to those in the controls. Microscopic differences between the laser cut femurs and the controls were observed at the cut edges of the bone. On the day of operation some charred bone debris from the cut bone edge was seen. The most notable finding revealed empty bone lacunae at a distance of about 450–500 microns from the osteotomy site on the remaining bone fragment (Figure 2).

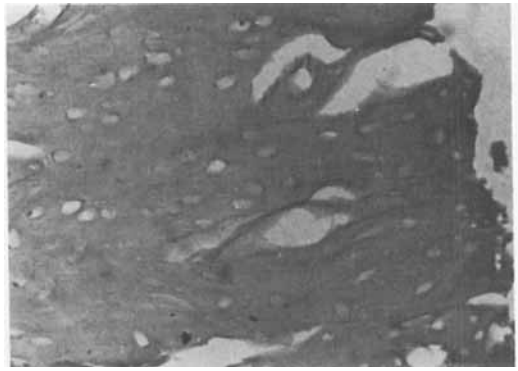

Figure 2. Margin of laser cut bone edge. Note the charred edge, empty lacunae and pycnotic nuclei on the left side of the preparation (approximately ×212).

Pycnotic nuclei in the lacunae marked the transitional area between "lased" and viable bone.

The cellular damage was much wider than the apparent damage to the bone matrix. All the osteocytes remained in place after osteotomy with the Gigli saw. Another notable feature was the sealing of small blood vessels in the bone (Figure 3). This phenomenon has been described by Ben Bassat et al. (1976), Verschueren (1976), and Frishmen et al. (1974).

Figure 4 shows the osteotomy site after 7 days. Non-viable bone and charred debris lie between the fragment and the haematoma.

Charred debris was incorporated into the callus and could be detected at the healed fracture site up to 60 days following the operation.

Microangiographic studies

There was a marked vascular response at the fracture site as early as 7 days after osteotomy. New vessels were formed, mainly in the periosteum and to a lesser degree in the endosteum (Figure 5). The vascular hyperplasia, which reached its peak 14 days after osteotomy, declined gradually.

Twenty-eight days after osteotomy the vascular hyperplasia was still noted, but at this stage the development of an overt pseudarthrosis in one specimen could be observed

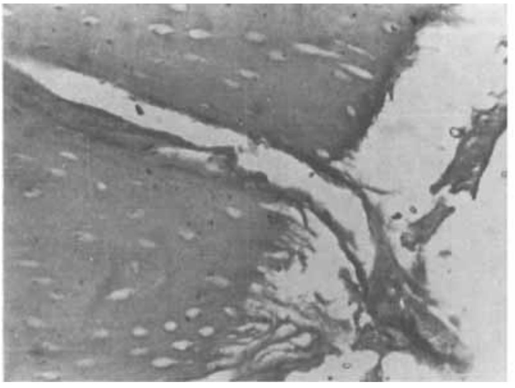

Figure 3. A sealed blood vessel in the bone at the laser cut edge. Note also the empty lacunae (approximately × 212).

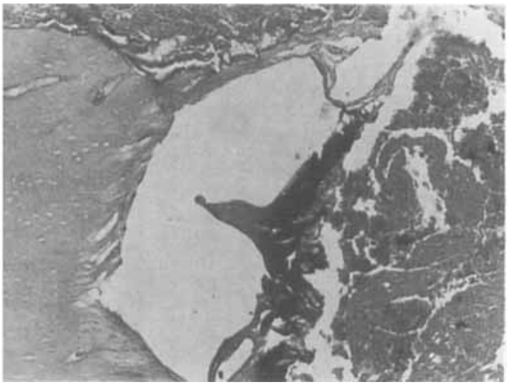

Figure 4. Osteotomy site after 7 days. The charred bone has broken off the cut edge in which the empty lacunae are seen (× 85).

Figure 5. Osteotomy site after 7 days. Periosteal vascular hyperplasia and endosteal vessels growing towards the fracture site (× 5.7).

Figure 6. A 28-day-old osteotomy developing into a pseudarthrosis. Note the sequestrum in its cavity (× 3.7).

(Figure 6). Endosteal vascular hyperplasia was marked in the femurs that united after 60 days.

DISCUSSION

Our findings correlate well with those of other authors (Verschueren 1976, Moore 1972). An initial delay in wound healing was also observed by Hall (1971). This initial delay is usually overcome at a later stage by the natural tissue healing process. A para-incisional necrotic zone due to thermal damage was observed macroscopically. It consisted of the charred bone which usually fell off, and an area half a millimetre wide in which the bone lacunae were devoid of osteocytes. This zone was at least twice as wide as a comparable area of damaged skin and mucous membranes, as demonstrated by Ben Bassat et al. (1976). A possible explanation is the fact that bone is a better heat conductor than soft tissues. The damaged bone was microscopically divided into three zones: a) the charred bone in the near vicinity of the cut area, which broke off during the laser cutting process; b) dead bone devoid of osteocytes; c) a transitional zone in which pycnotic nuclei were seen in the lacunae (Figure 2). We assume that further fragmentation of the laser cut bone occurs during the first postoperative week (Figure 1b) and that this is due to thermal damage which is more extensive than that which can be detected by simple light microscopy.

Haemostasis in laser cut tissues is obtained by sealing off small blood vessels without clotting (Ben Bassat et al. 1975), which was also observed by us in the laser cut bone edges (Figure 3). The vascular response, as examined in the microangiographic specimens, was essentially the same in the laser cut femurs and in the controls. It was compatible with the findings of other authors (Gothman 1961, Rhinelander 1973).

The internal fixation employed by us was not a rigid one and weight-bearing was not prevented. Thus hypertrophic callus formation was anticipated. The initial delay, caused by bone necrosis and further fragmentation, was overcome between the 4th and 8th week after surgery and was helped by the large callus which did in fact develop.

Verschueren (1976) employed compression plates in laser osteotomized femurs of dogs. In his series, bone healing was delayed for a much longer period than in the present report. This difference could be attributed to: a) a different species of experimental animal; b) the rigid internal fixation method, which prevented the formation of a large callus.

In our small series the incidence of pseudarthrosis in the laser cut femurs was lower than in the control group, after a period of 60 days. However, since the series is a small one, we do not consider the evidence to be conclusive. In spite of dead bone and charred debris at the fracture site, there were no deep-seated bone infections in our series, as might have been expected. The only two superficial wound infections occurred in the control group. We suggest that better haemostasis and an absolute "no touch technique" with the laser beam might explain this finding.

The implications of our study are:

A delay in healing after laser osteotomy is to be expected so long as the paraincisional bone necrosis cannot be minimized. Further experimental studies with an intermittent pulse beam, or with an inbuilt cooling system, should be conducted for possible solutions to this problem. A solution of this kind might also prove that the laser is a superior surgical instrument, particularly on account of its haemostatic effects and better aseptic properties.

ACKNOWLEDGEMENTS

The technical preparation of the specimens, as well as the histology and photography, were carried out at the Department of Medical Embryology and Teratology, Sackler School of Medicine, Tel-Aviv University, and the Chaim Sheba Medical Center, Tel Hashomer, Israel.

I wish to thank Professor L. Nebel for his encouragement and advice in preparing this paper, also Mrs. H. Orenstein and Mrs. M. Weinberg for their willing and able services in preparing the histological specimens and the photographs, respectively.

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